

Aug. 7, 1951

J. M. HANERT

2,562,908

ELECTRICAL MUSICAL INSTRUMENT

Filed April 16, 1949

3 Sheets-Sheet 1

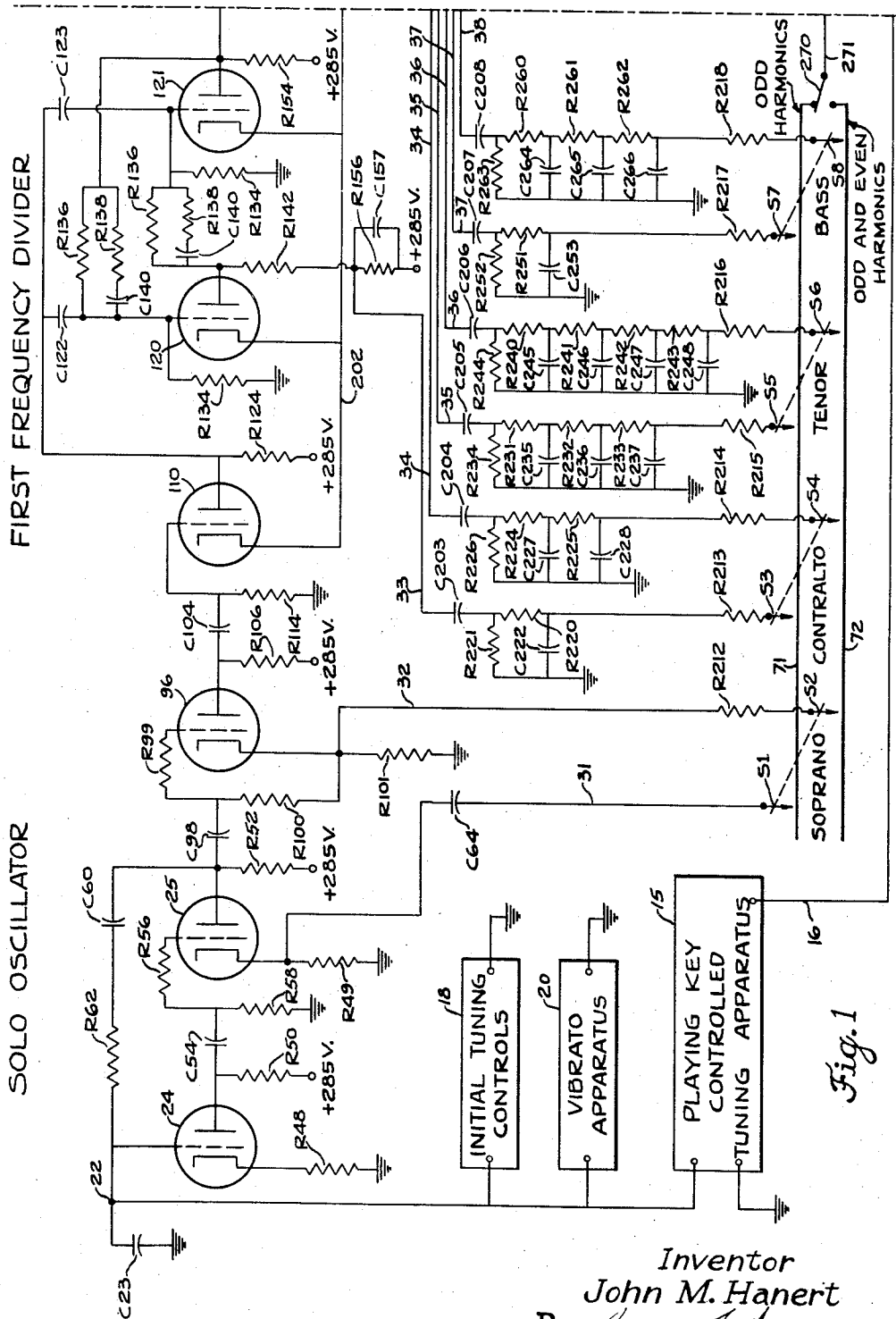


Fig. 1

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