March 7, 1961 C. L. FENDER 2,973,681

APPARATUS FOR PRODUCING TREMOLO EFFECTS

Filed June 8, 1959 2 Sheets-Sheet 1

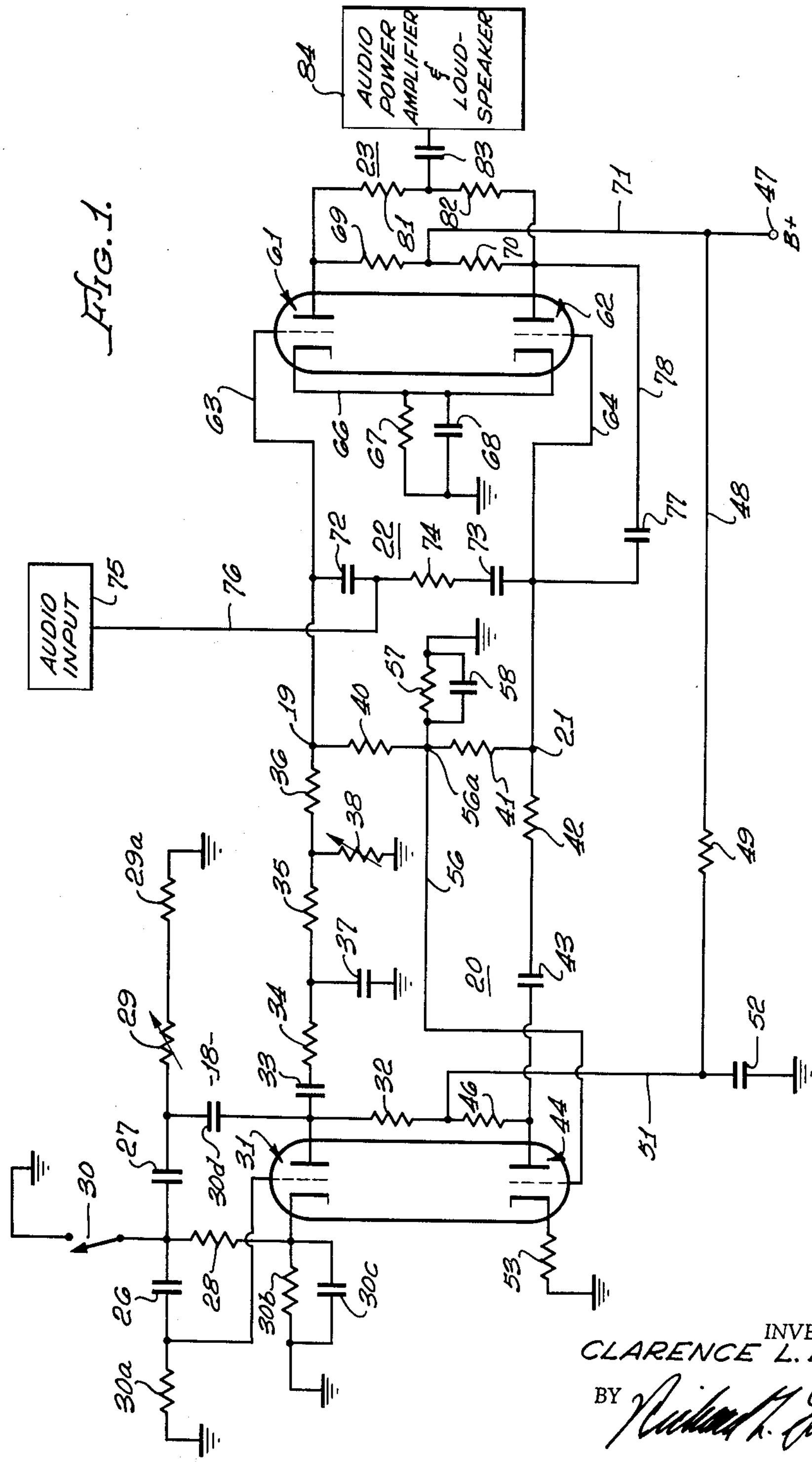

FIG. 1

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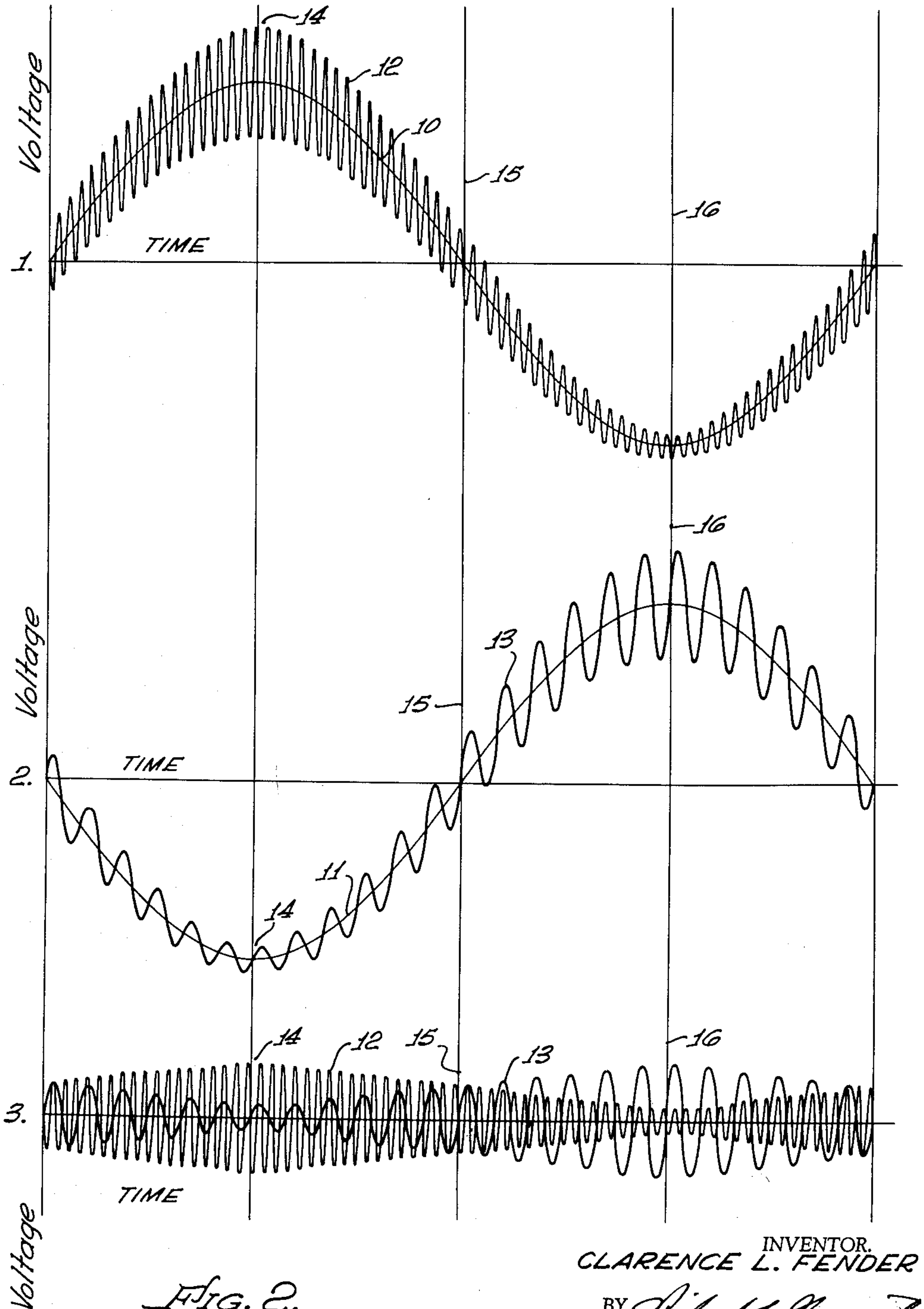

FIG. 2.

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APPARATUS FOR PRODUCING TREMOLO EFFECTS

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12 Claims. (Cl. 84—1.25)

This invention relates to an apparatus and method for producing tremolo effects, for example in connection with the notes produced by electrical musical instruments such as electric guitars and the like.

An object of the invention is to provide an apparatus and method for producing a tremolo effect which is extremely pleasing to the ear and does not become oppressive or undesirable even at loud volumes.

Another object is to provide a tremolo means and method which do not produce undesired effects, such as altered pitch or volume, during rapid picking or note playing by a guitarist or other musician.

A further object is to provide a tremolo means and method which is simple, reliable nad economical, and which operates properly at various tremolo frequencies and intensities.

A further object is to provide a tremolo circuit in which the tremolo action may be started or stopped at will, and in which no undesired effects are produced when the tremolo is not employed.

Another object is to provide a tremolo circuit adapted to be associated through a power amplifier with a loudspeaker, and which does not prevent the feeding into said power amplifier of audio inputs from sources with relation to which no tremolo effect is desired.

A further object is to provide a tremolo circuit and method in which a tremolo effect is achieved throughout the entire audio range, including bass notes, without producing undesirable noises in the loudspeaker.

A further object is to provide a tremolo means and method adapted to cause a single loudspeaker to do a better job of handling both the higher and lower frequencies without distortion or other undesirable effects.

A further object is to provide a tremolo circuit which produces a minimum of undesired effects such as distortion, chirping or beating in the loudspeaker.

A further object is to provide a tremolo circuit having the effect of causing a single loudspeaker to handle the higher frequencies cleanly and without distortion due to doeppler or other effects, and which permits the ear of the listener to hear the higher frequencies and the lower frequencies alternately so that an intervening rest period occurs relative to each frequency band.

These and other objects and advantages of the invention will be set forth more fully in the following specification and claims, considered in connection with the attached drawings to which they relate.

In the drawings:

Figure 1 is a schematic diagram of an electric circuit incorporating the present invention; and

Figure 2 is a view which illustrates graphically and schematically the manner in which the present circuit and method produce a tremolo effect without varying the pitch of an entire note or the volume thereof.

