

June 27, 1961

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2,989,885

ELECTRONIC MUSICAL INSTRUMENT AND METHOD

Filed April 14, 1955

5 Sheets-Sheet 1

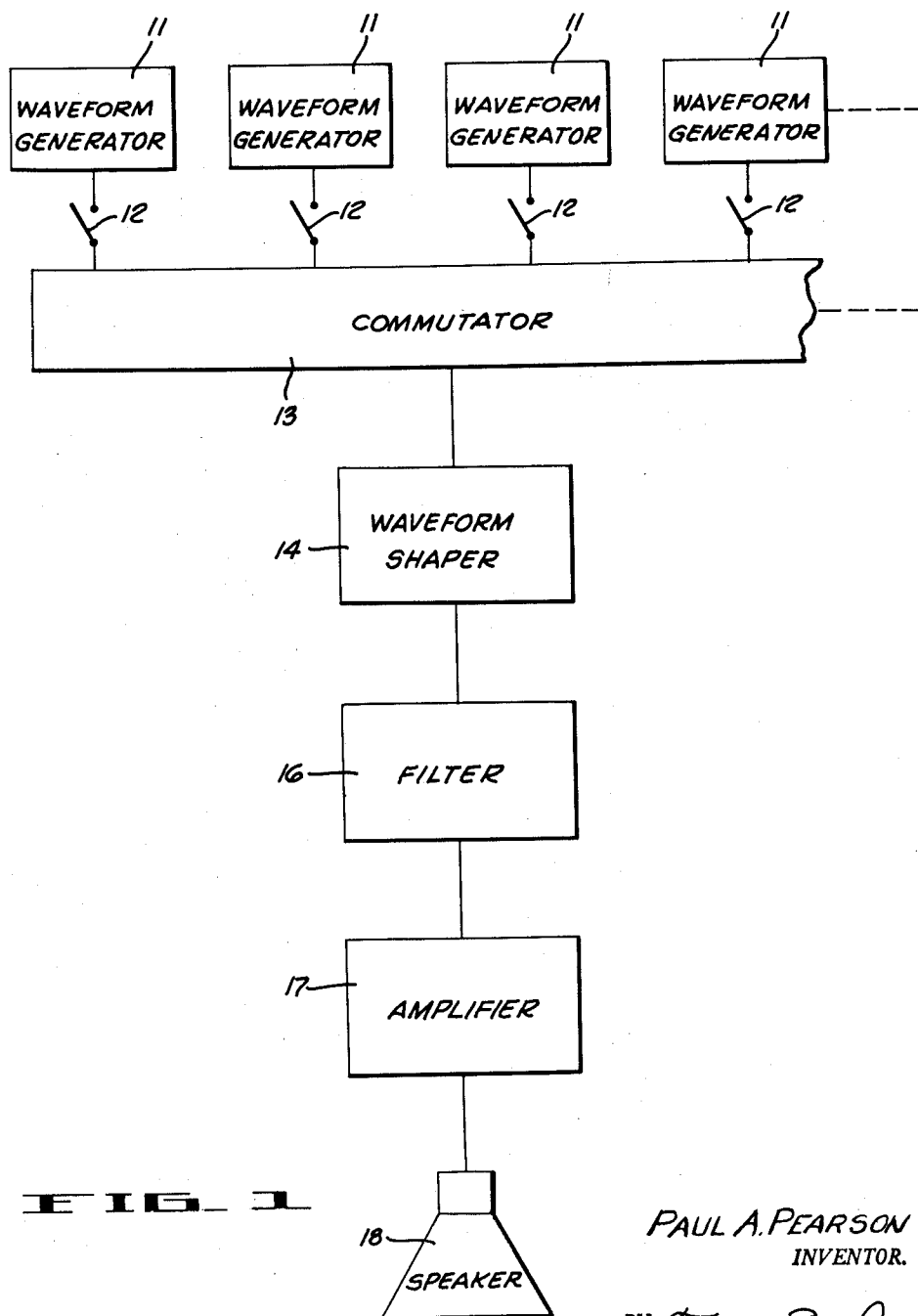


FIG. 1

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5 Sheets-Sheet 2

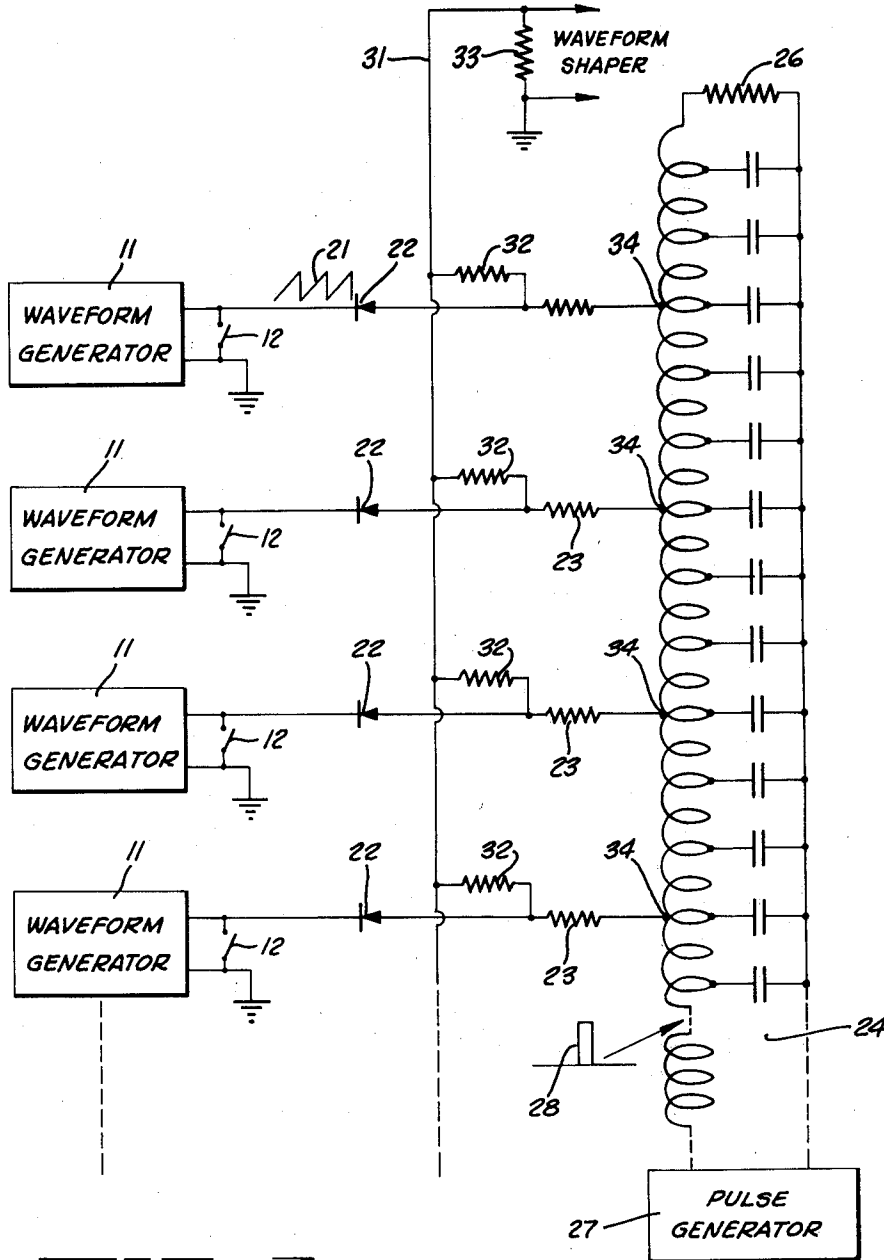