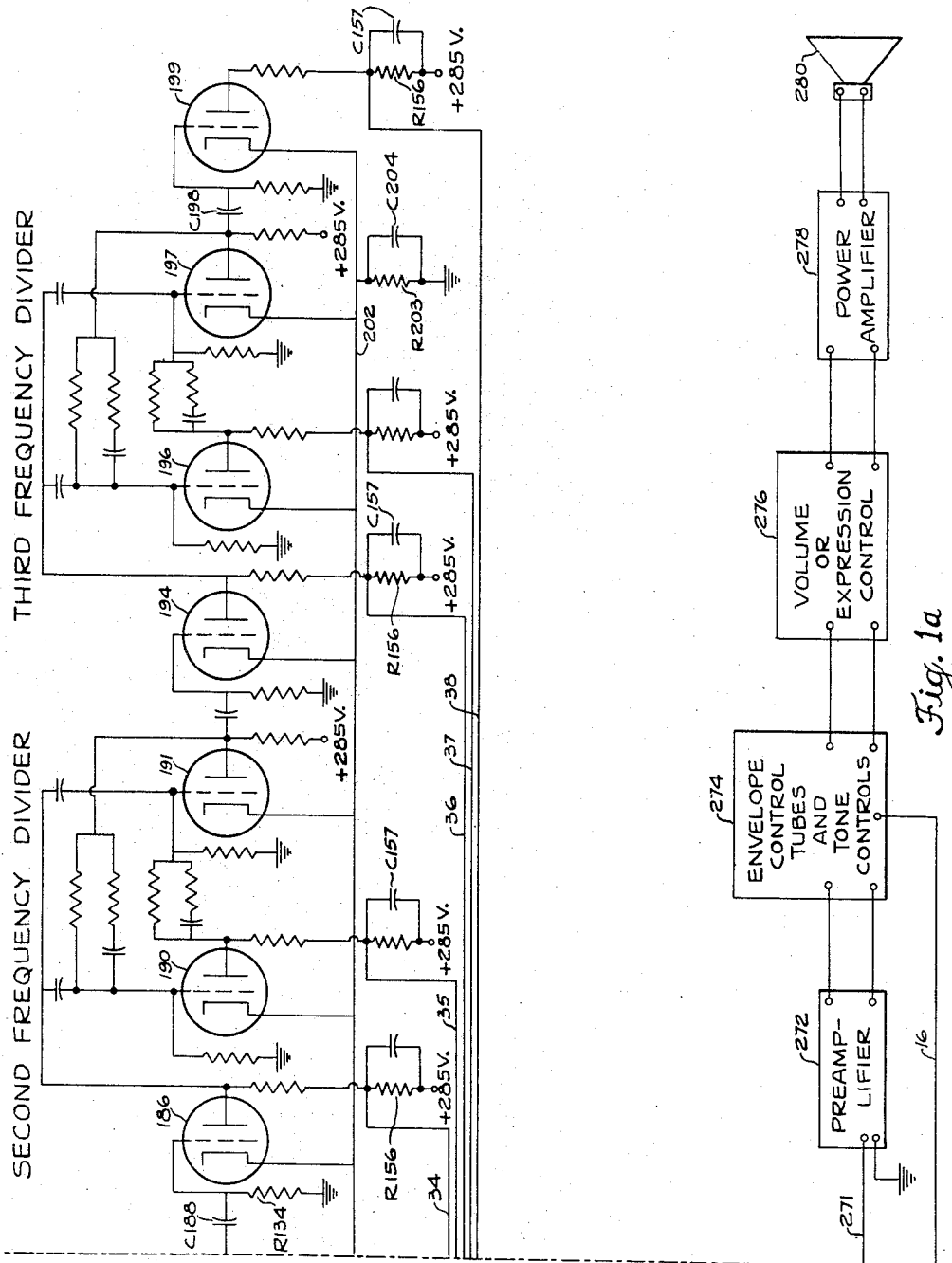


Fig. 1a

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3 Sheets-Sheet 3

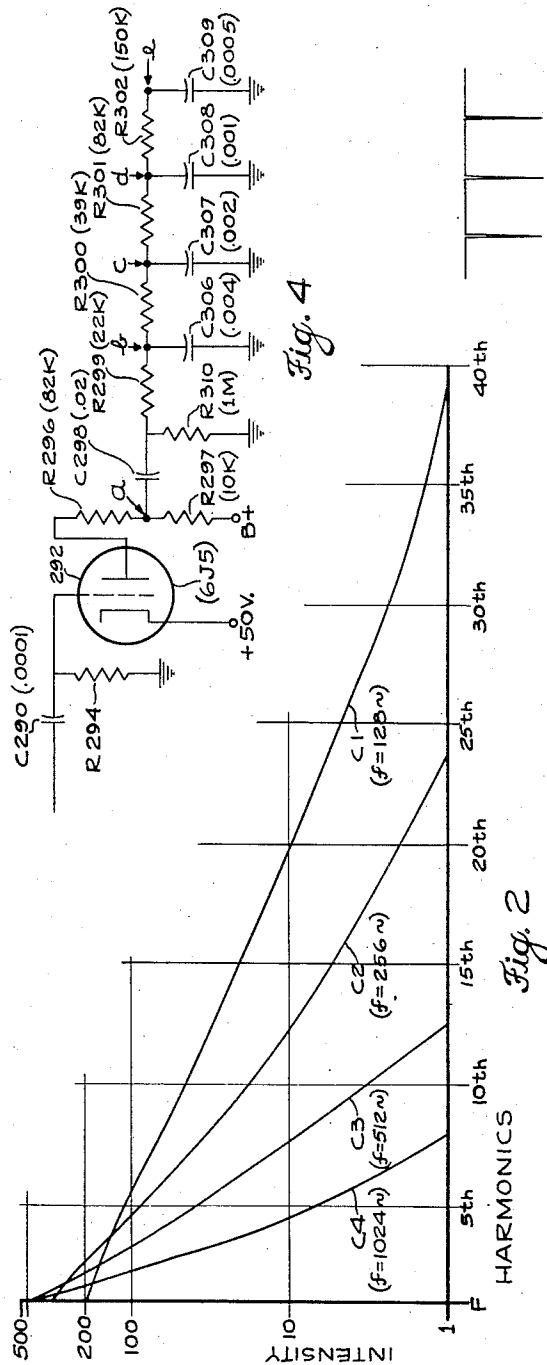
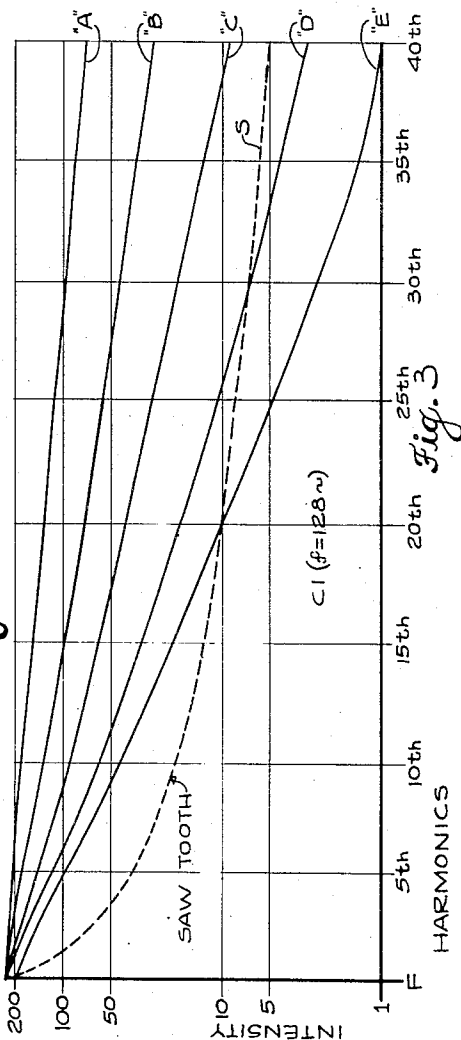


