# United States Patent

**Evans**

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## [54] TONE GENERATOR EMPLOYING ASYMMETRICAL WAVE GENERATOR RECTANGULAR


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[73] Assignee: **Columbia Broadcasting System, Inc.,** New York, N.Y.



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[21] Appl. No.: **58,239**

[52] **U.S. Cl.** .....**84/1.01,** 84/1.13, 84/1.24, 84/1.26

[51] **Int. Cl.** .....**G10h 1/00**

[58] **Field of Search** .....84/1.01, 104, 1.23, 1.26; 328/181; 332/9, 14; 331/107–108



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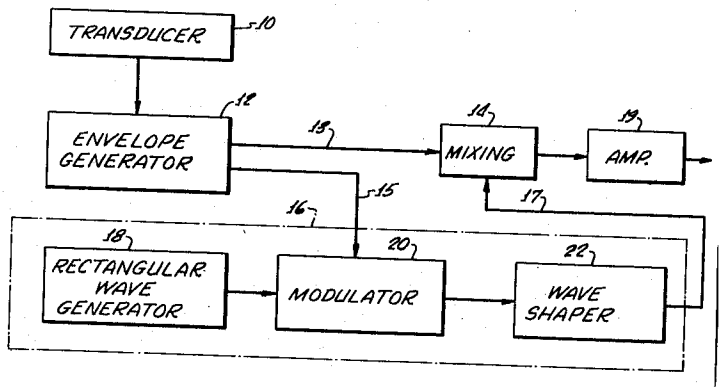


[57] **ABSTRACT**

A tone generator for an individual note of an electronic piano comprises an oscillator that provides an asymmetrical rectangular wave having a duty cycle of at least four to one. The rectangular wave is fed to a clipping diode gate where it is amplitude modulated in accordance with a signal envelope generated by the player of the piano. A capacitor is connected across the modulator output or, alternatively, connected within the modulator, to provide a modulated rectangular wave with a substantially sawtooth wave form.

Other instrument sounds may be provided and a tone control is achieved by duty cycle variation. Performance of a power amplifier is enhanced by driving it with a rectangular wave.


**24 Claims, 7 Drawing Figures**



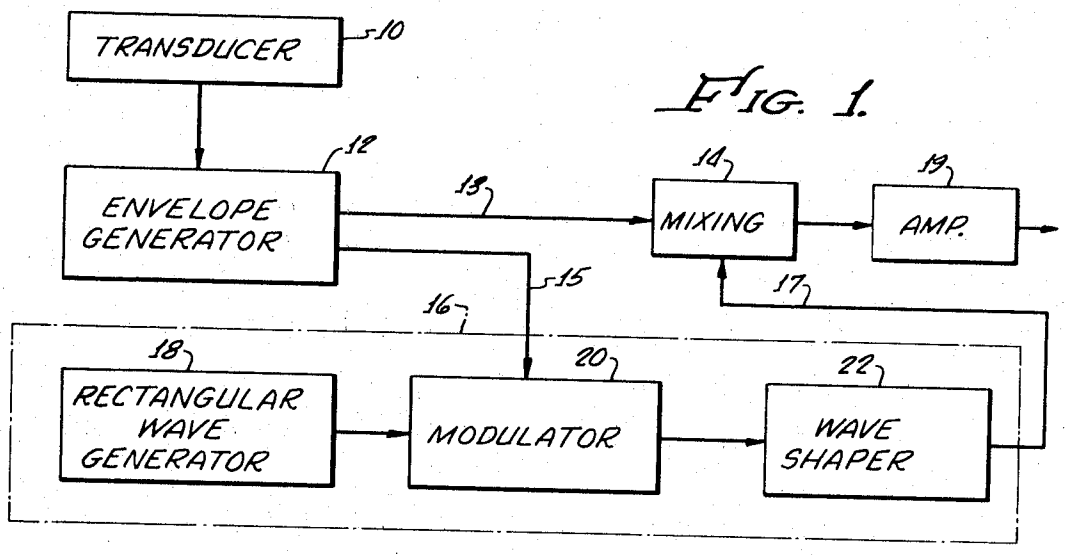



FIG. 1.

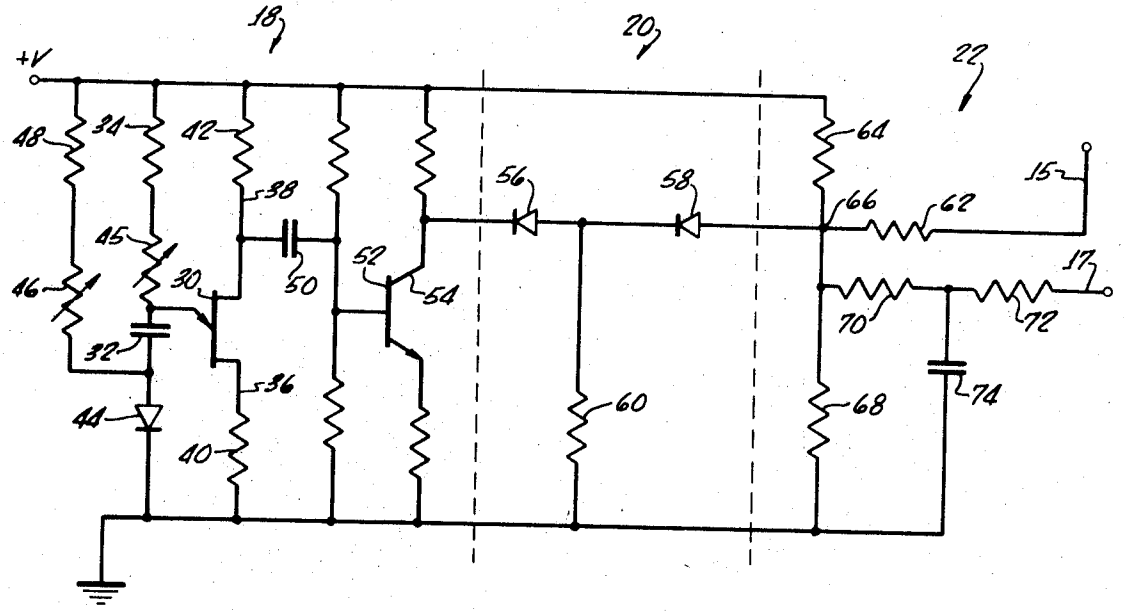



FIG. 3.

