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APPARATUS FOR PRODUCING TREMOLO EFFECTS

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APPARATUS FOR PRODUCING TREMOLO EFFECTS

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This invention relates to an apparatus and method for 15 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 ex- 20 tremely 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 25 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 ³⁵ 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 40 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. 50

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 2

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 to 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 20 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 30 10) and the lower frequencies in each note are imposed on the other wave (like wave 11). For example, a higherfrequency 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 10 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 15 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 selfbalancing 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 upperfrequency and lower-frequency ranges for each note, and to effect amplitude variation in such upper and lowerfrequency ranges in out-of-phase relationship relative to 30 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 ³⁵ 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. 45 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 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 65 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 lowpass filter adapted to smooth the wave from the phaseshift oscillator and cause it to be essentially sinusoidal as previously stated. Resistors 35 and 38 form a voltage 75

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.

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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 29a, 30a, 30b, 30c and 30d.

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 20 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 25 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 previouslyindicated 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 56a between equal resistors 40 and 41. Furthermore, such junction point 56a 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 56a 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 a switch 30 which provides a short to ground from the 55 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 56a 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 sepa-60 rate 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 70 resistor 40 to lead 56, and since any audio voltages present at point 56a 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

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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 10 connected to each other through a lead 65, and lead 65 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 15 plate resistors 69 and 70 having equal values. Plate voltage is thus supplied to the plates from the previouslyindicated 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 25 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 30 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 40 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) 45 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 50 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 55 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 60 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 65 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, 70 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.

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° outof-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 20 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 seriesconnected 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 As in the case of the triode 61, triode 62 has the non- 75 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 5 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 10 of resistor 38, is therefore transmitted to the circuit 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 15 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, 20 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 25 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 30 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 35 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 40 will not be present in the audio output 84. It is an important feature of the invention that the tremolofrequency waves have equal magnitudes, and thus cancel properly, despite variations in the tremolo frequency due to adjustment of resistor 29. A change in tremolo 45 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 selfbalancing 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 75 tained notes.

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 phaseshift 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 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 50 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 60 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 70 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 sus-

9 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	10
28	1,000	42	1,000	
29	2,000	46	220	
29 <i>a</i>	100	49	220	
30a	1,000	53	1.5	
30 <i>b</i>	2.7	57	1,000	15
32	220	67	. 15	
34	2,000	69	220	
35	2,000	70	. 220	
36	_1.000	74	220	
38	250	81	220	20
40	1.000	82	220	
41	1,000	n an Artan an Artan An		

Capacitors

Number:	Value	Number:	Value	25
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	30
37	0.10	77	0.0001	00
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 35vacuum tubes or transistors or like electronic currentflow 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 40or 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 50audio-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 60 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 amplitudemodulated 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.

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 amplitudemodulation 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 45 tremolo means include means to generate a first tremolofrequency 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, 55 electronic current-control means to cause the amplitudes of said superimposed signals to vary cyclically in out-ofphase 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 selfbalancing phase inverter circuit.

9. The invention as claimed in claim 7, in which said 65 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 70 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, 2. The invention as claimed in claim 1, in which said 75 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 5 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 10 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 ²⁰ first electric circuit means comprises electromagnetic

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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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