It is pointed out that each note produced by a musical instrument or the like contains not only the fundamental frequency but also many other frequencies—representing harmonics, distortion and the like. Throughout this

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specification and claims, each note will be referred to as having higher-frequency components, and lower-frequency components, as well as middle or intermediate-frequency components. These may also be referred to as higher, lower and middle-frequency "bands," although such terminology is not entirely accurate since there is much overlapping.

Stated generally, the present invention relates to the concept of taking each note produced by a musical instrument or the human voice, and alternately increasing and decreasing the amplitudes of the higher-frequency components and the lower-frequency components in such note and in out-of-phase relationship. The out-of-phase relationship should be such that the higher-frequency components are at peak amplitude while the lower-frequency components are at minimum amplitude, and vice versa, there being a middle period or interval when both the higher-frequency and lower-frequency components, as well as the intermediate-frequency components, come through strongly.

The illustrated circuit generates and makes use of two equal and opposite tremolo waves, generally like those indicated at **10** and **11** in Figure 2 (curves **1** and **2**). Such waves are at sub-audio tremolo frequency, normally in the range of about four to ten cycles per second, and are preferably sinusoidal in shape. Audio frequencies from each note of the audio input are superimposed on the tremolo waves in such manner that the higher frequencies in each note are imposed on one wave (like wave **10**) and the lower frequencies in each note are imposed on the other wave (like wave **11**). For example, a higher-frequency wave is indicated schematically at **12** in curve **1** of Figure 2, and a lower-frequency wave is indicated at **13** in curve **2**. Although the tremolo-frequency waves **10** and **11** are shown as being 180° out-of-phase with each other, it is pointed out that the audio-frequency waves **12** and **13** are in phase with each other. The amplitude of each superimposed audio wave **12** or **13** is then caused to vary cyclically in accordance with the tremolo wave but in 180° out-of-phase relationship relative to the other audio-frequency wave. Thus, the amplitude of wave **12** in the region **14** is illustrated as being at a maximum while the amplitude of wave **13** at the same instant of time is at a minimum. Finally, the tremolo waves **10** and **11** are eliminated in order to produce the result illustrated graphically at the lower portion (curve **3**) of Figure 2.

It is emphasized that the illustrated audio waves **12** and **13** are for purposes of explanation only and do not accurately represent conventional audio waves, such audio waves being made up of many high, medium and low frequencies. The wave **12** is a schematic representation of one of the higher-frequency components and the wave **13** is a schematic representation of one of the lower-frequency components, but many other high, low and middle-frequency components are involved. Furthermore, the shapes of waves **12** and **13** are misleading. The various middle-frequency waves are super-imposed on one or both of the tremolo waves **10** and **11**, and thus appear in the output waves shown in curve **3** at the lower portion of Figure 2, but are not illustrated herein.

Referring to curve **3** of Figure 2, it is pointed out that the end product is neither a conventional tremolo nor a conventional vibrato, but is instead a tremolo in which predetermined bands of frequencies in each note are alternately suppressed and enhanced in a certain manner. The over-all pitch and amplitude or volume remain relatively constant, it being pointed out that at point **15** the sum of waves **12** and **13** is somewhat the same as the sum of such waves at points **14** and **16**. Furthermore, it is emphasized that there are no nulls or dead spots, the amplitude at the intermediate point **15** being substantial with respect to both higher and lower frequencies as well as the unshown intermediate frequencies.

It is a feature of the invention that the various middle or intermediate-frequency components of each note are transmitted to the loudspeaker at relatively uniform strength, being much less affected by the tremolo means than are the higher and lower-frequency components. Thus, a particular middle frequency may be superimposed on both of the tremolo-frequency waves (like waves 10 and 11), so that upon recombination (as in curve 3 of Figure 2) such middle frequency will be present much as if no tremolo means had been employed. Although the amplitudes of the divided and superimposed portions of such particular middle frequency will vary, such variation is 180° out-of-phase so that the end product (curve 3) will have a relatively uniform amplitude.

Proceeding to a detailed description of the circuit illustrated in Figure 1, the various components include a variable-frequency oscillator 18 adapted to deliver to circuit point 19 a pure sinusoidal voltage wave (generally wave 10) at tremolo or sub-audio frequency. A self-balancing phase inverter 20 is provided in order to produce at circuit point 21 a sinusoidal voltage wave (generally like wave 11) which is the substantial mirror image of the wave at point 19. Circuit means 22 are provided to impress upon the waves present at points 19 and 21 audio frequencies which are respectively in the upper-frequency and lower-frequency ranges for each note, and to effect amplitude variation in such upper and lower-frequency ranges in out-of-phase relationship relative to each other. More specifically, and as will be described in detail subsequently, the circuit means 22 incorporates components adapted to separate the audio input into a treble band and a wide-range band, the latter band becoming mainly a bass band due to negative feedback of the higher frequencies. The circuit also incorporates means 23 to eliminate or cancel the tremolo-frequency waves 10 and 11 so that there will be no beating or overall amplitude variation in the loudspeaker.