Fig. 5



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UNITED STATES PATENT OFFICE

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ELECTRICAL MUSICAL INSTRUMENT

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11 Claims. (Cl. 84-1.22)

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The invention relates generally to electrical musical instruments and more particularly to means for improving the quality of the tones produced by an instrument of this type.

It is the primary object of the invention to provide an electrical musical instrument having improved means for producing electrical signals corresponding to musical tones of highly desirable tone quality.

A further object is to provide an improved musical instrument having a master oscillator and a plurality of alternate pulse responsive frequency divider stages, to derive from the oscillator and the frequency divider stages sharp pulse signal waves, and to provide means whereby such pulse waves are converted into electrical signals of wave shapes representing highly desirable musical tone qualities.

A further object is to provide an improved tone signal generating system for electrical musical instruments in which alternate pulse responsive frequency divider stages are employed, and in which an electronic rectifier is used to provide sharp peak pulse signals suitable for reliable operation of the frequency divider stages, such sharp peak signals being also employed to provide the musical tone signals containing a long series of both the odd harmonics and the even harmonic partials.

Other objects will appear from the following description, reference being had to the accompanying drawings in which:

Figs. 1 and 1a together constitute a schematic wiring and block diagram of an electrical musical instrument incorporating the invention;

Fig. 2 is a chart of curves showing the harmonic content of tone signals of various frequencies produced by the instrument;

Fig. 3 is a chart similar to Fig. 2 showing the effect of the taking off the signal at various points in the attenuating mesh utilized in the instrument;

Fig. 4 is a schematic wiring diagram showing the filtering mesh from which the data used to plot the curves of Fig. 3 were obtained; and,

Fig. 5 shows the wave form of the input signal to the circuit of Fig. 4 and which was used to obtain the data for the plotting the curves of Fig. 3.

In electrical musical instruments, particularly of the solo or melody type, in which a master oscillator has its frequency controlled by playing keys or the like, and in which frequency dividers are coupled in cascade to the master oscillator, it is highly desirable that the frequency

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dividers stages be capable of operating through a wide range of frequencies and that they have a high degree of stability so as always to produce signal frequencies which are the desired sub-multiples of the frequencies to which the master oscillator is tuned. Frequency dividers having these qualifications usually require a sharp pulse type of input signal to insure reliable operation, and have an output in which the wave shape is rectangular or of saw-tooth shape.

A saw-tooth wave is one in which the harmonics are of geometrically decreasing amplitude, in which, assuming the intensity of the fundamental to have a value of 1, the successive harmonics will have intensities of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, . . . etc. Such saw-tooth wave is musically unsatisfactory for two reasons: First, the rate of progressive attenuation of the low order harmonics (2nd to 5th) is too rapid. For example, the second harmonic is attenuated approximately 6 db (decibels) with respect to the fundamental. The other low order harmonics are correspondingly attenuated in relatively large steps. Such high attenuation of the low order harmonics relative to the intensity of the fundamental, results in the production of excessively "pure" musical tones since too much of the energy is concentrated in the fundamental frequency. The ear is more pleasantly stimulated by the reception of a tone in which the energy is more or less equally distributed over a reasonable number of low order harmonics.

A second reason that tones having a harmonic series as represented by a saw-tooth wave are not of a satisfactory quality is that the higher order harmonics are of substantially equal amplitude. This is well illustrated by the curve "S" in Fig. 3, in which the intensities of the partials of a saw-tooth wave are indicated. It will be noted that the right hand portion of the curve tends to become nearly horizontal, that is, the higher harmonics do not differ substantially in intensity. This latter condition is musically undesirable since it causes the tone to have a high pitch "buzzy" effect, which is due to the large number of comparatively high intensity harmonics in the upper frequency range. The over-all tonal effect of a saw-tooth wave is therefore that of a powerful flute-like fundamental tone accompanied by an undesirable high harmonic "buzz."

A rectangular, (or substantially square) wave has the same harmonic analysis as the saw-tooth wave except that no even harmonics are present. The musical tones represented by rectangular

or square wave shapes thus have the same deficiency as the saw-tooth wave in that the attenuation of successive low order harmonics is at a too rapid rate, while the rate of attenuation of successive higher order harmonics is at too low a rate.