FIG. 2

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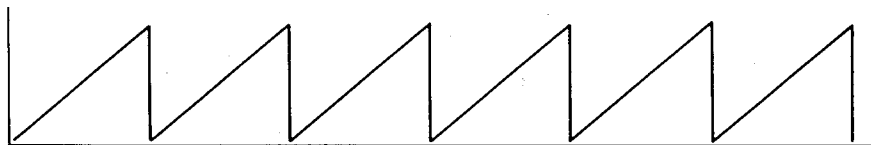
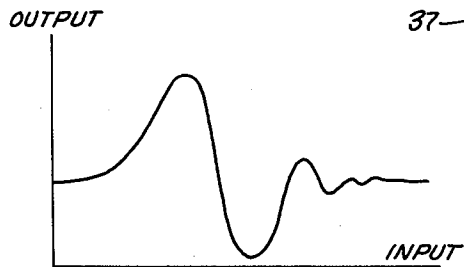
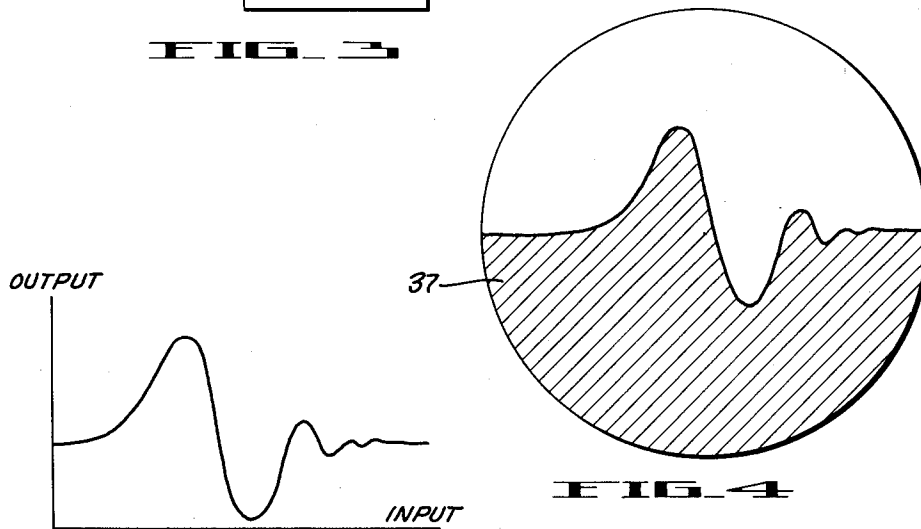
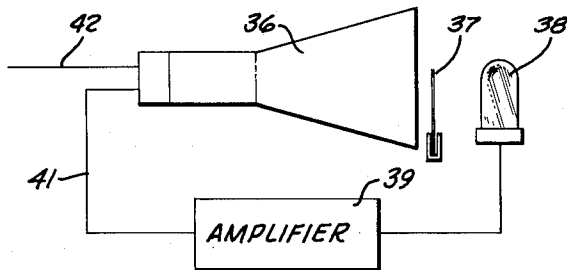
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5 Sheets-Sheet 3