It is pointed out that curves 1 and 2 of Figure 2 schematically represent the voltages at the output of circuit means 22. Curve 3 schematically represents the voltage at the output of circuit means 23.

The variable-frequency oscillator 18 may be of the general type described in my previous Patent No. 2,817,708, issued December 24, 1957, for an Amplifier With Tremolo. Thus, capacitors 26 and 27 of the present circuit correspond to capacitors 89 and 92 of the above-mentioned patent, and resistor 28 of the present circuit corresponds to resistor 90 of the patent. The frequency of the oscillations in the circuit, which is a phase-shift oscillator, are controlled by varying the setting of a variable resistor 29. Oscillations may be stopped and rapidly re-initiated by closing and opening a switch 30 which provides a short to ground from the circuit point between capacitors 26 and 27.

As described in the above-cited patent, the phase-shift oscillator incorporates a triode 31 from the plate of which the oscillator output is derived, being impressed across a plate resistor 32. Such oscillator output is fed through a suitable filtering and amplitude-control means including a capacitor 33 and three resistors 34–36 connected in series with each other between the plate of triode 31 and the previously-mentioned circuit point 19. A capacitor 37 is connected between the junction of capacitors 34 and 35 and ground, and a variable resistor 38 is connected between the junction of resistors 35 and 36 and ground.

The capacitor 33 is a blocking capacitor for blocking the direct voltage impressed upon the plate of triode 31 through resistor 32 from a suitable plate voltage source. Resistor 34 and capacitor 37 combine to form a low-pass filter adapted to smooth the wave from the phase-shift oscillator and cause it to be essentially sinusoidal as previously stated. Resistors 35 and 38 form a voltage divider and a shunt attenuator adapted to limit and control the amplitude of the signal delivered to circuit point 19 from the phase-shift oscillator 18. Resistor 36 is an isolating resistor which prevents resistor 38 from loading the audio input signal and also one of the tubes in the circuit means 22 to be described hereinafter.

It is to be understood that the circuit 18 may comprise any suitable means for delivering a relatively pure sinusoidal wave to circuit point 19 at a sub-audio tremolo frequency such as between 4 and 10 c.p.s. Thus, it is not believed to be necessary to present a further description of the various components in the phase-shift oscillator, etc., indicated above and in the cited patent. Additional components of the illustrated oscillator are numbered 29*a*, 30*a*, 30*b*, 30*c* and 30*d*.

Proceeding next to a description of the self-balancing phase inverter 20, this comprises two equal resistors 40 and 41 connected in series with each other between the circuit points 19 and 21. Circuit point 21 is connected through a series-connected resistor 42 and capacitor 43 to the plate of a second triode 44. The triode 44 is preferably a high-gain amplifying tube, having a plate resistor 46 connected to the previously-mentioned plate resistor 32 for triode 31. B+ voltage is supplied to the plates of both triodes through their resistors 32 and 46 from a suitable source 47. Such B+ voltage passes through a lead 48 incorporating a resistor 49, and also through a lead 51 extending between ground and the junction of resistors 32 and 46. A capacitor 52 is incorporated in lead 51, between the junction thereof with lead 48 and ground, and cooperates with resistor 49 in preventing coupling between the two double-triode tubes illustrated in Figure 1. One such double-triode incorporates triodes 31 and 44, and the other forms a part of circuit means 22.

The triode 44 has its cathode connected through a suitable cathode resistor 53 to ground. The previously-indicated capacitor 43 and resistor 42 in the plate circuit of triode 44 perform blocking and isolating functions to block the B+ voltage on triode 44 and to prevent loading of one of the triodes in circuit means 22.

It is an important feature of the self-balancing phase inverter 20 that the grid of triode 44 is connected through a lead 56 to the junction point 56*a* between equal resistors 40 and 41. Furthermore, such junction point 56*a* is connected through a parallel-connected resistor 57 and capacitor 58 to ground. The capacitor 58 has a value which is sufficiently high that all audio frequencies present at point 56*a* will be by-passed to ground, but sufficiently low to prevent by-pass of the tremolo frequency to ground. Resistor 57 is sufficiently high to prevent substantial shorting of current from the above-mentioned junction point to ground.

In the operation of the self-balancing phase inverter 20, the pure sinusoidal wave present at circuit point 19 is transmitted through resistor 40 and lead 56 to the control grid of triode 44. Any audio transmitted from circuit point 19 or circuit point 21 to junction 56*a* is by-passed through capacitor 58 to ground and thus has no effect on the triode 44. Furthermore, such by-passing or shunting of audio to ground through capacitor 58 maintains separate the signals impressed upon the grids of the double triode which forms part of the circuit means 22 to be described hereinafter.