A tone quality which is incalculably superior to that which can be attained by the use of a saw-tooth or a rectangular wave shape signal, is one in which each of the harmonic partials is attenuated a constant percentage relative to the preceding harmonic. With the apparatus of this invention, the rectangular wave output of the frequency divider is rectified to a very narrow pulse whose width is small in comparison with its period. All of the low order harmonics are then present in substantially equal amplitude. This equality of harmonic amplitude will continue to higher harmonics only if the pulse is sufficiently narrow. For musical purposes this initial quality of amplitude is desirable only for the lower order harmonics (such as below the fifth harmonic). The narrow pulse wave is extremely rich in high harmonics and generally of a quality far too bright for musical purposes. It is a wave which is too "buzzy" but nevertheless, it is not too "pure" in its low order harmonic energy distribution. Thus, the narrow impulse wave satisfies the first requirement of an "ideal" tone insofar as the low order harmonics are concerned. In order to attenuate the higher harmonics sufficiently, a multi-stage filter is provided which is effective to cause very great attenuation of the undesirable high harmonics without correspondingly affecting the fundamental and low order harmonic relations. By proper selection of the frequency characteristics of a multi-stage filter network, a substantially "ideal" tone may be obtained in which the 40th harmonic is attenuated 30 decibels. This corresponds to a 1.2 decibel per harmonic attenuation factor. When listened to, this is a very pleasing rich tone-quality corresponding to a carefully voiced cello in which there is no suggestion of unpleasant low order harmonic purity or high order harmonic "buzz."

As the musician plays up and down the keyboard the "ideal" tone is everywhere present. Furthermore, there is some variation in the slopes of the straight-line harmonic curves (see Fig. 3). The tones are more brilliant at the lower end of the keyboard and more mellow at the high-pitched end of the keyboard. This is desirably natural sounding, and corresponds to the reduction in brilliance occurring in fine pianos as the player ascends the scale. A smooth variation in tone quality over the compass of the keyboard is desirable because it believes tonal monotony and adds interest to the music being performed.

Curves indicating the harmonic analysis of such tones are shown in Fig. 2, and will be referred to hereinafter.

The invention is herein illustrated as forming part of an electrical musical instrument of the solo or melody type such, for example, as is shown in the Patent Nos. 2,203,569 and 2,233,258. Certain features of the oscillator and other parts of the instrument are shown and claimed in my co-pending application Serial No. 51,409 filed September 27, 1948.

The solo oscillator may be of any suitable construction but is herein illustrated as comprising triodes 24 and 25 having a resonant tuning circuit including a capacitor C23 connected to a

terminal 22 and hence to the grid of triode 24, and playing key controlled tuning apparatus 15, comprising the customary manual of playing keys, approximately three octaves long, which progressively connect suitable inductance elements in series between terminal 22 and ground. In addition, each of the playing keys completes a circuit between a conductor 16 and ground to control the transmission of the signal through the output system of the instrument.

The oscillator 24, 25 may include adjustable tuning controls 18 connected between ground and the terminal 22, and a vibrato apparatus 20 similarly connected between ground and terminal 22 to cause a periodic shift in the frequency of oscillation of the oscillator 24 through a range of approximately 3 percent and at a rate of from 5 to 7 cycles per second.

Triodes 24 and 25 are connected to ground through self bias resistors R48 and R49 respectively. The anodes of triodes 24 and 25 are connected to a suitable source of plate current, indicated as +285 v. terminal, through load resistors R50 and R52 respectively. The anode of triode 24 is connected to the grid of triode 25 through a blocking capacitor C54 and a series grid resistor R56, the junction between C54 and R56 being connected to ground through the grid return resistor R58. The anode of triode 25 is connected to the grid of triode 24 through a capacitor 60 in series with a resistor R62 to provide a feed back path. This oscillator, due in part to the provision of the series grid resistor R56, produces an output wave on the cathode of triode 25 which is nearly rectangular in shape. A wave of this character consists substantially exclusively of a fundamental and a long series of its odd harmonics.

In operation, the triode 24 functions in the manner of either a class A or class C amplifier (in neither case drawing grid current) and thus the signal appearing on the grid terminal 22 appears in opposite phase on its plate. Triode 25 operates in a non-linear manner to cut off its plate current when its relatively large grid signal is negative and further limits its plate current when its grid signal is positive. The positive limiting effect is made possible because of the provision of the series grid resistor R56. This resistor R56 functions to prevent further increase in signal amplitude at the grid itself when any grid current is drawn. This is because the internal input impedance of the triode 25 becomes very low in comparison with R56 when the grid becomes positive with respect to its cathode. Furthermore, resistor R56 functions to prevent the capacitor C54 from building up a negative bias which would thereby cause triode 25 to operate in a class C manner to produce positive pulses at its output instead of the rectangular wave which is musically desirable because of its content of a series of odd harmonics.

The series resistor R56 is made large in comparison with the shunt resistor R58 so that the charge on capacitor C54 is substantially unaffected by the grid rectification in triode 25. A still further advantage of including resistor R56 is that changes in the voltage of the signal at the anode of triode 24 are not effective to change the D. C. voltage across the capacitor C54. Therefore capacitor C54 can be made relatively large so as to prevent any undesirable phase shift within the oscillator frequency range, and no difficulty with cessation of oscillations is encountered even

if there are large changes in the impedance of the tuned mesh. Such changes would result in large amplitude changes on the plate of tube 24, which in turn would change the charge across condenser capacitor C54, were the resistor R56 omitted.

