Electronic Keyboard circuit based on the Relaxation Oscillator

Roland Nii Ofei Ribeiro
Analog and Mixed Signal Center
Texas A&M University

***Abstract*—This paper presents an electronic keyboard circuit based on the relaxation oscillator. The circuit, uses a single Operational Amplifier configured as a Schmitt trigger to synthesize precise frequencies whose values can be tuned with switches in much the same way as each separate key on the piano produces a separate frequency. The circuit is built for a single octave above the middle C and the results are (both simulated and measured) are presented.**

***Index Terms*—electronic keyboard, relaxation oscillator, Operational Amplifier, Schmitt Trigger**

I. Introduction

THE piano has steadily become an essential commodity in most households. The well documented benefits of music to the developing mind has driven this need over the years. Contrary to its hey days, the piano has become much more accessible to the everyday household mainly due to the advent of electronic design. Electronic keyboards employ oscillators that oscillate at the same frequencies as the strings of a classical piano vibrate as they are struck. The quality(timbre) of the sound produced can be varied by varying the harmonic content of the tone produced. This leads to the generation of varying sound types, from string, to violin all the way to pipe organ all from the same electronic instrument. This paper presents a simple electronic piano based on the relaxation oscillator.

II. Circuit Overview

THE schematic of the proposed circuit is shown in Fig.1.

The circuit consists of the LM741 Operational Amplifier, connected in positive feedback. This configuration is known as the Schmitt Trigger. This is a bistable circuit with a hysteresis window, outside which the output remains in one of the stable states. The circuit is analysed in more detail in the next section. The output of the Schmitt trigger charges or discharges the capacitor C_F through one of the resistors $R_1 - R_8$, which is selected by one of the push-to-make switches $S_1 - S_8$ (e.g. Closing switch S_1 causes the capacitor to charge and discharge through the resistor R_1). The capacitor charges or discharges to push the voltage at the negative terminal of the Op-amp out of the hysteresis window, causing the output to trip in the opposite direction. The alternate tripping of the Schmitt trigger output produces a square wave whose frequency of oscillation is related to the rate at which the capacitor charges and discharges.This is in turn related to the value of the resistances through which it charges and discharges ($R_1 - R_8$). The values of the resistors are calibrated, so that they produce the same frequencies as the keys in the Middle C scale.

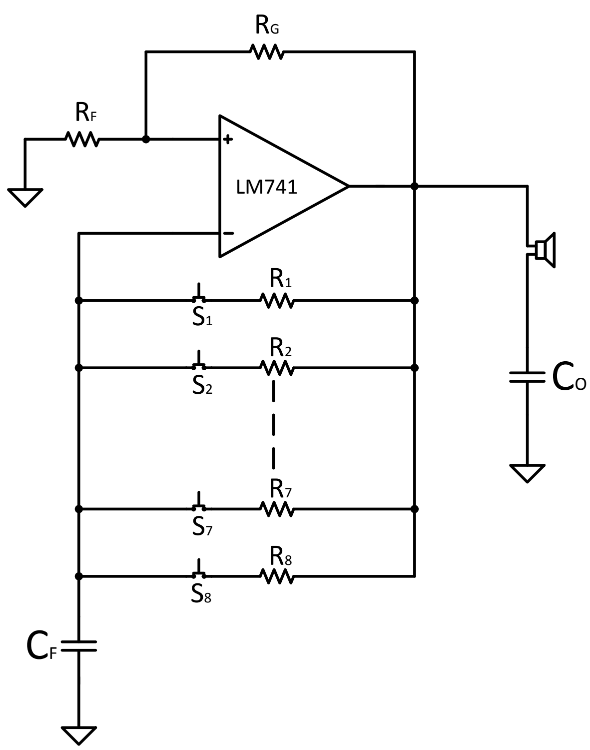

Fig. 1. Circuit Schematic

III. Theory

A. The Schmitt Trigger

The Schmitt trigger is a member of a class of circuits known as bi-stable circuits. The definitive property of this class of circuits it that their, outputs can only remain in one of two states - usually a high or a low state. One very important property of this circuit however is hysteresis. The circuit only switches between the two states when input voltage falls out of a certain range known as the hysteresis window. Within the hysteresis window, the circuit just remains in its most recent state. The circuit therefore operates as a kind memory element when the input voltage falls within the hysteresis window - a property that finds use in a wide range of applications. The schematic of the inverting Schmitt trigger is shown in Fig. 2. Let the stable states of the output be V_{OH} (High state) and V_{OL} (Low