The sinusoidal tremolo-frequency wave impressed upon the grid of triode 44, as described above, produces an inverse or negative feedback effect that causes the triode 44 to attempt to make the voltages at points 19 and 21 equal and opposite. Since a pure sinusoidal wave is delivered from oscillator 18 to point 19 and thence through resistor 40 to lead 56, and since any audio voltages present at point 56*a* are shorted through capacitor 58 to ground as previously stated, it follows that the triode 44 has the effect of duplicating a pure sinusoidal wave at circuit point 21 but in inverse-phase relationship.

Proceeding next to a description of the circuit means 22 for impressing the higher-frequency and lower-frequency components of each audio note on the tremolo-frequency waves respectively present at points **19** and **21**, and for effecting cyclic variations in the amplitudes of such audio components in accordance with the tremolo waves, such means includes the previously-indicated double-triode tube comprising two triodes **61** and **62**. Leads **63** and **64** are employed to effect, respectively, direct connections between circuit points **19** and **21** and the grids of the triodes **61** and **62**. The cathodes of the triodes are connected to each other through a lead **66**, and lead **66** is connected to ground through the parallel-connected resistor **67** and capacitor **68** which perform important functions to be set forth hereinafter. Connected between the plates of the triodes **61** and **62** are series-connected plate resistors **69** and **70** having equal values. Plate voltage is thus supplied to the plates from the previously-indicated B+ source **47**, by means of a lead **71** which connects not only to lead **48** but to the junction between resistors **69** and **70**.

Capacitors **72** and **73** are respectively connected to the leads **63** and **64** and are also connected to a resistor **74** in such relation that the elements **72–74** are in series across the leads **63** and **64**. A suitable audio input source, indicated at **75**, is connected through a lead **76** to the junction between capacitor **72** and resistor **74**. Such source **75** may comprise, for example, the electromagnetic pickup of an electric guitar, a microphone, etc., and may include pre-amplifier means.

In the operation of the circuit means **22** as thus far described, let it be assumed that a single audio note is fed from source **75** and through lead **76** to the junction of capacitor **72** and resistor **74**. This note may comprise, to give just one of very many examples, middle C as produced by an electric guitar. It is to be understood that the operation is the same when many notes are fed in at the same time, as when a chord is struck or when several instruments (or phonographs or microphones) are connected to the input.

The capacitor **72** is selected to have a relatively low value which will block the lower and middle frequencies of such note but will permit passage of the higher frequencies thereof to lead **63** and thus to the grid of triode **61**. Such higher frequencies are thus superimposed on the sine wave (generally like wave **10** of Figure 2) which is delivered directly from circuit point **19** to the grid of triode **61**. Triode **61** is selected to have such a non-linear characteristic that the amount of amplification of such higher-frequency audio components will be greater when the tremolo sine wave is in the positive portion of its cycle, as indicated at region **14** in Figure 2, than when it is in the negative portion of its cycle as indicated at region **16** therein. The result is an output wave schematically represented by curve **1** of Figure 2. Capacitor **72** also performs the function of preventing the tremolo-frequency wave from affecting the audio input.

A relatively wide band of frequencies, derived from the note fed in from source **75** through lead **76** as stated above, is passed by the resistor **74** and medium-value capacitor **73** to lead **64**. Such relatively wide band is, however, converted into a bass band by means of a low value capacitor **77** which is interposed in a lead **78** between the plate and grid of triode **62**. Since capacitor **77** has a low value, it effects inverse or negative feedback only of the higher frequencies and thus has the effect of attenuating the higher frequencies which are passed to the plate resistor **70** of triode **62**. The result is that the voltage present at the output of triode **62** is in the nature of the middle wave (curve **2**) shown in Figure 2, incorporating lower frequencies impressed upon the sinusoidal tremolo-frequency wave which was fed directly to the grid of triode **62** from circuit point **21** as previously stated.

As in the case of the triode **61**, triode **62** has the non-linear effect of performing greater amplification of the audio when the tremolo-frequency wave is in its positive half-cycle than when it is in its negative half-cycle. However, and as shown in the upper two curves in Figure 2, the 180° out-of-phase relationship between waves **10** and **11** causes the amplitude variations between the higher and lower-audio frequencies to be 180° out-of-phase. It is to be remembered, however, that, although the amplitudes vary in out-of-phase relationship, the higher and lower-frequency components of the note are actually in phase with each other. By this it is meant that no audio signal is cancelled out when the higher-frequency and lower-frequency components are combined.

The capacitor **73** is selected in such manner that it is large enough to pass the lower audio frequencies from lead **76** to lead **64**, but small enough to prevent the tremolo-frequency voltage to pass from lead **64** to lead **76** and affect the audio input. Resistor **74** performs the function of aiding in reducing the higher frequencies which, as stated above, are effectively attenuated by negative feedback through capacitor **77**.

It is emphasized that the tremolo-frequency waves are isolated from the audio input by capacitors **72** and **73**, as stated above, and that there is no substantial interaction between the audio components in leads **63** and **64**. Thus, as previously stated, the audio frequencies which attempt to pass between leads **63** and **64** through series-connected resistors **40** and **41** are shunted to ground through capacitor **58**. Furthermore, should any audio frequencies penetrate to the point between the plate resistors **32** and **46**, they are shunted to ground through capacitor **52**.