Therefore, the inclusion of resistor R56 serves not only to cause tube 25 to operate in a desirable non-linear manner, but also prevents the development of a self-bias across the relatively large capacitor C54, which bias would cause stopping of the oscillator when playing legato from a note at which the resonant mesh impedance is high (thereby tending to cause a large self-bias voltage to be developed) to a note at which the resonant mesh impedance is relatively low. If this were to happen the change in the bias voltage across capacitor C54 would be of such value as to cut off the triode 25 when first playing the second note, thereby causing cessation of oscillation for a period related to the time constant of C54 and R58. As explained above this time constant should be long in comparison with the periodicity of the lowest note, so that no undesirable phase shift will occur. By inclusion of R56 this time constant problem is obviated and the oscillator does not stop oscillating. In a particular circuit which I have found satisfactory the triode 24 may be one-half of a 6SL7 double triode tube, and the triode 25 may be one-half of a 6SN7 double triode tube. The value of R56, under these circumstances is .1 megohm, and R58 is .05 megohm.

The rectangular signal appearing across the cathode resistor R49 is utilized in the output of the instrument, being transmitted through a switch S1, a blocking (and low frequency attenuating) capacitor C64 and a conductor 31. The switch S1 forms one of a group of 8 switches S1 to S8, the odd numbered switches being adapted to make contact with an odd harmonic bus-bar 71, while the even numbered switches S2, S4, S6, and S8 are adapted to make a connection with an odd and even harmonic bus-bar 72. The switches are operated in groups, S1 and S2 being adapted to be manually operated together by any suitable control, S3 and S4, S5 and S6, and S7 and S8 being similarly operated together, as indicated by the dotted lines in Fig. 1.

The plate of triode 25 is coupled through a blocking capacitor C98 and a series grid resistor R99 with the grid of a pulse sharpening and rectifying triode 96. The junction of the capacitor C98 and R99 is connected to the cathode by grid resistor R100 and the cathode is connected to ground through a signal resistor R101. Due to the provision of a small current limiting condenser C—98, the substantially square wave signal appearing on the plate of triode 25 is changed to a signal having acute positive and negative peaks symmetrically disposed about the horizontal axis. In as much as triode 96 is operating with zero bias, the negative signal peak is effective to cut the tube off (thereby producing a positive signal pulse in signal resistor R101). However the series grid resistor R99 and the lack of bias prevents the positive signal peak from causing substantial plate current change. This rectifying action results in a signal being generated across R101 which contains even as well as odd harmonics. In addition the wave-fronts of this rectified wave are steep and well-suited for operation of the succeeding frequency divider stages.

Plate voltage for the triode 96 is supplied from a +285 v. terminal through a load resistor R106,

and the plate of triode 96 is connected to the grid of a rectifier triode 110 through a coupling capacitor C104 and resistor R114.

The normally cut-off triode 110 operates to further rectify the signal so as to provide sharp negative pulses for the operation of the first frequency divider stage which comprises triodes 120 and 121. Plate voltage is supplied to the triode 110 through a load resistor R124 from a suitable potential source indicated +285 v. The pulse signal appearing on the plate of the triode 110 is impressed upon the grids of triodes 120 and 121, and these grids are connected to ground through grid resistors R134. The grids of triode 120 and 121 are respectively connected to the plates of triode 121 and 120 through meshes, each comprising a series resistor R136 shunted by a capacitor C140 and a resistor R138 in series. Plate voltage is supplied to the triode 120 through a load resistor R142 which is connected to a +285 v. terminal through a mesh comprising a resistor R156 having a capacitor C157 in parallel therewith. The junction of R142 and R156 has a conductor 33 connected thereto for transmitting a signal to the output system of the instrument. Plate voltage is supplied to the triode 121 through a load resistor R154 connected to a +285 v. terminal.

The output signal appearing on the plate of triode 121 is impressed upon the grid of triode 186 (Fig. 1a) through a coupling capacitor C188, the grid of triode 186 being connected to ground through a resistor R134. Triode 186 operates as a rectifier to supply very sharp, narrow, negative pulses to triodes 190 and 191 which form parts of the second frequency divider stage. This divider stage, comprising the rectifier tube 186 and triodes 190 and 191, is similar to the first frequency divider stage and corresponding components have therefore had the same reference characters supplied thereto, it being understood that the components function in the same manner but that they may have doubled values to insure more reliable operation at the sub-octave frequency at which the second frequency divider stage operates.

Similarly, a third divider stage is similar to the first frequency divider stage and comprises a rectifier triode 194 and a pair of alternate pulse responsive triodes 196 and 197. The plate of the triode 197 is connected by a coupling capacitor C198 to the grid of a pulse sharpening triode 199. This triode is included so as to provide a sharp peaked pulse signal for the output of the third divider stage. This signal is derived across a mesh R156, C157 in the plate circuit of triode 199 and is transmitted through a conductor 38 in a manner similar to that in which the signal is derived from the plate of triode 120.

It will be noted that signals are also taken from the plate circuit of triode 186 through a conductor 34, from the plate of triode 190 through a conductor 35, from the plate circuit of triode 194 through a conductor 36, and from the plate circuit of triode 196 through a conductor 37.

The cathodes of triodes 110, 120, 121, 186, 190, 191, 194, 196, 197, and 199 are connected to a cut-off bias by means of a common conductor 202 which is biased to ground potential by a self-bias resistor R203 (Fig. 1a) having a capacitor C204 in parallel therewith.

It will be clear from the foregoing that each of the odd numbered conductors 31 to 37 is adapted to transmit a square or box wave signal,

whereas the even numbered conductors 32 to 38 are connected so as to receive a sharp, narrow, needle-like, negative pulse signals from their respective divider stages.