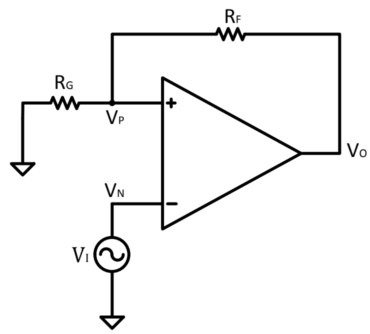

Fig. 2. Schmitt Trigger

state). It can be shown that , $V_o = V_{OH}$ when $V_N < V_{TL}$, and $V_o = V_{OL}$ when $V_N > V_{TH}$, where

$$V_{TL} = \frac{R_G}{R_G + R_F} V_{OL}$$

and

$$V_{TH} = \frac{R_G}{R_G + R_F} V_{OH}$$

so that the hysteresis window ΔV is given by

$$\Delta V = V_{TH} - V_{TL} = \frac{R_G}{R_G + R_F}(V_{OH} - V_{OL})$$

The transfer characteristic of the circuit is shown in Fig.3

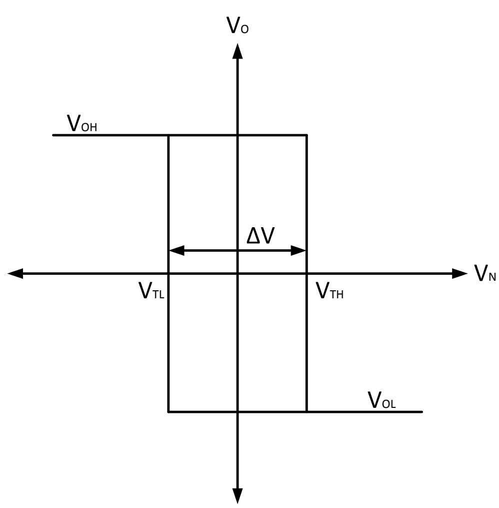

Fig. 3. Inverting Schmitt Trigger Transfer Characteristic

B. The Electronic Piano circuit

The electronic piano circuit, as shown in Fig. 1 uses the Schmitt Trigger in a relaxation oscillator to produce precise frequencies depending on the resistors that are switched into the circuit. The capacitor C_F repeatedly charges and discharges causing the voltage V_N to ramp across the hysteresis window. This causes the Schmitt trigger to periodically switch between its stable states, thus producing an oscillation. Assuming that over the first half cycle t_1, the capacitor charges across the hysteresis window through the resistor R_X, it can be shown that[2]

$$t_1 = R_X C_F \ln\left(1 + \frac{\Delta V}{V_{OH}}\right)$$

The capacitor discharges through the same resistor during the second half cycle t_2. It can also be shown that

$$t_2 = R_X C_F \ln\left(1 - \frac{\Delta V}{V_{OL}}\right)$$

The period of oscillation T is given by $T = t_1 + t_2$ which evaluates to

$$T = R_X C_F \left[\ln\left(1 + \frac{\Delta V}{V_{OH}}\right) + \ln\left(1 - \frac{\Delta V}{V_{OL}}\right)\right]$$

Assuming the circuit is symmetrical, $V_{OH} = -V_{OL}$. Substituting into the above equation and simplifying yields the following result

$$T = 2R_X C_F \ln\left(1 + \frac{2R_G}{R_F}\right)$$

from which

$$f = \frac{1}{T} = \frac{1}{2R_X C_F \ln\left(1 + \frac{2R_G}{R_F}\right)}$$

Keeping R_G, R_F, and C_F constant allows the frequency of the output voltage to be directly controlled by the resistor R_X. This is the basic principle of operation of the circuit.

IV. Design Procedure

THE frequency of the sound produced by the nth key on the keyboard is given by the following expression[1]

$$f(n) = 2^{\frac{n-49}{12}} \times 440\text{Hz}$$

The middle C is the 40th key on the keyboard. Using the positions of all the keys in the Middle C scale, their frequencies were determined using the above expression. With $C_F = 22\mu$F, the values of the resistors $R_1 - R_8$ were determined to synthesize those frequencies. The results are summarised in Table I.

The circuit was simulated in LTSpice with the resistance values calculated above and the LM741 operational amplifier. The frequencies synthesised were very close to the frequencies on the middle C scale. The maximum error was about 0.2Hz. In the actual assembling of the circuit the resistances were realized by carefully tuning eight 10K potentiometers until the frequencies were as close as possible to the required values. The results for all eight keys in the scale are shown below. Since the human ear is capable if discerning a minimum frequency difference if 3Hz, the frequencies of all the keys was kept within 3Hz of the actual values. The actual and measured frequencies in Table II.