There will next be described the very important functions of the cathode resistor **67** and capacitor **68**. Resistor **67** is caused to have a relatively high value in relation to normal amplifier practice for the particular plate resistor **69** and triode **61**. On the other hand, the resistor **67** should have a lower value than in normal circuits in which the triode is used as a phase splitter, one reason for this being because it is desired that triode **61** perform amplification. Capacitor **68** has a value sufficiently high to pass substantially all of the audio frequencies but sufficiently low to prevent passage of the tremolo frequencies. Thus, the audio frequencies are shunted to ground through the capacitor **68**, whereas the tremolo frequencies must pass through the cathode resistor **67**. It follows that in discussing the function of resistor **67**, the tremolo frequencies are all that are referred to.

The high-value cathode resistor **67** has been found to be extremely important in creating greater tremolo (differential amplification) action in the triodes **61** and **62**, so that the tremolo-frequency waves need only have relatively small amplitudes. This may best be understood by considering the situation when the grid of triode **61** is positive and the grid of triode **62** is negative. When the grid of triode **61** is thus relatively positive, the flow of plate current therein is increased. This causes a voltage change across resistor **67** which is such that the end of such resistor adjacent lead **66** is more positive than previously, causing the cathode of triode **62** to be more positive than previously. Such increase in the positive condition of the cathode of triode **62** has the effect of making the grid of such triode more negative with respect to the cathode thereof, so that the flow of plate current in triode **62** is much less than would be the situation if resistor **67** had only a lower (normal) value with consequent small voltage thereacross. This reduction in the plate current in triode **62** (change in the operating point) reduces the amount of amplification of the superimposed audio components, as is desired. It is to be understood that the reverse action occurs when the grid of triode **61** is negative and that of triode **62** is positive, the flow of plate current in triode **61** then being much less than would be the case if cathode resistor **67** were of normal (smaller) size.

Although reference was made in the preceding paragraph to the grids of triode **61** and **62** becoming positive and negative, it is to be understood that these are only relative terms and that the grid of neither tube should actually become sufficiently positive to effect grid-current clipping or distortion of the audio components. The cathode resistor **67** plays an important role in this also, since such high-value resistor causes the cathode voltages to fluctuate with the grid voltages in such manner that grid-current clipping or distortion will not occur unless the amplitude of the tremolo-frequency wave is great. Stated otherwise, the voltage on the cathode of each tube fluctuates along with the voltage on the grid of such tube, to a certain degree, and in such manner that the grid may become more positive without resulting in undesirable grid current and thus in clipping and distortion of the audio. Although the cathode voltage and grid voltage of each tube thus fluctuate somewhat together, the cathode voltage on each tube fluctuates oppositely to the grid voltage on the opposite tube to create the highly desirable result described heretofore.

Proceeding to a description of the means **23** for effecting cancellation or elimination of the tremolo-frequency waves **10** and **11** so that the final product has the general nature indicated in curve **3** at the lower portion of Figure 2, this comprises two equal resistors **81** and **82** which are series-connected between the plates of triodes **61** and **62**. The center point between such resistors is connected through a coupling capacitor **83** to the audio power amplifier and loudspeaker **84**. It is a feature of the present invention that other inputs may also be connected to such power amplifier, without passing through the present tremolo circuit, in instances where no tremolo is desired.

Since the resistors **81** and **82** are equal, and since the tremolo-frequency waves impressed thereacross are of equal magnitude and are 180° out-of-phase with each other, it follows that such waves will be eliminated and will not be present in the audio output **84**. It is an important feature of the invention that the tremolo-frequency waves have equal magnitudes, and thus cancel properly, despite variations in the tremolo frequency due to adjustment of resistor **29**. A change in tremolo frequency has the strong tendency to cause waves **10** and **11** to become unbalanced, since the capacitors **72**, **73** and **77** act as loads which become greatly unbalanced when the tremolo frequency is varied. Thus, the self-balancing operation of circuit **20** is extremely important in maintaining the tremolo waves in balance so that there will be perfect cancellation and no pulsing in the loudspeaker.

As previously stated, the audio frequency components are in phase with each other and are therefore combined and passed to the audio output **84** in a wave having the general nature of the one shown in curve **3** at the bottom of Figure 2. This desirable action would not occur, however, were it not for the cathode capacitor **68** which prevents triodes **61—62** from acting as phase inverters. Stated otherwise, capacitor **68** prevents the audio signal on one triode **61—62** from producing an inverted signal at the other, with consequent cancellation at mixer **81—82**. In summary, therefore, the second double triode **61—62** is caused to act efficiently as an amplifier at the audio frequencies, having a cathode resistor **67** and capacitor **68**. At tremolo frequencies, tube **61—62** operates as a tube with no cathode capacitor, and resistor **67** provides the important biasing effect stated heretofore.