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5 Sheets-Sheet 4

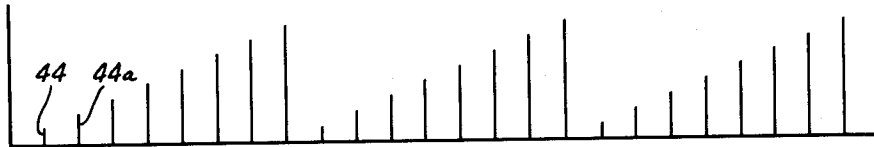


FIG. 7A

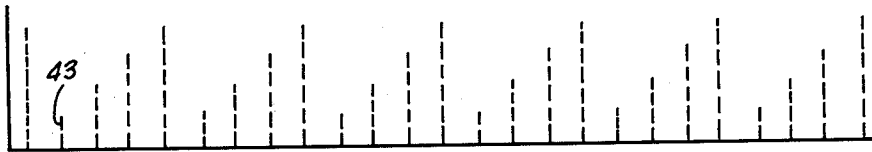


FIG. 7B

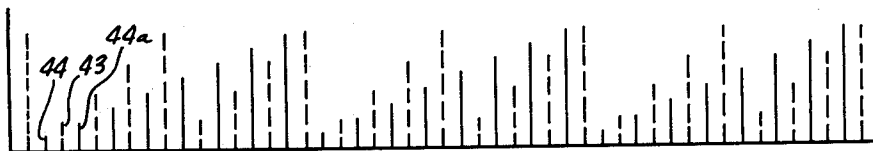


FIG. 7C

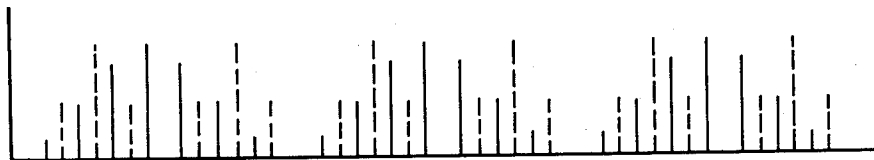


FIG. 8

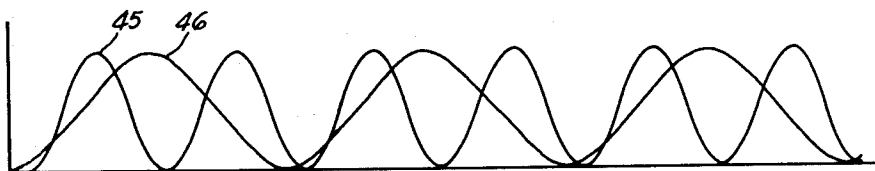


FIG. 9

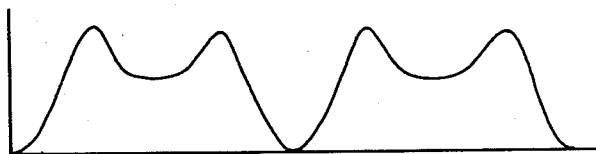


FIG. 10

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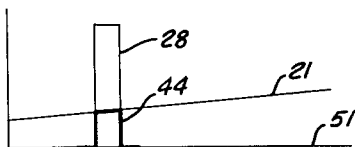