As previously stated, the rectangular, clarinet-like, signal appearing across cathode resistor R49 is supplied to switch S1 through a small current-limiting capacitor C64. This capacitor thus serves to equalize the low order harmonics. The string-like signal (having both even and odd harmonics) appearing across the cathode resistor R101 is impressed through conductor 32 and decoupling resistor R212 upon the switch S2.

The conductors 33 to 38 inclusive are connected to their respective switches S3 to S8 through suitable filtering meshes which include small current-limiting capacitors C203 to C208 and decoupling resistors R213 to R218 respectively. These small condensers also serve to equalize the amplitudes of the fundamental and low order harmonics. The filtering mesh for attenuating the higher order harmonics in the "contralto" range odd harmonic signal supplied by the conductor 33 includes a series resistor R220 the terminals of which are connected to ground through R221 and C222 respectively. R221 is of high value such as 1 megohm and serves to maintain the switch contact 53 at ground potential, and thus prevents possible transients when closing switch 53. In a similar manner the attenuating mesh for the sharp pulse signal supplied by the conductor 34, that is, the "contralto" odd and even harmonic signal, includes series resistors R224 and R225, shunt resistor R226, and shunt capacitors C227 and C228. The "tenor" odd harmonic signals supplied through the conductor 35 have their higher harmonics attenuated by the filtering mesh comprising series resistors R231, R232 and R233, shunt resistor R234 and shunt capacitors C235, C236 and C237.

The "tenor" pulse signals containing the odd and even harmonics, supplied through conductor 36, have their higher harmonics attenuated by the filtering mesh comprising series resistors R240, R241, R242 and R243 and shunt resistance R244 and shunt capacitors C245, C246, C247 and C248.

The "bass" signals containing only the odd harmonics, supplied through the conductor 37, have their higher order frequencies attenuated by the filtering mesh comprising series resistor R251, shunt resistor R252 and shunt capacitor C253.

The "bass" odd and even harmonic signals, supplied through the conductor 38, have their higher harmonics attenuated by the filtering mesh comprising series resistors R260, R261, R262, shunt resistor R263 and shunt capacitors C264, C265 and C266.

Whether the signal is to comprise only tones having odd harmonic partials or tones having both the odd and even harmonic partials is determined by the position of a switch 270 which is adapted to connect a conductor 271 to either of the bus conductors 71, 72. The conductor 271 feeds the selected signals to a preamplifier 272 and the latter supplies the amplified signals to a suitable envelope and tone control apparatus 274 from which the signals are supplied to a volume or expression control device 276, a power amplifier 278 and speaker 280.

It will be recalled that the playing key controlled tuning apparatus 15 not only includes

means controlled by the playing keys to tune the solo or master oscillator but also includes a switch under each key adapted to connect conductor 16 to ground. Conductor 16 leads to the envelope control apparatus 274 and, by operating on the bias of vacuum tubes included in the apparatus 74, renders this apparatus capable of transmitting the signal from the pre-amplifier to the volume or expression control 276, in a manner disclosed generally in the aforesaid Patent No. 2,233,258.

The results attained by the use of the filtering meshes for the outputs of the various frequency signal sources may best be understood by reference to Figs. 2 to 5. Fig. 4 illustrates a filtering mesh similar to that connected to conductor 36 and which was used to obtain readings from which most of the curves of Fig. 3 were plotted. A signal comprising a pair of positive and negative peaks, symmetrical about the zero-axis was supplied to the circuit of Fig. 4 through a blocking capacitor C290 connected to the grid of a triode 292, the grid being connected to the ground through a resistor R294. The cathode was connected to a suitable potential source, such as +50 v., to provide the desirable grid cut-off bias. Plate current was supplied to this tube from a suitable potential source B+ through voltage divider load resistors R296 and R297. The signal appearing at the junction of the latter two resistors, that is, at the point *a* in Fig. 4, had the wave shape of Fig. 5, and was attenuated by a filtering mesh comprising series capacitor C298 and series resistors R299, R300, R301 and R302. The junctions following the latter four resistors bear the reference characters *b*, *c*, *d*, and *e*, and are connected to ground through capacitors C306 to C309 respectively, while the junction between C28 and R299 is connected to ground through a resistor R310.

In Fig. 4 the various components have their values (in ohms and microfarads) indicated in the parenthesis following the reference character. A pulse type signal of the form described above was impressed upon the grid of the triode 292 and harmonic analyses made of the signals appearing at the terminals *a*, *b*, *c*, *d* and *e* and the intensities the harmonics plotted to produce curves A, B, C, D and E respectively of Fig. 3. (It will be understood that these curves designate merely the intensities of different harmonics, and do not represent continuous variables.)

In Fig. 3 the intensity is plotted vertically to a logarithmic scale while the harmonic numbers extend along the horizontal axis. From these curves it will be noted that very desirable musical tone qualities are produced by the attenuating meshes of Fig. 4 which correspond to the meshes by which the generators are coupled to the output of the instrument. Each of the curves A to E is substantially a straight-line, which means that the successive harmonic partials are attenuated progressively by equal percentages. The frequency of the signal supplied to the network shown in Fig. 4 was that of the note C1 having a frequency of 128 C. P. S. With a note of this frequency it is desirable that the number of harmonics be very large since many of the harmonics lie well within the range of audibility. These curves show how the tone quality of the signal is progressively changed as it is attenuated by the successive sections of the filtering mesh of Fig. 4.

As shown by curve E, the higher harmonics are of sufficiently lesser intensity than the lower or-

der harmonics that the tone does not sound buzzy. For higher pitch notes it is not desirable to have the slope of the curve representing the intensities of the harmonics be as gradual as the slope of the curve E of Fig. 3.