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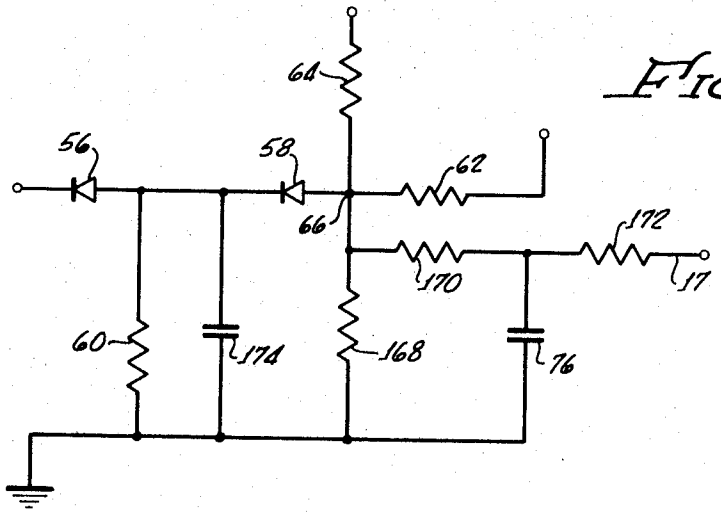



FIG. 5.

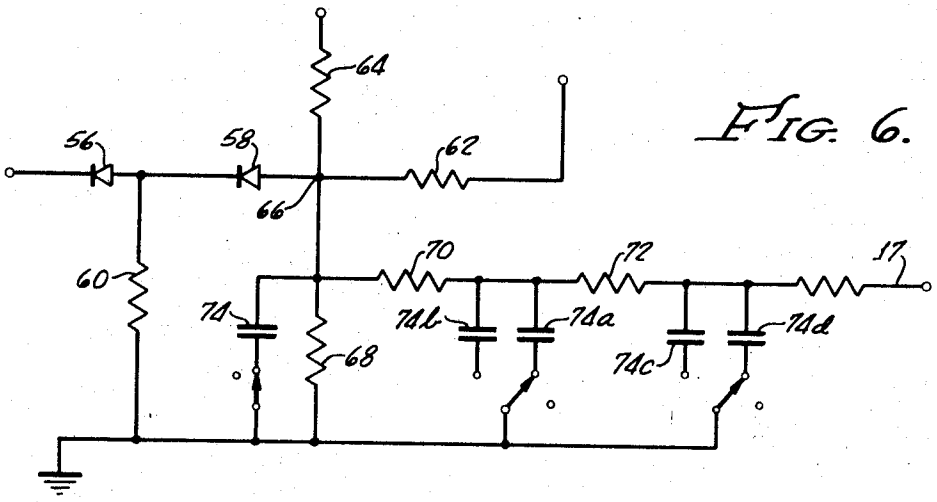



FIG. 6.

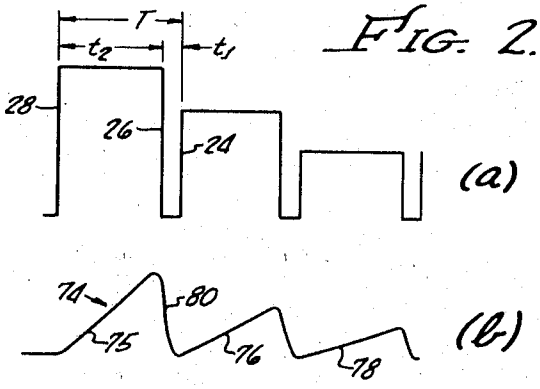



FIG. 2.

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FIG. 7.

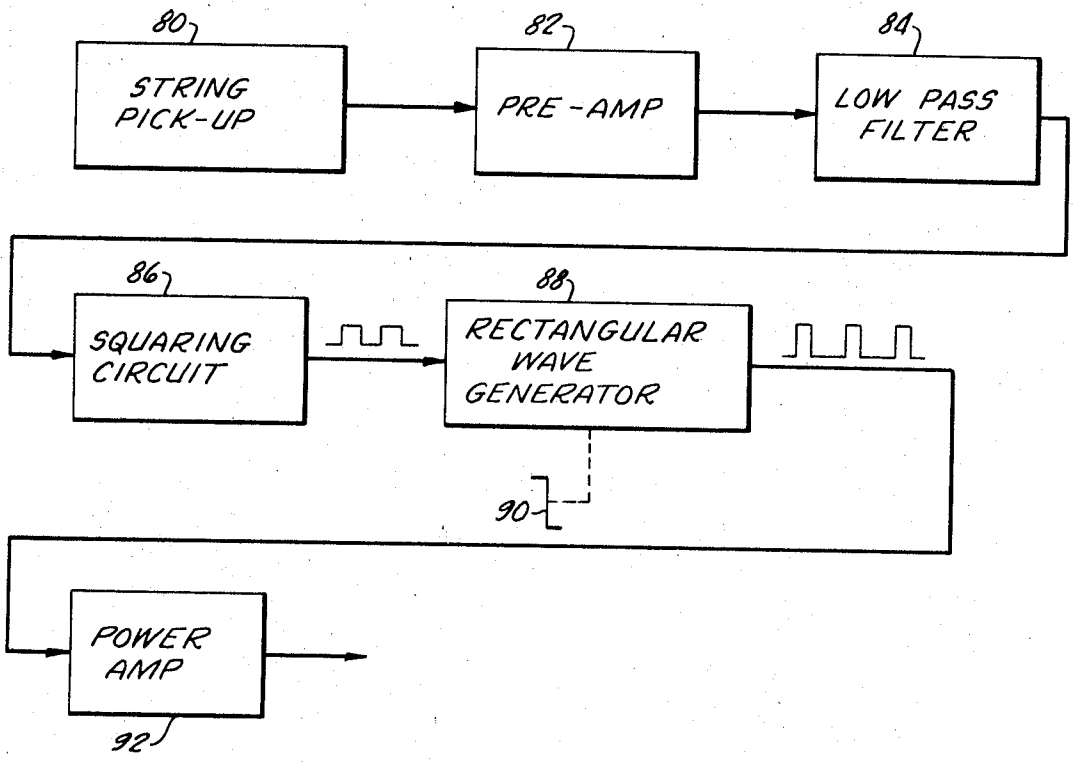
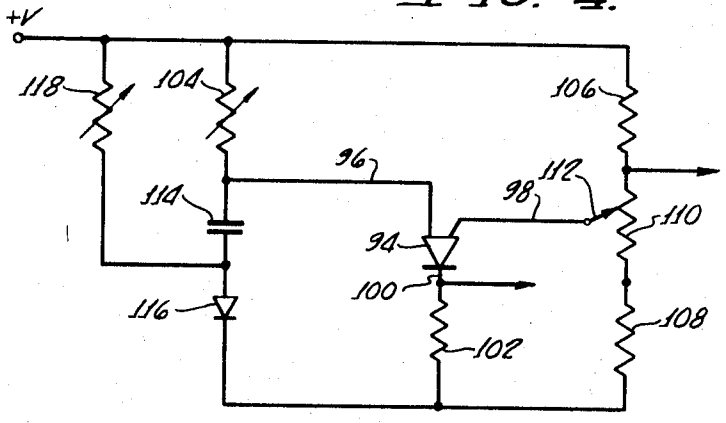



FIG. 4.