FIG. 11

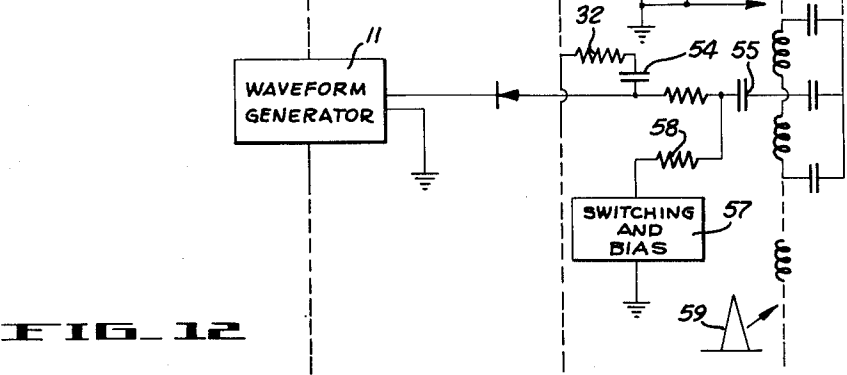


FIG. 12

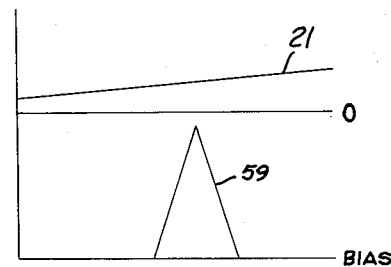


FIG. 13

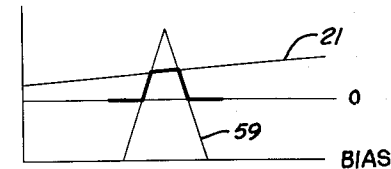


FIG. 14

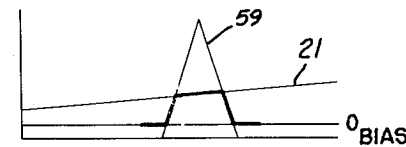


FIG. 15

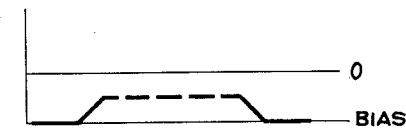


FIG. 16

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ELECTRONIC MUSICAL INSTRUMENT AND METHOD

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Filed Apr. 14, 1955, Ser. No. 501,239
16 Claims. (Cl. 84-1.19)

This invention relates generally to an electronic instrument and method of the type capable of producing music.

It is an object of the present invention to provide an electronic instrument and method capable of producing music having any desired tonal qualities.

It is another object of the present invention to provide an electronic musical instrument and method in which the various frequencies (pitch) are generated as simple, easy to obtain waveforms.

It is a further object of the present invention to provide a means for sampling waveforms singly, sequentially and recurrently.

It is still a further object of the present invention to provide a means for shaping the waveforms in any desired manner to impart the desired tonal qualities (timbre).

It is still a further object of the present invention to provide an electronic instrument in which the various frequencies or tones are selected by means associated with individual tone waveform generators.

It is a further object of the present invention to provide means for preselecting the tonal qualities (timbre).

It is still a further object of the present invention to provide a commutating means and method capable of sampling items of intelligence singly, sequentially and recurrently at a preselected frequency.

It is still another object of the present invention to provide a means by which a single waveform shaper may be used to shape waveforms being generated simultaneously.

It is a further object of my invention to provide means for controlling the attack and decay characteristics of the various frequencies (tones) as they are turned on and off.

These and other objects will be more apparent from the following description of the invention in which:

FIGURE 1 is a block diagram of a portion of an instrument incorporating the present inventions;

FIGURE 2 is a circuit diagram of a commutator which may be used to sample waveforms;

FIGURE 3 is a schematic diagram of a waveform shaper;

FIGURE 4 is a mask which may be used in conjunction with the wave shaper of FIGURE 3;

FIGURE 5 shows a plot of output as a function of input for a wave shaper employing the mask of FIGURE 4;

FIGURES 6A and 6B show sawtooth waves generated by waveform generators;

FIGURES 7A, 7B and 7C show the output for the commutator of FIGURE 1 when the sawtooth waves of FIGURES 6A and 6B are commutated;

FIGURE 8 shows the output of a waveform shaper having sine wave characteristics.

FIGURE 9 shows the individual waveform output of the filter associated with a waveform shaper of FIGURE 8;

FIGURE 10 shows the input to the audio amplifier again referring to the waveform shaper of FIGURE 8;

FIGURE 11 shows the formation of an output pulse for the commutator of FIGURE 1;

FIGURE 12 shows another embodiment of a commutator which may be used in the present instrument;

FIGURES 13, 14 and 15 show output waves corresponding to those of FIGURE 11 for the circuit of FIGURE 12; and

FIGURE 16 shows a possible variation of the bias voltage for operation of the commutator.