This fact is illustrated by the curves in Fig. 2 wherein the curve C1 corresponds to the curve E of Fig. 3. This curve represents the intensity of the various partials of the note of a pitch C1, that is having a fundamental frequency of 128 C. P. S. Similarly, the curve C2 represents the intensities of the partials of the note C2 having a fundamental frequency of 256 C. P. S. It will be noted that the harmonics of the note C2 decrease in intensity at a substantially more rapid rate than that of the note C1. Likewise, the curves C3 and C4 representing the intensities of the partials of the notes C3 and C4, respectively of 512 C. P. S. and 1024 C. P. S., are of progressively greater slope than the curve C2. The note C4 is quite high in the musical register and if it contained audible frequencies much above the sixth or seventh harmonic the tone would sound disagreeable since it would be extremely buzzy.

The constants of the filtering meshes for attenuating the higher order harmonics of the signal supplied through the conductors 33 to 38 inclusive, are such as to cause the attenuation to conform generally to that represented by the curves of Fig. 2.

By this method of tone production, whereby a signal containing practically all of the audible harmonics in substantially equal amplitude, has its higher order harmonics attenuated progressively, by a substantially constant factor, as their harmonic number increases, musical tones of very desirable basic quality are obtained.

These tone signals are then passed through the usual adjustable filtering R-L-C meshes whereby certain tonal ranges are accentuated due to the resonance effects of these circuits, to produce a large variety of different tone qualities. It will be understood that such resonant networks are much more effective if the signal supplied to it includes a large number of harmonics of substantial amplitude than if the signal includes but a few harmonics of audible amplitude. These filtering tone control networks are much more effective on a signal having a wave-shape similar to that shown in Fig. 5 than on a signal of the saw-tooth wave shape, of which the harmonic analysis is illustrated by the curve S in Fig. 3. For example, if a saw-tooth wave having the characteristics of the curve S of Fig. 3 were passed through a filter tending to pass a band of frequencies centering around the fifth harmonic, it will be clear that the first and second, and possibly the third, harmonics could not readily be attenuated sufficiently to be of lower amplitude than the fifth harmonic whereas the harmonics of higher order than the fifth would be greatly attenuated. On the other hand, if the signal represented by curves C, D or E were filtered by such a band pass filter, the lower order harmonics such as first, second and third could, without much difficulty, be attenuated so as to be of lesser amplitude than the fifth harmonic and the harmonics above the fifth would be attenuated substantially. Thus the tone signals produced by the generating systems disclosed in this application are more readily susceptible to control as to quality by band pass filtering meshes.

While it will be apparent to those skilled in the art that the particular values of the components of the filtering circuits may be varied consider-

ably and yet produce substantially the same results, it is believed desirable to set forth the values of a number of the important components of filtering circuits which have been found to be satisfactory for the accomplishment of the purposes set forth as objects of this invention. The values may be varied considerably, especially if the compensatory changes are made in the values of other components. In the particular circuits shown in this application the various important components have the following values, in ohms and microfarads:

C64, .0001	C245, .004	R216, .27 M	R240, 22 K
C203, .001	C246, .002	R217, .15 M	R241, 39 K
C204, .01	C247, .001	R218, .15 M	R242, 82 K
C205, .0025	C248, .0005	R220, 39 K	R243, .15 M
C206, .02	C249, .003	R221, 22 K	R244, 1 M
C207, .005	C250, .004	R222, 39 K	R251, 39 K
C208, .04	C251, .002	R223, 82 K	R252, 22 K
C227, .001	C252, .001	R224, 1 M	R253, 39 K
C228, .0005	R212, .47 M	R231, 39 K	R261, 83 K
C235, .0008	R213, .27 M	R232, 82 K	R262, .15 M
C236, .0004	R214, .39 M	R233, .15 M	R263, 1 M
C237, .0002	R215, .1 M	R234, 22 K	

The capacitors C157 may have values in the order of .005 to .01, while the resistors R156 may have values in the order of 10 K to 18 K, depending somewhat upon the signal strength of the output of the frequency divider stages to which they are connected.

In the foregoing description, and in the following claims, the term "alternate pulse responsive frequency divider" is used to refer to any frequency dividing device, which has two, and only two, stable output voltages, and which will continue to deliver one of these voltages until a controlling input pulse is applied thereto, whereupon the other output voltage will be delivered. Thus, upon application of successive controlling impulses, the device will deliver the two output voltages alternately, and the output voltages alternately, and the output wave will be generally rectangular in shape and have a frequency one-half that of the controlling input pulses.

While I have shown and described particular embodiments of my invention, it will be apparent to those skilled in the art that numerous modifications and variations may be made in the form and construction thereof, without departing from the more fundamental principles of the invention. I therefore desire, by the following claims, to include within the scope of my invention all such similar and modified forms of the apparatus disclosed, by which substantially the results of the invention may be obtained by substantially the same or equivalent means.

I claim:

1. In an electrical musical instrument of the melody type, having an output system, the combination of a variable frequency master oscillator, keyboard controlled means for tuning the master oscillator over a range of at least two octaves in accordance with the intervals of the tempered musical scale, an alternate pulse responsive frequency divider coupled to said master oscillator and supplying a substantially rectangular shaped output signal of one-half the frequency of the master oscillator, a high pass filter network coupled to said frequency divider greatly to attenuate the fundamental and low order harmonics of the output signal and effective to alter its wave from a rectangular shape to one in which there are two peaks substantially equally spaced in time but oppositely polarized for each cycle of the signal, a rectifier coupled to said network and effective to attenuate one of said peaks relative to the other and thereby to introduce musically desirable even harmonics into the signal, an output

terminal for said rectifier, a low-pass filtering network coupled to said terminal for attenuating undesirable high harmonics in the signal present at such output terminal, a second alternate pulse responsive frequency divider coupled to said output terminal and effective to divide the frequency thereof by a factor of two, and means for transmitting the output signal from said low pass filtering network to the output system of the instrument.