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# TONE GENERATOR EMPLOYING ASYMMETRICAL WAVE GENERATOR RECTANGULAR

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to tone generators for electronic musical instruments and more particularly concerns an improved and simplified arrangement for generating a tone of selected harmonic content and of controlled amplitude envelope.

2. Description of Prior Art

Electronic instruments such as the piano, organ and the like, generally comprise a group of master oscillators producing desired fundamental tones, one or more wave shaping circuits that provide a selected and desired voicing or harmonic content of the particular signal, and a player actuated control that selects one or more notes and which may also provide each of the notes with an amplitude envelope of a unique form. In such instruments, it is common to provide 12 highly stable LC tuned master oscillators and, using binary techniques or conventional flip-flops, divide the output of each oscillator a number of times equal to the number of octaves embodied in the particular instrument.

Binary dividing circuits provide a square wave output. A square wave is a symmetrical rectangular waveform, a waveform having a 1 to 1 duty cycle. As well known, such a square wave includes only odd harmonics of the fundamental and accordingly must be shaped to provide desired tone or harmonic content. Commonly, such shaping is provided by an amplifier that drives a sawtooth generator. Sawtooth generators previously employed in musical instrument circuitry are relatively involved, generally including at least one transistor.

If a modulation envelope is to be provided as for example the "thump" and decaying amplitude of a struck piano string, the sawtooth waveform is then submitted to a modulating circuit. Such modulating circuit must provide linear control and modulation over a broad range of frequencies so as to properly handle the full harmonic content of the tone signal. To meet such stringent requirements the modulator becomes elaborate and costly.

The above-described conventional arrangements are complex and expensive, relatively difficult to tune and subject to distortion and frequency shifting due to aging of the many components involved. Even so, it is difficult to properly control harmonic content and envelope of the several tone signals.

In a common electronic piano or organ circuit for generating a sawtooth in response to a square wave, there is a relatively long duration "dead" time between the fall of one waveform and the beginning of the rise time of the next. This dead time is due to the fact that the sawtooth generator generally operates upon only one of the half cycles of its square wave input. Such a dead time is undesirable because of its effect on composition of the generated tone.

Accordingly, it is an object of the present invention to provide a simple and inexpensive tone generator having desired or readily controllable harmonic content. Another object of this invention is to provide an improved circuit for generation of a tone that closely simulates a piano sound.

## SUMMARY OF THE INVENTION

An asymmetrical rectangular wave generator drives a combined modulator and sawtooth generator to provide a sawtooth signal closely simulating a piano tone. In a specific embodiment of the invention, a rectangular wave signal drives a clipping diode modulator, an integrating capacitor is coupled with the modulator to provide a sawtooth waveform, and a modulating signal is caused to bias the diodes of the modulator to provide the output tone signal with the desired amplitude envelope. According to another feature of the invention, an improved tone control is provided by variation of the duty cycle of a rectangular wave. In still another aspect of the invention, operation of a power amplifier for a musical instrument is enhanced by driving it with a rectangular wave.



## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a piano tone generator constructed in accordance with principles of this invention,

FIG. 2 illustrates waveforms that depict operation of the tone generator of FIG. 1,

FIG. 3 is a detailed circuit diagram of a preferred embodiment of the tone generator of this invention,

FIG. 4 shows circuitry of another form of rectangular wave oscillator,

FIG. 5 shows a modification of a part of the circuit of FIG. 3,

FIG. 6 shows a second modification of a part of the circuit of FIG. 3, and

FIG. 7 shows a system employing principles of the invention for tone control and improved amplifier operation.

## GENERAL DESCRIPTION

Illustrated in FIG. 1 is the general arrangement of a tone generator for a single note or tone of an electronic piano. It will be readily appreciated from the ensuing description that principles of the present invention may be applied to many types of electronic musical instruments, such as those in the nature of a guitar or the like, having a plucked string, wind instruments employing a vibrating reed, and other instruments having an element that is set into motion by a player and of which the motion is transduced into an electrical signal. Principles of the invention are also applicable to those instruments such as an organ in which the tone including its amplitude envelope is wholly generated by the instrument, the operator simply selecting those notes that are to be played. Nevertheless, principles of the present invention have been mechanized in an electronic piano and it will be in such an application that the preferred embodiment is described.

An electronic piano for which the present invention is most particularly applicable is described and claimed in a copending application of Chauncey R. Evans for Electronic Piano With Piezoelectric Transducer, Ser. No. 65,619, filed on Aug. 20, 1970, assigned to the assignee of the present invention, and fully incorporated herein by reference. The piano described in my copending application does not employ the prior art arrangement of a master oscillator and frequency divider for providing a number of like tones of different octaves. Rather, a circuit such as that illustrated in FIG. 1 is provided for each note of the instrument. For example, in a piano having 88 notes, 88 circuits each identical to that illustrated in FIG. 1 (except for variations provided to accommodate different frequencies) are employed. Although a large number of oscillators is required, there is no requirement for complex and expensive dividing circuits. The oscillator, modulator and sawtooth generator as particularly described in the present application are of such a simple and inexpensive nature as to result in an overall savings in equipment and complexity, and a concomitant decrease in cost of manufacture.

Briefly, as described in the aforesaid copending patent application, player operated motion of a piano key energizes a piezoelectric transducer **10** and provides an electrical signal to an envelope generator **12**. Envelope generator **12** includes several stages of amplification and impedance matching circuitry arranged to simulate the amplitude envelope of a piano tone as is achieved by conventional piano damping or pedal operation. The envelope generator provides a first modulating signal that is fed directly to a mixing circuit **14** via a lead **13**. The signal on lead **13** is a "thump" signal that simulates a struck piano key as is more particularly described in the copending application. Via a lead **15**, the envelope generator provides a second envelope signal to a tone generator designated generally at **16**. The output of tone generator **16** on lead **17** comprises a second input to the mixing circuit **14**, and the resultant combined signal is thence fed to a conventional amplifier **19** and to suitable speakers (not shown).

It is to arrangement and details of tone generator **16** that the present invention, as applied to a piano, is directed.

Basically, tone generator **16** comprises a rectangular wave generator **18** that feeds a modulator **20** to which is applied the amplitude modulating envelope signal on line **15**. The modulated rectangular wave is provided with suitable sawtooth wave shape by a wave shaper **22**. Harmonic content and "rolloff" of the modulated signal are also controlled by wave shaper **22**. As will be more particularly described below, the function of wave shaper **22** may be provided by circuitry following the modulator or it may be combined with the modulator itself.