METHOD AND SUMMARY OF OPERATION

Let it be assumed that one or more musical instruments, microphones, phonographs, etc., are connected to the audio input **75**. During periods when no tremolo action is desired, the switch **30** is maintained in closed condition to prevent oscillations in the circuit **18**. The

audio input therefore passes through lead **76** and both of the triodes **61** and **62** to output **84** in a substantially unaffected manner as is desired.

When tremolo action is desired, the operator opens the switch **30** to immediately initiate oscillations in the phase-shift oscillator circuit **18** and in the manner described in the cited patent. The resulting tremolo-frequency wave, having a frequency determined by the setting of resistor **29** and an amplitude determined by the setting of resistor **38**, is therefore transmitted to the circuit point **19**. Such wave may correspond generally to the wave **10** indicated by curve **1** of Figure 2, as stated previously. A substantial mirror image of the tremolo wave present at point **19** is created by the self-balancing phase inverter **20** and caused to be present at the circuit point **21**, this wave being generally like the one represented by wave **11** (curve **2** of Figure 2). This action is substantially unaffected by the audio-frequency components due to the presence of the capacitor **58** which shunts the audio frequencies to ground.

The incoming audio is separated into a treble band by the capacitor **72**, and a wide-range band by resistor **74** and capacitor **73**. The treble band is impressed upon the tremolo-frequency wave in lead **63**, and by differential action of tube **61** is amplified more greatly when such tube is relatively positive than when it is relatively negative, the result being represented by the wave **12** indicated in curve **1** of Figure 2.

The wide-range band passed to lead **64** by resistor **74** and capacitor **73** is impressed upon the tremolo-frequency wave in lead **64**. By differential action of triode **62**, and because of negative feedback of the higher-frequency components through capacitor **77**, the resulting wave at the output of triode **62** is in the general nature of wave **13** shown in curve **2** of Figure 2. As previously stated in detail, the cathode resistor **67** and capacitor **68** perform extremely important functions in the proper action of the triodes **61** and **62**.

The output waves from triodes **61** and **62** are combined, by means of resistors **81** and **82**, to form the wave generally represented at the bottom (curve **3**) of Figure 2, the tremolo frequencies having been cancelled and the audio frequencies having been added.

The result is the creation of a tremolo audio output which is extremely pleasing to the ear, even at loud volumes, and produces great advantages not only in connection with loudspeakers for electrical musical instruments or vocalists but in connection with radios, phongraphs, and the like. To name only some of these advantages, all of the bass frequencies are passed through the tremolo circuit yet there is no rumbling noise produced in the loudspeaker. The loudspeaker is permitted to do a much better job of handling the high frequencies, without distortion due to the doeppler effect and other factors, because the bass frequencies are relatively weak when the high frequencies are relatively strong. Furthermore, since the ear of the listener is not required to listen to bass and treble frequencies at the same time and of equal magnitude, the listener is conscious of a more pleasant and desirable sound than heretofore. This effect is in some respects comparable to persistence of vision.

There is no substantial variation in over-all volume, or in the over-all pitch of each note, with the result that sharp and rapid picking by a guitarist (or comparable action in another instrument) does not appear to produce relatively high or low notes, or weak notes, in irregular and unpredictable array. This is to be contrasted with a conventional amplitude tremolo, for example, in which a sharp pick performed during a low-amplitude portion of the cycle would appear undesirably soft with relation to the other notes. It is a very pleasing and important feature of the present tremolo effect that the tremolo does not appear to become evident except on relatively sustained notes.

SPECIFIC EXAMPLE

The following is a specific example of circuit values which may be employed in the circuit of Figure 1, all capacitance values being given in microfarads and resistance values being given in kilohms. Each of the double triodes may be a 12AX7. The B+ voltage at 47 may be 350 volts.

Resistors

Number:	Value	Number:	Value
28	1,000	42	1,000
29	2,000	46	220
29a	100	49	220
30a	1,000	53	1.5
30b	2.7	57	1,000
32	220	67	15
34	2,000	69	220
35	2,000	70	220
36	1,000	74	220
38	250	81	220
40	1,000	82	220
41	1,000		

Capacitors

Number:	Value	Number:	Value
26	0.01	52	20
27	0.01	58	0.05
30c	25	68	0.5
30d	0.03	72	0.000125
33	0.05	73	0.02
37	0.10	77	0.0001
43	0.05		

It is to be understood that, throughout this specification and claims, reference to the triode vacuum tubes (and components thereof) applies also to comparable vacuum tubes or transistors or like electronic current-flow control devices. Thus, the cathode of each vacuum tube would normally correspond to the emissive element or emitter of a transistor, the plate of each vacuum tube would normally correspond to the collecting electrode or collector of the transistor, and the grid of each vacuum tube would normally correspond to the base of the transistor.

Various embodiments of the present invention, in addition to what has been illustrated and described in detail, may be employed without departing from the scope of the accompanying claims.