2. In an electrical musical instrument having an output system and a plurality of alternate pulse responsive frequency divider stages each operable throughout a wide range of musical frequencies in response to variable frequency input signal pulses, and each producing a rectangular wave output signal comprising a fundamental frequency and a long series of odd harmonics thereof; the combination of means for coupling the output of one stage to the input of the next stage comprising a current limiting and rectifying device effective to change the rectangular wave in the output of the first stage into a sharply peaked wave in which the peaks of one polarity are greatly attenuated, and a multistage filter coupling the output of the coupling means to the output system and effective to attenuate the harmonics progressively to greater extents with increasing frequency by a substantially constant fractional factor.

3. In an electrical musical instrument having an output system and a plurality of alternate pulse responsive frequency divider stages each operable throughout a wide range of musical frequencies in synchronism with variable frequency input signal pulses, and each producing a rectangular wave output signal comprising a fundamental frequency and a long series of odd harmonics thereof of nearly equal amplitude; means for coupling the output of one stage to the input of the next stage comprising a current limiting and rectifying device effective to change the rectangular wave in the output of the first stage into a sharply peaked wave in which the peaks of one polarity are greatly attenuated, and multi-section filters respectively coupling the output of the coupling means and the outputs of the divider stages to the output system of the instrument, said filters being constructed and arranged to attenuate the harmonics of the signals to an extent that such each harmonic has an intensity which is a predetermined fraction of that of the preceding lower harmonic.

4. In an electrical musical instrument the combination of a musical frequency signal source, an electron discharge device having a current limiting input circuit operable to peak the signal supplied by the source and having an output circuit in which the signal appears as a wave comprising a series of sharp peaks of one polarity spaced far apart along the time axis, an output system for the instrument, and a circuit coupling the output of the electron discharge device to the output system, said circuit including a multi-section filter having high-frequency attenuating characteristics such that each successive higher order partial is of lower intensity than the preceding partial by substantially the same fractional factor.

5. The method of electrically producing musical tone signals of high harmonic content which comprises, producing electrical signals comprising waves having spaced sharp peaks of only one polarity, each wave thus comprising a fundamental frequency and all of its harmonic partials

in the audible range in nearly equal high amplitude, attenuating the harmonics of the lower frequency waves so that the intensity of each harmonic partial is a predetermined large fraction of the intensity of the next lower partial, and attenuating the higher frequency waves so that the intensity of each harmonic partial is a predetermined lesser fraction of the intensity of the next lower partial.

6. In an electrical musical instrument having an output system, the combination of a series of cascaded alternate pulse responsive frequency divider stages, means to supply a controlling frequency to the first divider stage of the series, a plurality of peaking and rectifying devices respectively forming coupling means between each divider stage and the succeeding divider stage of the series, and a plurality of selectively operable means respectively coupling the outputs of the individual speaking and rectifying devices and the individual divider stages to the output system, said last named means including filter means effective to attenuate the higher order harmonics.

7. The combination set forth in claim 6 in which the filter means for the tone signals attenuates the partials of the signals approximately in direct proportion to the frequencies of the partials.

8. In an electrical musical instrument having an output system, the combination of a master oscillator, a first alternate pulse responsive frequency divider coupled to said master oscillator and effective to divide its frequency by a factor of two, a rectifier coupled to the output of said first frequency divider, an output terminal for said rectifier, a second alternate-pulse-responsive frequency divider coupled to said terminal, and a signal utilization circuit coupling said terminal to the output system, whereby said rectifier is effective to distort the rectangular wave shape of the output of said first frequency divider in a manner to introduce desirable even harmonic content suitable for musical signal utilization and for stable operation of said second frequency divider.

9. In an electrical musical instrument having an output system, the combination of a source of electrical musical tone signals of substantially rectangular wave form, a first signal transmission path including pulse-forming means coupling the source with the output system and transmitting sharp pulses of alternating polarity comprising substantially only odd harmonic partials to the output system, and a second signal transmission path including pulse-forming means and rectifying means connecting the source with the output system and transmitting sharp pulses of only one polarity comprising both even and odd harmonic partials.

10. In an electrical musical instrument having an output system, the combination of a source of electrical musical tone signals, means coupled to the source for producing symmetrical rectangular wave signals, current limiting means connected to the output of the last named means for producing substantially needle sharp pulses of alternating polarity, rectifying means connected with the output of the current limiting means for transmitting pulses of one polarity only, and a filter connecting the rectifying means with the output system attenuating the harmonics of the pulses approximately in direct proportion to the frequencies of the harmonics.

11. In an electrical musical instrument having

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an output system, the combination of a source of electrical musical tone signals including substantially odd harmonics only and having steep wave fronts, a signal transmission apparatus connecting the source with the output system including differentiating and rectifying means and a filter, the differentiating and rectifying means providing sharp pulses of only one polarity and the filter attenuating the harmonics in the pulses approximately directly in proportion to the frequencies of the harmonics, whereby musically desirable signals having both even and odd harmonic partials are supplied to the output system.

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