A rectangular wave such as illustrated in FIG. **2***a*, for example, has a sharply falling or early vertical leading edge **24** followed by a relatively low amplitude that continues for a portion of the cycle during a time $t_1$, thence a sharply rising nearly vertical portion **26**, a relatively high constant amplitude cycle portion having a duration $t_2$, and terminates in a sharply falling nearly vertical edge **28**. A most common species of rectangular waveform is the square wave wherein each cycle portion such as $t_1$ and $t_2$ is equal to each other cycle portion and each is equal to one-half of the full period T of the waveform. Such a square wave may be considered to have a 1 to 1 duty cycle whereas an asymmetrical rectangular wave such as that illustrated in FIG. **2***a* is designated as having a duty cycle of $t_2$ to $t_1$. For example, if in the rectangular waveform illustrated, $t_2$ is six times as great as $t_1$, the rectangular waveform is said to have a duty cycle of 6 to 1. The symmetrical rectangular waveform is lacking in even harmonics of its fundamental frequency. Such characteristics of a square wave are described for example in my copending application for Octave Jumper for Musical Instruments, Ser. No. 46,249, filed on June 15, 1970, assigned to the assignee of the present application, and fully incorporated herein by reference.

A significant feature of the present invention is generation of a piano tone by the use of an asymmetrical rectangular wave, preferably one having a duty cycle of 4 or more to 1 and driving a sawtooth wave form generator.

## DETAILED DESCRIPTION

As illustrated in FIG. **3**, rectangular wave generator **18** is comprised of a free-running oscillator and amplifier. The oscillator includes a unijunction transistor **30** that has its emitter connected to a capacitor **32** and fixed and variable resistors **34**, **45**. The base one and base two electrodes **36** and **38** are connected to a common line or ground and a source of positive voltage, +V, via resistors **40** and **42** respectively. Capacitor **32** has one side thereof connected to the common line through a diode **44** and also returned to +V through a variable resistor **46** and a fixed resistor **48**.

The emitter of unijunction transistor **30** is normally reversed biased whereby the transistor is cut off. Capacitor **32** begins to charge from the positive voltage source through resistors **34** and **45** and diode **44**. When the charge on capacitor **32** reaches a value sufficient to trigger the unijunction transistor, the latter conducts and its base one, base two resistance drops to thereby drop the potential at its base two electrode **38**. Capacitor **32** thereupon discharges through a path including resistors **48** and **46**, the emitter to base one electrodes of the unijunction transistor and the resistor **40**.

With the described arrangement, the capacitor charges through one path including resistors **34**, **45**, and discharges through a second path including resistors **46** and **48**. When the resistance **46**, **48** is made considerably larger than the resistance **34**, **45**, the charging time of the capacitor is considerably shorter than the discharging time. Thus, an asymmetrical wave is produced at the base two electrode of the unijunction transistor. For example, with a value of capacitor **32** of 0.008 microfarads, a value of resistance of **34**, **45** of about 22,000 ohms, and a value of resistance **46** and **48** of about 150,000 ohms, the waveform at the base two electrode of the unijunction transistor will be highly asymmetrical, having a duty cycle of substantially more than 4 to 1.

Resistors **46** and **45** may be varied to tune the oscillator. Increasing resistor **46** increases the discharge time of the oscillator and vice versa. Similarly, increase in resistor **45** will increase the charging time. A variation in either discharge time or charge time changes the total period to thereby change the oscillator frequency. The effect that a small variation of resistors **45** or **46** may have upon the duty cycle of the oscillator has a substantially negligible affect upon the harmonic content of the output signal, since the latter can tolerate relatively wide variations in duty cycle of the driving rectangular wave as long as the duty cycle is substantially greater than 4 to 1. Because resistance **46**, **48** is several times greater than resistance **34**, **45**, the former is varied to achieve tuning with minimum change of duty cycle. Additional aspects of frequency and duty cycle control are described below in connection with another embodiment.

In order to amplify and sharpen the waveform provided at the base two electrode **38** of unijunction transistor **30**, the signal is fed via a capacitor **50** to the base of a squaring amplifier transistor **52**. The latter is driven between full cutoff and full conduction to provide, at its collector **54**, the sharply rectangular waveform illustrated in FIG. **2***a*.

The collector of transistor **52** drives modulator **20**. The latter is a diode gate substantially similar to that shown and described in the above-identified copending application for Octave Jumper for Musical Instruments.

Modulator **20** comprises first and second similarly poled diodes **56**, **58** having the common junction therebetween connected to ground through a resistor **60**. The rectangular wave input to the modulator is coupled to the cathode of diode **56**. The modulating signal from envelope generator **12** of FIG. **1** is transmitted to the anode of diode **58** via a resistor **62**. To compensate for the forward voltage drop of diodes **56**, **58**, when conducting, a fixed increment of positive potential is established at the anode of diode **58** by means of a resistor **64** that is connected between the diode anode and the positive potential source.

Diode modulator **56**, **58**, operates upon the asymmetrical rectangular wave in a manner substantially similar to its operation upon a square wave. The amplitude of the input signal is attenuated in accordance with the modulating signal potential established at point **66**, the anode of diode **58**.

When the rectangular wave at the collector of transistor **52** is high, diode **56** is reversed biased and cut off. Since resistor **60** is relatively high, in the order of 100,000 ohms, and resistor **62** is relatively low, in the order of 33,000 ohms, point **66** will substantially follow the modulating signal provided on line **15** from the envelope generator **12**.

Transistor **52** conducts during the relatively short cycle portion of the rectangular wave, during time $t_1$. Its collector drops to a relatively low value, since its emitter resistor is small. Point **66** now follows the collector voltage, differing therefrom only by the forward voltage drops across the two diodes. Thus, it will be seen that the positive-going, long duration cycle portion of the input rectangular wave is clipped or modulated to provide it with an amplitude envelope that follows the signal developed on line **15** by the envelope generator. For purposes of exposition, FIG. **2***a* shows several cycles of the rectangular wave at different clipping levels.

The modulated rectangular signal at point **66** is fed to the wave shaper **22**, which in this embodiment comprises resistors **68**, **70**, and **72** and a capacitor **74** connected as illustrated in FIG. **3**. The modulated rectangular wave signal is fed across resistor **68** through resistor **70** and across the capacitor **74** to integrate the signal and provide the desired wave shaping thereof. The output of the described tone generator circuit is provided on line **17** and fed as previously described to the mixing circuit **14** employed in the exemplary electronic piano of the above-identified copending application for Electronic Piano with Piezoelectric Transducer.