I claim:

1. Apparatus for producing an effect in the nature of a tremolo relative to a musical source adapted to generate audio-frequency musical waves which are complex and rich in harmonics, which apparatus comprises first electric circuit means for selecting from a complex wave generated by said source a first band containing predominantly the higher-order harmonics present in said complex wave, second electric circuit means for selecting from the same complex wave generated by said source a second band overlapping said first band and containing predominantly the lower-order harmonics present in said complex wave, tremolo means associated with said first electric circuit means to amplitude-modulate the signals present in said first band at a predetermined tremolo frequency, tremolo means associated with said second electric circuit means to amplitude-modulate the signals present in said second band at the same predetermined tremolo frequency but in substantially out-of-phase relationship relative to the amplitude modulation of the signals present in said first band, and means associated with said tremolo means to transmit the amplitude-modulated signals in said first and second bands to loudspeaker means, whereby the listener to said loudspeaker means is alternately conscious of the signals in said first band and then in said second hand at said predetermined tremolo frequency.

2. The invention as claimed in claim 1, in which said tremolo means include means to effect amplitude-modulation of the signals present in said first band in substantially 180 degree out-of-phase relationship relative to the amplitude-modulation of the signals present in said second band, and in which said predetermined tremolo frequency is in the range of four to ten cycles per second.

3. The invention as claimed in claim 1, in which said tremolo means include means to effect generally sinusoidal amplitude-modulation of the signals present in said first band, and generally sinusoidal amplitude-modulation of the signals present in said second band in substantially 180 degree out-of-phase relationship relative to the amplitude-modulation of the signals present in said first band, said tremolo means being such that the amplitude modulations are of substantially equal degree whereby the signals present in said first band and in said second band have substantially the same magnitude at intervals 90 degrees out-of-phase with the peak amplitudes of the signals present in either band.

4. The invention as claimed in claim 1, in which said apparatus includes means for generating and conducting to a single circuit point electrical signals corresponding to said complex wave, and in which said first and second electric circuit means include segregation means connected to said circuit point to at least partially segregate the electrical signals present thereat into said first and second overlapping bands.

5. The invention as claimed in claim 1, in which said electric circuit means and tremolo means are constructed to cause the signals present in said first and second bands to remain in phase with each other.

6. The invention as claimed in claim 1, in which said tremolo means include means for generating at least two generally sinusoidal tremolo-frequency voltage waves having the same frequency, means for superimposing on one of said voltage waves the signals present in said first band, means for superimposing on the other of said voltage waves the signals present in said second band, means for causing the amplitudes of said superimposed signals on each of said voltage waves to vary at the frequency of such voltage waves, means for causing said amplitude variations to be out of phase relative to each other, and means for eliminating said tremolo-frequency voltage waves.

7. The invention as claimed in claim 1, in which said tremolo means include means to generate a first tremolo-frequency voltage wave in a sub-audio range, means to generate a second tremolo-frequency voltage wave which is a substantial duplicate of said first wave and is in phase inversion relative thereto, means to superimpose the signals present in said first band onto said first voltage wave and the signals present in said second band onto said second voltage wave, said last-named means being adapted to cause said signals present in said first band and in said second band to be in phase with each other, electronic current-control means to cause the amplitudes of said superimposed signals to vary cyclically in out-of-phase relation relative to each other and in accordance with said first and second voltage waves, and means to cancel said first and second voltage waves.

8. The invention as claimed in claim 7, in which said means to generate a second voltage wave which is a substantial duplicate of said first wave comprises a self-balancing phase inverter circuit.

9. The invention as claimed in claim 7, in which said electronic current-control means comprises first and second vacuum tubes having non-linear amplification characteristics, in which said vacuum tubes each have a plate, cathode and control grid, in which capacitor means are provided between the cathodes of both of said vacuum tubes and ground, said capacitor means having a capacitance sufficiently low to prevent passage of sub-audio tremolo-frequency currents to ground and sufficiently high to permit passage of audio-frequency currents to ground, in which means are provided to impress respectively on

said control grids said tremolo-frequency voltage waves in phase inversion relative to each other, and in which relatively high-value cathode resistor means are provided in parallel relation to said capacitor means, said cathode resistor means being sufficiently high in value that when the control grid of one of said vacuum tubes is in a relatively positive condition with respect to its cathode the control grid of the other of said vacuum tubes will be in a more negative condition with respect to its cathode than would be the case in the absence of said relatively high-value cathode resistor means.

10. The invention as claimed in claim 9, in which said cathode resistor means is much higher in value than conventional circuit practice with respect to the particular vacuum tubes and load when the vacuum tubes are employed as amplifiers, and is lower in value than conventional circuit practice for the particular vacuum tubes and load when the vacuum tubes are employed as phase splitters.

11. The invention as claimed in claim 1, in which said first electric circuit means comprises electromagnetic pickup means of an electric guitar and filter means to select predominantly the higher-order harmonics present in the complex wave generated by the guitar and sensed by said pickup means, and in which said second electric circuit means comprises said electromagnetic pickup means of the guitar and second filter means for selecting from the same complex wave generated by said guitar and sensed by said pickup means predominantly the lower-order harmonics present in said complex wave.

12. The invention as claimed in claim 11, in which said pickup means comprises a single electromagnetic pickup.

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