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Generally, my invention makes use of a plurality of tone waveform generators which generate simple and easily obtained waveforms. Combinations of these waveforms or tones are selected, commutated and shaped to give desired tonal qualities. Audio components are then amplified and reproduced by a suitable loud speaker or speaker system.

My electronic instrument may be more clearly understood with reference to the schematic diagram of FIGURE 1. A plurality of tone waveform generators 11, one for each of the desired notes of a musical scale, are provided. In general, the tone waveforms which are generated are chosen to be simple and easily obtained. For example, they may have a sawtooth waveform. Means are provided for connecting the tone waveform generators to the commutator 13. Such means may be integral with the waveform generator or the commutator, or may for example comprise external switches. For example, a series of switches 12 which might correspond to the keys of a keyboard, are connected to the waveform generators and determined which of the generator outputs will be connected to the commutator 13. In general, a single frequency or a combination of frequencies may be selected by operation of switches 12. In this manner, it is possible to produce single musical notes or tones or combinations such as chords.

The waveform sampling commutator 13 is connected to all of the waveform generators 11 and serves to sample the generator waveforms singly, sequentially and recurrently. As will be presently shown, this sampling must take place at a rate which is substantially above the audio frequencies being generated.

The output of the commutator 13 is fed into a waveform shaper 14. The output amplitude of the waveform shaper 14 can be made any arbitrarily chosen function of the input amplitude. The waveform shaper shapes the commutated waveforms to give the desired tonal qualities (timbre). The filter 16, designed to pass the desired audio frequencies, is connected to the output of the waveform shaper. The output of the filter 16 is fed into an audio amplifier 17 which amplifies the signal and gives sufficient power to drive a speaker 18. In some applications, the amplifier may be omitted and the output of the filter fed directly to the speaker.

Each tone waveform generator 11 may be any device which is capable of generating a simple waveform having desired frequency. For example, they may be electronic sawtooth generators such as are well known in the art. These generators are selected to have frequencies corresponding to the notes of the musical scale which are to be included in the instrument. The frequency may be modulated to provide tremolo.

In FIGURE 2, I have shown a novel high speed commutator which may be used to commutate the various generator waveforms. A typical output wave for the waveform generator is shown at 21. Other output waves will have the same shape but will have different frequencies as described above. Diode 22 and resistor 23 are connected in series between the tone generators and the taps on the delay line 24. The delay line 24 may be of conventional construction with the constants selected to provide the desired delay, as will be presently described. If the length of the line is such that excessive attenuation is present it may be necessary to introduce amplifier repeaters or pulse generators which are properly triggered to compensate for the attenuation. The line is terminated in the proper resistance 26 to prevent reflection. A pulse generator 27 is connected to the line, and may be an electronic device which generates a rectangular pulse such as is shown at 28, and which are well known in the art.

The common junction of diodes 22 and resistor 23 is connected to the line 31 through resistor 32. Resistor 33 is a common output resistor having a comparatively low resistance to prevent interaction between the various generators.

Operation of the commutator is as follows: As the pulse voltage rises, assuming finite rise time at a particular tap, for example, tap 34 on the video delay line 24, this voltage appears across the output resistor 33 attenuated by the ratio

$$R_{33}/R_{33}+R_{32}+R_{23}$$

When the pulse voltage at the junction of R23 and R32 reaches a value equal to the output voltage of the corresponding waveform generators, the diode will conduct and clamp this pulse voltage. (Assuming the internal impedance of the waveform generators to be small compared to R23). The value at which the voltage is clamped is equal to the voltage of the waveform generator attenuated by the factor

$$R_{33}/R_{33}+R_{32}$$

Thus it is seen that the peak pulse voltage appearing across resistor 33 is the voltage of the simple waveform generator at that particular instant attenuated by the aforementioned ratio.

Other means may be employed in conjunction with the delay line for sampling the waveform generator voltages. For example, other vacuum tube or semiconductor devices might be employed.

The total delay of the line must be such that the delay is less than the interpulse time. In this manner sampling of more than one waveform generator at any particular time is prevented. This result may be achieved in many ways. For example, by allowing the pulse generator to run freely at a particular frequency which is within these limits or by triggering the pulse generator with a signal obtained at the end of the delay line.