The output waveform on line **17** has the sawtooth shape as illustrated by waveform **73** in FIG. **2***b*. Cycle portion **75** of waveform **74** illustrates the amplitude of the sawtooth when a

relatively large value of envelope modulating signal is provided via line **15**. With a lesser value of modulating signal, this sawtooth has a decreased slope, but a substantially equal period as indicated by curve **76** of FIG. **2***b*. With a still lesser value of modulating signal, the sawtooth slope is still less but the period remains unchanged as indicated at **78** in FIG. **2***b*.

By driving the sawtooth generator **22** with a modulated rectangular waveform, the integrating capacitor **74** charges to a value determined by the amplitude of the rectangular wave at any given time. Thus, the slope of the sawtooth depends upon the amplitude envelope of the rectangular wave. Nevertheless, since the charging and discharging circuits remain the same and the RC time constants are unchanged, the duration of the rising and falling portions of the sawtooth remain substantially unchanged. Further, the rising leading edge of the sawtooth as indicated at **80** in FIG. **2***b* is controlled to have a duration substantially equal to $t_1$ which is the time during which modulated diode **56** and transistor **52** conduct. Therefore, this rise time will be relatively short as compared to the lower slope and longer duration trailing edge of the sawtooth. Not only is the sharply rising leading edge **80** of the sawtooth relatively short, but as indicated in FIG. **2***b*, it follows the fall of the trailing edge of the immediately preceding sawtooth waveform with no significant delay. Thus, the dead time that is common with a sawtooth generator driven by a square wave is almost entirely eliminated.

## MODIFIED OSCILLATOR

An alternate asymmetrical rectangular wave generator is shown in FIG. **4**. This circuit has many advantages including convenience of tuning, low cost and good frequency stability over a wide range of ambient conditions. This oscillator is analogous to oscillator **18** of FIG. **3**, but instead of employing the conventional unijunction transistor **30**, a programmable unijunction transistor **94** is employed. Such a transistor may be of the type identified as D13T1 or D13T2 and described in Bulletin No. 60.20 Nov., 1967, and Bulletin No. 60.01 June, 1968, of the General Electric Corp., Semiconductor Products Dept.

The programmable unijunction transistor has an anode electrode **96**, a gate electrode **98** and a cathode electrode **100**. The latter is connected to ground through a resistor **102**, the anode is connected to a source of positive voltage through a first timing resistor **104**, and the gate electrode is connected to a voltage divider. The voltage divider is comprised of first and second resistors **106**, **108**, connected between the positive voltage supply and ground. For the purpose of tuning this oscillator and adjusting the divider there is series connected between resistors **106**, **108**, a potentiometer **110** having a wiper arm **112** connected to the transistor gate electrode. As in the oscillator **18** of FIG. **3**, a charging capacitor **114** has one side connected to the anode **96** and the other side connected to one side of a diode **116** of which the other side is connected to ground. A second timing resistor **118** is connected between the positive voltage supply and the junction of the capacitor and diode. The output of this oscillator, a relatively sharp rectangular wave, is taken from the junction of the potentiometer and resistor **108** in a manner analogous to the output derived from the base two electrode of oscillator **18**. Alternatively, an output signal may be derived from the cathode **100** of the programmable unijunction transistor.

Operation of the oscillator illustrated in FIG. **4** is substantially similar to operation of oscillator **18** of FIG. **3**. Capacitor **114** charges through the first timing resistor **104**. Resistors **106**, **108**, and **110** control the voltage at which the anode to gate electrodes of the transistor become forward biased. When the charge on capacitor **114** rises to a value sufficient to forward bias the anode to gate electrodes, the transistor switches on, generating a negative resistance characteristic from anode to cathode. Capacitor **114** accordingly discharges through the transistor and through the second timing resistor **118**.

Just as in oscillator **18** of FIG. **3**, one of the timing resistors, resistor **104**, is in the capacitor charge path and the other timing resistor, resistor **118**, is in the capacitor discharge path. Accordingly, the relative values of these two timing resistors control and determine the relative durations of the charge and discharge cycle portions of the oscillator. Either resistor **118** or **104** may be the larger of these two resistors. For example, with capacitor **114** of 0.015 microfarads, resistor **118** may be in the order of 68,000 ohms and resistor **104** in the order of 470,000 ohms to thereby provide a 10 to 1 duty cycle.

It has been found that the desired duty cycle is more readily established and controlled with the oscillator arrangement illustrated in FIG. **4**. Further, fine tuning is also facilitated. Potentiometer may have a total resistance on the order of 5–10 percent of the total resistance of the voltage divider resistors **106**, **108**, and is readily adjusted to change the oscillator frequency. In effect, the position of the arm of potentiometer **110** controls the bias on the gate electrode and the potential on capacitor **114** controls the bias on the anode electrode, where the anode and gate electrodes of this programmable unijunction transistor form, in effect, a diode.

Instead of using potentiometer **110** for frequency control, this potentiometer may be omitted and one or both of resistor **106** and **108** may be made variable to provide the desired fine tuning. Again, as described in connection with the oscillator **18**, either or both of the timing resistors **104** and **118** may be varied individually or together, in opposite sense, so as to selectively control the duty cycle or asymmetry of the resultant output waveform.

## MODIFICATIONS

Employing the clipping diode modulator as described above, several arrangements and locations of the wave shaper **20** are readily available. Thus, as illustrated in FIG. **5**, the wave shaper may be modified to provide all or a major portion of the capacitor integrating operation within the modulator itself instead of following the modulator as in the arrangement of FIG. **3**. In FIG. **5**, the diode modulator employs the same diodes **56**, **58**, resistor **60**, and biasing and input resistors **64**, **62**, all connected and arranged just as described in relation to the embodiment of FIG. **3**. In the arrangement of FIG. **5**, however, an integrating capacitor **174** is connected between the common junction of the diodes and the common line or ground.

When the asymmetrical rectangular wave input is low, diode **56** conducts, the junction between diodes **56** and **58** is relatively low and the modulator output at point **66** is low. Capacitor **174** is rapidly discharged. When the input in high, diode **56** is cut off, and integrating capacitor **174** now charges to the value of the modulating signal provided via resistor **62**. Neglecting the forward voltage drop across diode **58**, point **66** follows the charge on capacitor **174**, which discharges relatively slowly through resistor **60**. The signal at point **66** is the desired sawtooth (the varying charge of capacitor **174**) having a slope and a maximum value determined by the particular value of the modulating envelope at a given instant. The modulated sawtooth is developed across resistor **168** and fed through resistors **170** and **172** to the output lead **17**.

For many purposes, the circuit described so far in connection with FIG. **5** may be employed without any additional circuit components. However, for various reasons such as those now to be described, additional wave shaping may be desired.

The harmonic content and, in particular, the number of higher order harmonics of the rectangular waveform, is related to its asymmetry. The greater the asymmetry, the greater the number of higher order harmonics contained therein. Nevertheless, even though these additional desirable harmonics are included in the asymmetrical waveform, their relative amplitudes are not properly proportioned for certain desired tone characteristics. It is found that for certain frequency ranges, and in particular for a group of piano notes in middle frequency ranges, the tone provided does not have

adequate "rolloff." This means that relative amplitudes of higher harmonics of the fundamental are too great. In order to provide additional rolloff or, stated otherwise, in order to attenuate high frequency content of the generated tone, additional high frequency shunting of the output signal is achieved, as by a capacitor **76** that is connected between the junction of resistors **170** and **172** and ground. From the standpoint of wave shaping, capacitor **76** keeps the output sawtooth waveform from rising too steeply.

Although the described oscillators are astable and need no external trigger, it will be readily appreciated that they may be externally triggered as by application of a suitable triggering signal to either of the base electrodes of the unijunction transistor **30** or to the gate or anode electrodes of the oscillator of FIG. **4**. Thus, the illustrated tone generator may also be employed in an instrument that uses a number of master oscillators and a frequency divider to provide the fundamental tone for each like note of a different octave. In such a situation, the output of the frequency divider may be employed via a suitable peaking or differentiating circuit to provide an external trigger that controls the frequency of the illustrated tone generator.

The system employing master oscillators and frequency division loses its capability of tuning individual notes since variable resistors such as **46** and **45** will not change the frequency where the oscillator is externally triggered. Accordingly, it will be seen that an arrangement wherein the rectangular wave generator is astable and needs no external trigger, is to be preferred from the standpoint of convenience of individual tuning of each and every note provided by the instrument. Such individual tuning is closely analogous to the tuning of the conventional entirely mechanical piano. It may be noted that conventional piano tuning is commonly nonlinear in that the precise mathematical relation of frequencies is not retained but is subjectively modified by the tuner in a commonly employed pattern. For this reason, an electronic piano provides for separate tuning of individual notes is preferred.

The illustrated unijunction rectangular wave oscillators are advantageous from the standpoint of stability, tunability, and economy. Nevertheless, it will be readily appreciated that many other asymmetrical waveform generators may be employed. For example, the common free running multivibrator may be provided to produce an asymmetrical rectangular wave output. Similarly, the conventional one-shot or monostable multivibrator may be externally triggered to produce a rectangular wave of internally determined asymmetry and externally determined frequency. Many digital techniques, such as those including suitably gated flip-flops, are well-known rectangular waveform producers.

It is common in an electronic instrument to provide a number of different types of voices or instrument tones. For example, there may be provided among others, the sound of a piano, the sound of an organ, the sound of a harpsichord, clavichord, or like instrument. These different voices are often achieved by selective switching of different ones or groups of circuits components. It will be understood that where other tonal characteristics are deemed necessary or desired, either or both of capacitors **76** and **174** of FIG. **5** may be dispensed with. In such a situation, the tone characteristics of the output signal depend only upon the period or frequency of the asymmetrical wave and the degree of its asymmetry.

Thus, the circuit of FIG. **3** may have the wave shaper thereof modified as illustrated in FIG. **6**. In the arrangement of FIG. **6**, diodes **56** and **58** and resistors **60**, **62**, **64**, **68**, **70** and **72** may be constructed and arranged just as the like components of FIG. **3**. Further, integrating capacitor **74** is similarly connected to provide the desired sawtooth waveform on output lead **17**. In this modification, selectively operable tone and voice variations are provided by additional capacitors **74***a*, **74***b*, **74***c*, and **74***d*. All of the capacitors are individually or collectively switched so as to be operative in any group or combination or individually.

When all of capacitors **74**, **74***a*, **74***b*, **74***c* and **74***d* are disconnected, there is provided at output lead **17**, an amplitude modulated asymmetrical rectangular wave. Such a waveform is exceedingly rich in tonal quality. That is, the amplitudes of the higher frequency harmonics are relatively high. To attenuate such higher frequency harmonics and provide different voices, one or more of the illustrated capacitors may be connected via the illustrated switches.

## TONE CONTROL

As previously indicated, the asymmetrical rectangular wave includes high harmonics of relatively large amplitude to thereby provide rich tonal quality. The symmetrical rectangular wave, the square wave, on the other hand, contains no even harmonics and gives a flat tone that closely simulates that of a closed organ pipe. Accordingly, it will be observed that by varying the duty cycle of the rectangular wave, the tonal quality of the resulting sound may be varied. Thus, a unique and improved tone control may be achieved simply by providing a means to effect a step by step or continuous variation of the asymmetry of the rectangular wave. As the waveform changes from the square wave of full symmetry to a rectangular wave of increasing asymmetry, the number and magnitude of even harmonics increases. With an asymmetrical wave having a duty cycle of 7, 10 or more to 1, many harmonics, both odd and even, including the seventh or tenth or higher are present. Further, these harmonics are present with amplitudes greater than the amplitudes of the comparable harmonics of the sawtooth waveform. As the asymmetry is decreased and the duty cycle is changed to bring the waveform more nearly toward the square waveform, the even harmonic content is decreased and, relatively, the magnitude of the odd harmonics is increased.

Various circuits well known to those skilled in the art are available for selectively changing the duty cycle of a rectangular wave generator. For example, in the rectangular wave oscillator **18** illustrated in FIG. **3**, it has been previously stated that variable resistor **46** is provided for tuning. The relatively slight amount of variation required of resistor **46** to achieve the desired tuning in such as to provide no significant change in duty cycle. For those situations in which duty cycle of oscillator **18** is to be changed with little or no change in frequency, there may be employed the second variable resistor **45**, series connected between resistor **34** and capacitor **32**. Resistor **45** is in the capacitor charging path and resistor **46** is in the capacitor discharging path. For duty cycle control the variable resistors **45** and **46** are ganged to be simultaneously changed in opposite sense; that is, whenever the value of resistor **46** is increased, the value of resistor **45** is decreased. In this situation, the opposite sense variation of the two resistors operates to increase one portion of the oscillator cycle and concomitantly decrease the other portion of its cycle. Accordingly, the total period is substantially unchanged, at least to the extent that the increase in one cycle portion is equal to the decrease in the other cycle portion. Obviously, the rate of change of resistance of the two variable resistors **45** and **46** may be modified so as to ensure equal magnitude change or any desired relation of change of the two portions of the asymmetrical wave produced by oscillator **18**.