As the pulse 28 travels along the delay line 24, it meets with the consecutive taps which are connected by resistors 23 and diode 22 to the tone waveform generators. As the pulse 28 passes a given tap a pulse is transmitted along line 31 to the resistor 33. As was previously shown, the peak of this pulse will be proportional to the amplitude of the tone waveform generator voltage or output waveform at that particular instant. The pulse from the pulse generator travels along the delay line and rises at each of the various taps sequentially. As it passes each of these taps, a pulse will be transmitted across resistor 33 which will correspond to the voltage at the particular waveform generator. It is to be observed that in this manner the output of the various generators is sampled individually, sequentially and recurrently, since the pulse generator generates recurrent pulses. As will presently be shown, in order to have resulting pulses which have an envelope corresponding to the waveshape of the waveform generators it is necessary that the recurrence rate be considerably higher than the highest generator frequency.

Although I have shown a particular type of novel type of commutator, it is to be understood that other means for singly, sequentially and recurrently sampling the output voltage are available and that use of these will not depart from my invention.

In FIGURE 3 I have shown a waveform shaper of the type which may be used in conjunction with my invention. A waveform shaper is a device which permits making the output amplitude any desired function of the input amplitude. The wave shaper shown comprises a cathode ray tube 36, a mask 37, a phototube 38 and an amplifier 39. The output of the phototube 38 is amplified by amplifier 39 and fed to the vertical deflection plates of the cathode ray tube along line 41. It is possible by using a photomultiplier tube to eliminate the amplifier 39 and feed the signal through appropriate circuits directly from the photomultiplier tube to the verti-

cal deflection plates. The envelope of the pulses which are to be shaped are fed to the horizontal deflection plates of the cathode ray tube along line 42.

Operation of the wave shaper shown is as follows:
5 The amount of illumination from the cathode ray tube which falls on the phototube 38 determines the vertical position of the cathode ray tube spot. The input to the vertical deflection plates from the phototube is phased so that the spot moves in the direction of the mask 37 as the amount of illumination on the phototube increases.
10 When the spot intensity and the amplification are properly adjusted, the only stable position of the spot is at the edge of the mask. Above this position the spot is driven towards the mask, and below this position the spot is driven upwards towards the edge of the mask. Consequently, the spot as it travels horizontally across the cathode ray tube follows the edge of the mask. This will occur regardless of the shape of the mask 37. For example, the mask 37 may have a shape as is shown in
20 FIGURE 4. The output of the amplifier for such a mask would vary as a function of input as is shown in the curve of FIGURE 5. Although I have shown a mask having a complex waveshape, any shaped mask may be used and the output of the amplifier will vary accordingly. For example, a wave may be shaped to have sine wave characteristics. It is obvious that by mechanically shifting masks any desired selection of shapes may be imparted to the input signals.

The filter 16 can be a conventional low pass filter designed to pass the time average of its input pulses. The amplifier 17 can be a conventional audio amplifier designed to have a suitable response over the audio frequency range, and the speaker or speaker system 18 can be one of conventional type having the desired frequency characteristics.

Operation of the instrument shown in FIGURE 1 may be more clearly understood with reference to FIGURES 6A, 6B, 7A, 7B, 7C, 8, 9 and 10. Although the output of any number of the tone waveform generators 11 may be connected to the commutator 13, for simplicity the discussion will be with reference to two such tone waveform generators connected to the waveform sampling commutator. For example, the generators may be generating frequencies which are one octave apart, as shown in FIGURES 6A and 6B. With the pulse rate being substantially above audio frequencies, the pulse will recur a number of times during each period of the generated wave. This is more clearly shown in FIGURE 7A where the pulse has recurred eight times during one period of the generator frequency. As previously explained, the amplitude of the pulse transmitted to resistor 33 will have an amplitude which corresponds to the amplitude of the generated signal at that particular instant. As can be seen in FIGURE 7A, the envelope for the pulses has a shape which corresponds to the generator signal shown in FIGURE 6A. As the pulse moves along the delay line and encounters the successive generator taps, a signal will be transmitted to resistor 33 wherever switches 12 are operated. After a delay corresponding to the delay between the taps along the video delay line, the pulse for the next switched generator in our example will be transmitted as is shown in FIGURE 7B. Again, the series of pulses will have an amplitude which is included in an envelope having a shape corresponding to the generator waveform (in this case, the generator which generates the shape shown in FIGURE 6B). The pulses which appear across the resistor 33 are shown in FIGURE 7C. The pulse 43 is delayed with respect to pulse 44 an amount corresponding to the delay along the delay line. The pulse 43, depending on the position of its corresponding tap, may lie anywhere between the recurring pulses 44 and 44A.

Assuming for purposes of simplicity, that the mask employed in the waveshaper is selected to shape all inputs into sine wave outputs, the various pulses shown in FIG-

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URE 7C will be shaped to have amplitudes corresponding to those shown in FIGURE 8. When these pulses pass through the filter 16, the audio time average of the pulses will be passed. The curve 45 corresponds to the wave generator output shown in FIGURE 6B and curve 46 corresponds to the wave generator output shown in FIGURE 6A. These are shown as separate waves merely for purposes of illustration. Actually, the two waves are combined and appear as the wave shown in FIGURE 10.