Thus, it will be seen that with the circuit illustrated in FIG. **3**, fine frequency tuning may be achieved by relatively small variations of one or the other of resistors **45** and **46**. Tone control is achieved by simultaneous opposite sense variation of both variable resistors. Thus, still further control of the tone of the sawtooth provided on output lead **17** may be achieved. Equivalent tuning and duty cycle control is available in the oscillator of FIG. **4** as previously described.

Where the rectangular wave oscillator duty cycle control is employed in a tone generator having the selectively switchable capacitors shown in FIG. **5**, even greater variations of tone control are available. Thus, tone control in such an arrangement can be achieved either by variation of the oscillator duty

cycle, by selectively switching one or more of the capacitors 74–74*d*, or by some combination thereof.

The control that is achieved by variation of the duty cycle of an essentially asymmetrical rectangular wave has wide application to a broad variety of electronic musical instruments. An exemplary application of such tone control to a stringed instrument such as an electronic bass guitar is illustrated in FIG. 7. A bass guitar, as for example, the guitar described in my copending application for Octave Jumper for Musical Instruments, includes a number of strings and a circuit for each of such strings substantially identical to that illustrated in FIG. 7. Such circuit includes a conventional string pickup 80 which transduces sensed motion of the string into an electronic signal. This signal is fed to an amplifier 82, thence to a low-pass filter 84 and is squared in a squaring circuit 86, all substantially described in the copending application.

The square wave signal from circuit 86, which is a symmetrical rectangular wave having a 50/50 duty cycle, is caused to trigger or synchronize a rectangular wave generator 88 which may be a monostable multivibrator or a rectangular wave oscillator of the type illustrated in FIGS. 3 or 4.

External triggering of the unijunction relaxation oscillator may be achieved in a variety of ways that are well known to those skilled in the art. For example, a negative-going signal provided at the base two electrode can be employed to trigger the change between nonconduction and conduction of the unijunction transistor 30 of FIG. 3.

The rectangular wave generator 88 is provided with a manual control knob 90 that enables adjustment of its duty cycle to provide a variation from full symmetry to an asymmetry of as much as 7 or more to 1. In the arrangement of FIG. 7, the asymmetrical rectangular wave is fed, without further modulation or shaping, directly to a power amplifier 92 which may include a preamplifier. The output of power amplifier 92 is fed to a loud speaker (not shown).

The system illustrated in FIG. 7, will provide a unique and improved tone variation that is controlled by the operator upon manipulation of control knob 90 to change the duty cycle of the waveform fed to the amplifier. If deemed necessary or desirable, the rectangular wave output of generator 88 may be modulated by a diode modulator to provide the resulting output signal with an amplitude envelope that follows the envelope of the signal generated by pickup 80. Such arrangements are shown in my copending application for Octave Jumper for Musical Instruments and in FIG. 1 of the present application.

Tone variation in the arrangement of FIG. 7 is achieved by two different characteristics of the system. First, as previously described, operator control and movement of knob 90 will selectively and independently change the asymmetry of the rectangular wave provided from generator 88. However, a second tone variation is inherent in the system because the rectangular wave generator, whether the oscillator 18 of FIG. 3 or the common monostable multivibrator or other conventional circuit is triggered by the square wave provided from circuit 86. The frequency of the square wave varies with the frequency of the electrical signal provided by pickup 80. Even though the latter is responsive to but a single string of the instrument, the conventional fretting arrangement of such instrument allows the frequency of the plucked string to vary through about one full octave. Accordingly, as the frequency of the square wave provided by circuit 86 is increased, the frequency of the trigger to the rectangular wave generator 88 also increases.

The conventional monostable multivibrator has but a single stable condition. When it receives a trigger signal, it switches to an unstable condition and remains in such unstable condition for a period determined by internal circuit arrangements and component values thereof. At the end of such internally determined unstable period, the circuit switches back to its stable condition where it remains until receipt of the next trigger. A change in frequency of the trigger signal will change the time in which the circuit remains in its stable condition. The period of its unstable condition remains unchanged. Thus, when frequency is changed in this manner, the duty cycle is likewise changed. With this arrangement, as different frets of the instrument are employed, not only is the frequency of the resulting tone changed, but its harmonic content is also changed. This is analogous to the acoustic guitar in which tone color (harmonic content) variation with pitch is employed by the player.

A significant aspect of the circuit of FIG. 7, when employed as shown, without any modulation of the rectangular wave output of generator 88, is the increased undistorted power available from the amplifier 92. Such power increase is achieved without any further change of the amplifier's circuitry and without distortion.

In driving the conventional power amplifier such as amplifier 92 with the usual complex waveform provided by an electronic instrument system, the amplitude of the input signal to the power amplifier must be limited if distortion is to be avoided. Thus, the power amplifier, as well known, must be operated within the linear portion of its characteristic curve. If the input signal exceeds a given value, the power amplifier begins to operate upon the knee of its curve and distortion results. The output waveform is no longer of the same shape as the input waveform because of such distorted operation.

If, however, the power amplifier is driven with a rectangular wave as shown in FIG. 7, the full extent of the linear portion of the amplifier may be employed. Furthermore, the amplitude of the input signal to the power amplifier may be allowed to increase to cause operation of the power amplifier upon the nonlinear portion of its curve. This results only in a limiting of the amplitude of the output signal, but entails and creates no distortion. The output signal is still a rectangular wave. Furthermore, an improved physiological effect is achieved because when driven to its maximum capability, that is, at a condition of maximum gain, the amplifier acts upon the rectangular wave as an instantaneous limiter whereby all notes will have the same loudness.

Thus, the arrangement for driving the system power amplifier with a rectangular wave, whether symmetrical or asymmetrical, eliminates distortion at high gain when the amplifier is in overdriven condition, allows use of the full power of the amplifier to achieve a greater power output from the same amplifier without the distortion, and provides an equal loudness of all notes when overdriven.

There has been described an improved tone generator employing an asymmetrical rectangular wave and suitable wave shaping that provides a simple reliable and inexpensive signal of desired harmonic content and amplitude envelope. The arrangement particularly lends itself to improve generation of realistic piano tones wherein the duty cycle of the asymmetrical rectangular wave is at least 4 to 1. For other types of instruments or instrument sounds, use of the rectangular wave enables unique tone control and improved amplifier efficiency.

The foregoing detailed description is to be clearly understood as given by way of illustration and example only, the spirit and scope of this invention being limited solely by the appended claims.

I claim:

1. A tone generator for an electronic musical instrument, said tone generator comprising

a rectangular wave generator for producing an asymmetrical rectangular wave having a duty cycle of at least 4 to 1, and having relatively steeply rising and falling portions separated by portions of relatively unvarying amplitude,

a modulator connected to modulate the output of said wave generator and to impose upon said output an envelope representing a chosen musical sound.

said modulator comprising a diode connected to receive the output of said rectangular wave generator and means for biasing the diode in accordance with a modulating signal, and

means for integrating the modulated wave of said modulator to change the shape of said modulated wave and modify its tonal quality.

2. The tone generator of claim 1 wherein said means for integrating comprises a capacitor connected across the output of said modulator at one side of said diode.

3. A tone generator for an electronic musical instrument, said tone generator comprising

a rectangular wave generator for producing an asymmetrical rectangular wave, having relatively steeply rising and falling portions separated by portions of relatively unvarying amplitude,

a modulator connected to modulate the output of said wave generator and to impose upon said output an envelope representing a chosen musical sound,

said modulator comprising first and second series connected diodes,

said first diode having a first side connected to receive the output of said rectangular wave generator, and said second diode having one side thereof connected to receive a modulated signal, and

means for integrating the modulated wave of said modulator to change the shape of said modulated wave and modify its tonal quality.

4. The tone generator of claim 3 wherein said means for integrating comprises a capacitor connected between one side of said second diode and a common line.

5. The tone generator of claim 4 wherein said capacitor is connected between said common line and that side of the second diode that is connected to receive said modulating signal.

6. The tone generator of claim 4 wherein said capacitor is connected between said common line and the junction between said first and second diodes.

7. The tone generator of claim 4 including means for varying the effective value of said capacitor.

8. A tone generator comprising

an asymmetrical rectangular wave generator,

a modulator connected to modulate the output of said wave generator,

said modulator comprising a diode having one side connected to be biased by said output of said rectangular wave generator and the other side connected to be biased by a modulating signal, and

means for modifying the shape of the modulated wave of said modulator.

9. The tone generator of claim 8 wherein said means for modifying the shape of the modulated wave comprises a capacitor connected to said other side of said diode.

10. The tone generator of claim 8 wherein said means for modifying the shape of the modulated wave comprises a capacitor connected to said one side of said diode.

11. A tone generator for an electronic musical instrument comprising

means for generating a first wave of asymmetrical rectangular form,

means for modifying the rectangular wave to provide a second wave of sawtooth form,

an envelope generator, and

means responsive to the envelope generator for amplitude modulating said first wave.

12. The tone generator of claim 11 wherein said means for modulating comprises means for modulating said first wave.

13. A tone generator comprising

an asymmetrical rectangular wave oscillator,

a first diode having one side connected to the output of said oscillator,

a second diode having one side thereof connected to the other side of said first diode,

a resistor connected between ground and the junction between first and second diodes,

an envelope generator,

a resistive connection between the output of said envelope generator and the other side of said second diode, and

means for integrating the signal at said second diode.

14. The apparatus of claim 13 wherein said means for integrating comprises a capacitor connected between ground and said other side of said second diode.

15. The apparatus of claim 13 wherein said means for integrating comprises a capacitor connected between ground and the junction of said first and second diodes.

16. The apparatus of claim 13 wherein said integrating means comprises a first capacitor connected between ground and the other side of said second diode and a second capacitor connected between ground and the junction between said first and second diodes.

17. The apparatus of claim 13 wherein said oscillator comprises

a unijunction transistor having base electrodes resistively connected to ground and a potential source respectively, and having an emitter electrode,

a first resistor connecting said emitter electrode to said source,

a capacitor having one side connected to the emitter electrode,

an oscillator diode having one side connected to the other side of the capacitor, the other side of said oscillator diode being connected to ground,

a second resistor connected between said source and the junction between said capacitor, said emitter electrode and said oscillator diode, and

means for varying at least one of said first and second resistors.

18. The apparatus of claim 13 wherein said oscillator comprises

a programmable unijunction transistor having a cathode resistively connected to ground, an anode connected to a potential source through a first timing resistor, and a gate electrode,

a voltage divider having an intermediate point thereof connected to said gate electrode,

a capacitor having one side connected to said anode,

an oscillator diode connected between ground and the other side of said capacitor, and

a second timing resistor connected between said source and the junction between said capacitor and said oscillator diode.

19. The apparatus of claim 18 including means for controlling the frequency of the tone generated thereby, said frequency controlling means comprising means for varying said voltage divider.

20. The apparatus of claim 18 including means for varying the tone of the signal produced by said tone generator comprising a means for effecting variation of at least one of said timing resistors to thereby vary the duty cycle of the rectangular wave generated by said oscillator.

21. A tone generator for an electronic musical instrument comprising

a transducer,

a squaring circuit responsive to the transducer,

a rectangular waveform generator connected to be synchronized with the squaring circuit and producing an output wave of rectangular form having a relatively high degree of asymmetry,

means for controlling the harmonic content of said asymmetrical rectangular output waveform to achieve tone control,

said means for controlling harmonic content comprising means for selectively varying the degree of asymmetry of said asymmetrical rectangular output waveform and retaining the general rectangular form thereof, and

a power amplifier connected to be driven by the asymmetrical rectangular output waveform from said generator.

22. A tone generator for an electronic musical instrument, said tone generator comprising

a rectangular waveform generator for producing an asymmetrical rectangular wave having a duty cycle of at least 4 to 1, and

tone control means for varying the tone of said generator by varying the harmonic content of said asymmetrical rectangular wave,

said tone control means comprising means for selectively varying the degree of asymmetry of said rectangular wave so that the duty cycle thereof may be varied within the range of 4 to 1 to greater than 10 to 1, without varying the generally rectangular shape of said output waveform.

**23**. The tone generator of claim **22** including means for modulating the asymmetrical rectangular output waveform from said generator, and

an envelope generator for controlling said modulator.

**24**. A tone generator for an electronic musical instrument, said tone generator comprising

a asymmetrical rectangular wave generator for producing a fluctuating electrical signal having relatively steeply rising and falling portions separated by portions of relatively unvarying amplitude,

a modulator connected to modulate the output of said wave generator and to impose upon said output an envelope representing a chosen musical sound, said modulator comprising

a diode connected to receive the output of said rectangular wave generator, and

means for biasing the diode in accordance with a modulating signal, and

means comprising a capacitor connected across the output of said modulator for integrating the modulated wave and said modulator to change the shape of said modulated wave and modify its tonal quality.

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# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,637,913 Dated January 25, 1972

Inventor(s) Chauncey R. Evans

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the title, cancel "TONE GENERATOR EMPLOYING ASYMMETRICAL WAVE GENERATOR RECTANGULAR" and substitute --- TONE GENERATOR EMPLOYING ASYMMETRICAL RECTANGULAR WAVE GENERATOR ---.

Column 14, line 14 (line 16 of claim 24), after "wave" cancel "and" and substitute --- of ---.

Signed and sealed this 26th day of September 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

PO-1050
(5/69)

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