It is seen that the waves transmitted to the speaker will have characteristics which have the combination of the pitches connected to the commutator and which will have a wave shape (timbre) corresponding to the shape of the wave shaper.

When the switches 12 are employed to turn on and off the various frequencies, abrupt changes result which are displeasing to the ear. It is desirable to have the tones "come on" or "turn off" gradually for a more pleasing effect. In other words, controllable attack and decay characteristics are desirable. Since the amplitude of the output signal from the filter 16 is a time average of the amplitude of the input pulses, it can be seen that the amplitude of the output signal may be controlled by varying the length of the output pulses. This fact is useful in developing means for controlling the attack and decay of any particular tone as it is turned on and off.

In the description of the operation of the apparatus of FIGURES 1 and 2, a rectangular pulse 28 was assumed to be delivered by the pulse generator 27. If a particular waveform generator and its associated clamping circuit is chosen for consideration, FIGURE 11 shows a typical output pulse 42 in bold outline. The sawtooth wave shape 21 with its base 51 is shown. The amplitude of the pulse 28 which travels along the delay line is shown extending above the output pulse 44 which is clamped by the sawtooth wave 21.

Referring now to the commutator circuit shown in FIGURE 12, a reverse voltage clamping diode 53, or its equivalent, is placed across the output circuit of the commutator so that a signal of less than zero voltage will not appear across the output terminals. The capacitors 54 and 55 allow application of a bias voltage to the clamping circuit without any detrimental effects upon the transmission of pulses. Switching and bias means 57 is connected to the common junction of the resistor 23 and capacitor 55 through a resistor 58. The switching means, for example, may comprise a switch together with suitable bias means. Thus, when the switch is closed, a bias is applied to the clamping circuit. The pulse generator 27 delivers a pulse of a triangular shape such as shown at 59.

In FIGURES 13 through 15, I have shown one sawtooth output wave shape from a particular waveform generator associated with the commutator, together with the pulse 59 travelling along the delay line. If the bias voltage supplied by the switching and bias means 57 is greater than the peak amplitude of the pulses 59 and of reverse polarity, no signal will appear at the output of the commutator since the net voltage at any time is of reverse polarity. By closing or opening the switch, as the case may be, a portion of the bias voltage may be removed, part of the pulses will then appear in the output circuit (clamped if the value becomes large enough) as shown in bold outline in FIGURE 14. By decreasing the bias still further, the pulses appearing at the output of the commutator may be as shown in FIGURE 15, which is of the same amplitude for the given waveform voltage generator but of longer duration. Obviously, the time average of the pulses of FIGURE 15 is larger in amplitude than that for those of FIGURE 14. Thus it is seen that I have provided means for varying the length of the output pulses.

If now time constants of appropriate type are introduced in the switching circuits, the bias voltage can be made to vary slowly, rather than abruptly, on opening and closing of the switch. For instance, the bias voltage

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value may vary as shown in FIGURE 16 for operation of the switch. The output pulses delivered while the bias voltage is changing will have constantly changing width, and the resulting time average of that amplitude will vary in accordance with the bias voltage. I have provided means for having the tones "come on" and "turn off" gradually rather than abruptly, which is more pleasing to the ear than the abrupt on-off tones of the circuit of FIGURE 2. Thus, it is seen that I have provided means for controllable attack and decay characteristics of the instrument. Although I have described a particular circuit for obtaining desired attack and decay characteristics it is to be understood that other circuits may be employed to achieve these results. Use of such other circuits are encompassed within the scope of this invention.

As previously indicated, the masks 37 may be adapted to be mechanically interchanged to change the tonal qualities as the instrument is being played. It is also possible to duplicate the system and have rows of switches 12 corresponding to two or more keyboards. The two or more waveshapers would impart different tonal qualities to the output of the two or more sets of generators simultaneously. There are many other possible variations of the system and any such variation will not depart from the spirit of this invention.

I claim:

1. An electronic musical instrument for producing a plurality of musical tones comprising at least one tone waveform generator, a waveform sampling commutator operatively connected to said generator, a waveform shaper operatively connected to said commutator, and an electro-acoustical transducer operatively connected to said shaper to convert the shaped waveform into sound.

2. An electronic musical instrument as in claim 1 in which said wave shaping means comprises a cathode ray tube having vertical and horizontal deflection plates, a phototube positioned to receive the illumination from the cathode ray tube screen, and amplifying means having input and output terminals, said input terminals connected to the phototube and said output terminals connected to the vertical deflection plates of the cathode ray tube, and said horizontal deflection plates connected to receive the sampled signal.

3. An electronic musical instrument as in claim 1 wherein the electro-acoustical transducer serving to receive the shaped sampled signal and to translate the same into sound comprises a filter together with an audio amplifier and speaker.

4. An electronic musical instrument as in claim 1 in which said waveform sampling commutator comprises a pulse generator, a delay line connected to receive pulses from said pulse generator and having at least one tap, said tap being operatively connected to the tone waveform generator to derive pulses whose waveform is a function of the tone waveform.

5. An electronic musical instrument as in claim 1 in which means are operatively connected in circuit with said waveform sampling commutator for controlling the attack and decay characteristics of the signal samples.

6. An electronic musical instrument for producing a plurality of musical tones comprising at least one tone waveform generator serving to generate a tone having a characteristic frequency, a waveform sampling commutator operatively connected to said generator and including a pulse generator serving to generate pulses at a predetermined frequency which is high in comparison to the characteristic frequency of the highest generated tone, a delay line having at least one tap operatively connected to receive the pulses from said pulse generator, gating means operatively connected to said tap and to the tone waveform generator, said gating means being controlled by the pulse travelling along the delay line to form output pulses having an envelope corresponding to the tone waveform, a waveform shaper operatively connected to said commutator, and an electro-acoustical transducer

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operatively connected to said shaper to convert the shaped waveform into sound.

7. An electronic musical instrument as in claim 6 in which said wave shaping means comprises a cathode ray tube having vertical and horizontal deflection plates, a phototube positioned to receive the illumination from the cathode ray tube screen, and amplifying means having input and output terminals, said input terminals connected to the phototube and said output terminals connected to the vertical deflection plates of the cathode ray tube, and said horizontal deflection plates connected to receive the samples of the tone waveform.

8. An electronic musical instrument for producing a plurality of musical tones comprising a plurality of waveform tone generators, selective connecting means operatively connected to each of said tone waveform generators, a waveform sampling commutator operatively connected to said selective connecting means whereby selected ones of said tone waveform generators can be connected to said waveform sampling commutator, a waveform shaper operatively connected to said commutator, and an electro-acoustical transducer operatively connected to said shaper to convert the shaped waveform into sound.

9. An electronic musical instrument as in claim 8 in which said wave shaping means comprises a cathode ray tube having vertical and horizontal deflection plates, a phototube positioned to receive the illumination from the cathode ray tube screen, and amplifying means having input and output terminals, said input terminals connected to the phototube and said output terminals connected to the vertical deflection plates of the cathode ray tube, and said horizontal deflection plates connected to receive the samples of the tone waveform.

10. An electronic musical instrument as in claim 8 wherein the electro-acoustical transducer serving to receive the shaped sampled signal and to translate the same into sound comprises a filter together with an audio amplifier and speaker.

11. An electronic musical instrument as in claim 8 in which said waveform sampling commutator comprises a pulse generator, a delay line connected to receive pulses from said pulse generator and having a plurality of taps, said taps being operatively connected to the tone waveform generator serving to derive an output pulse whose amplitude is a function of the waveform generator connected to said tap.

12. An electronic musical instrument as in claim 8 in which means are operatively connected in circuit with said waveform sampling commutator for controlling the attack and decay characteristics of the signal samples.

13. An electronic musical instrument for producing a plurality of musical tones comprising a plurality of tone waveform generators, individual switching means opera-

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tively associated with each of said tone waveform generators, a waveform sampling commutator operatively connected to said individual switching means to receive signals from selectively switched tone generators to form pulses having an envelope which corresponds to the tone waveform of the selected tone waveform generators, a waveform shaper operatively connected to said commutator, and an electro-acoustical transducer operatively connected to said shaper to convert the shaped waveform into sound.

14. An electronic musical instrument as in claim 13 in which said waveform sampling commutator means includes a pulse generator serving to generate pulses at a predetermined frequency, a delay line having a plurality of taps connected to receive the pulses from said generator, clamping means connected between each of said taps and said individual switching means, said clamping means serving to form a pulse which corresponds in amplitude to the amplitude of the selected tone waveform at the instant the pulse travelling along the delay line reaches the associated tap, and bias means associated with said clamping means for controlling the pulse to thereby control the attack and decay characteristics.

15. An electronic musical instrument as in claim 14 in which said electro-acoustical transducer comprises a filter which serves to form a time average at the pulses, an audio amplifier, and an output speaker.

16. An electronic musical instrument as in claim 15 in which said wave shaping means comprises a cathode ray tube having vertical and horizontal deflection plates, a phototube positioned to receive the illumination from the cathode ray tube screen, and amplifying means having input and output terminals, said input terminals connected to the phototube and said output terminals connected to the vertical deflection plates of the cathode ray tube, and said horizontal deflection plates connected to receive the samples of the tone waveform.

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