TABLE I
Resistor values for each frequency

n	Key	Frequency (Hz)	R
40	C	261.626	3772.687
42	D	293.665	3361.085
44	E	329.628	2994.384
45	F	349.228	2826.328
47	G	391.995	2517.973
49	A	440.000	2243.257
50	B	493.883	1998.516
51	C	523.251	1886.347

TABLE II
Actual vrs Measured frequencies

Key	Frequency (Hz)	Measured Frequency(Hz)
C	261.626	263.553
D	293.665	292.593
E	329.628	331.127
F	349.228	348.601
G	391.995	392.969
A	440.000	442.591
B	493.883	492.520
C	523.251	524.351

V. Results

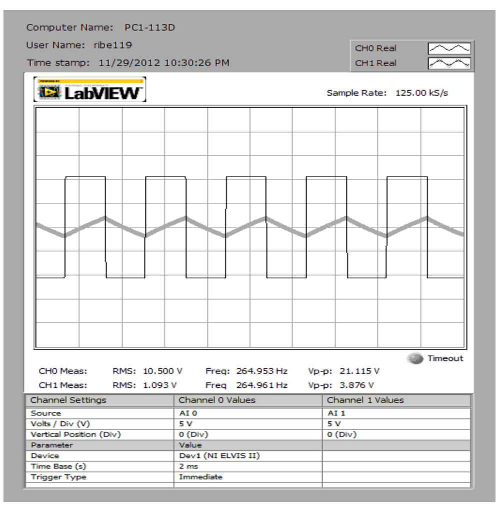

Fig. 4. Output and capacitor voltage waveforms for Middle C

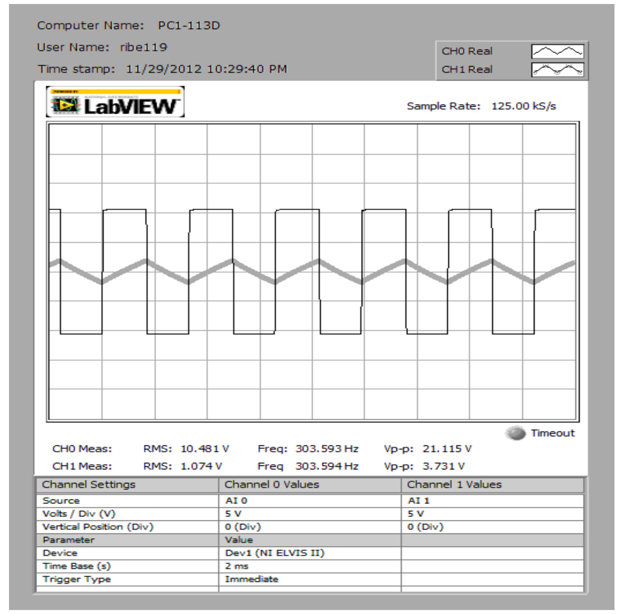

Fig. 5. Output and capacitor voltage waveforms for key D

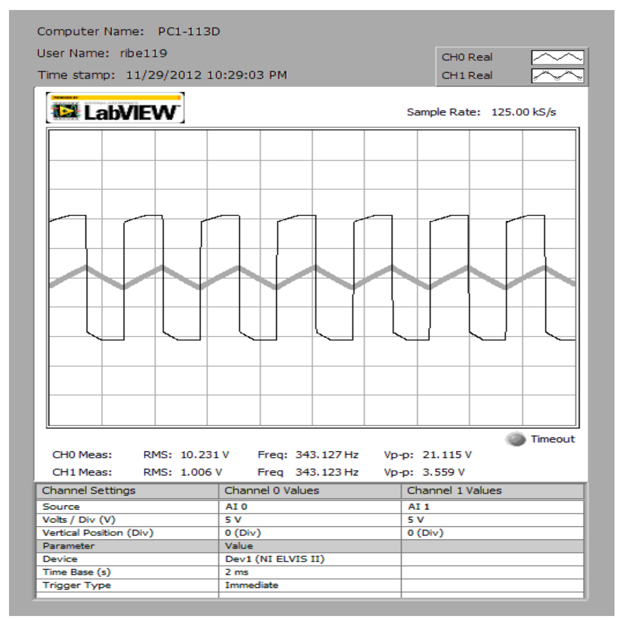

Fig. 6. Output and capacitor voltage waveforms for key E

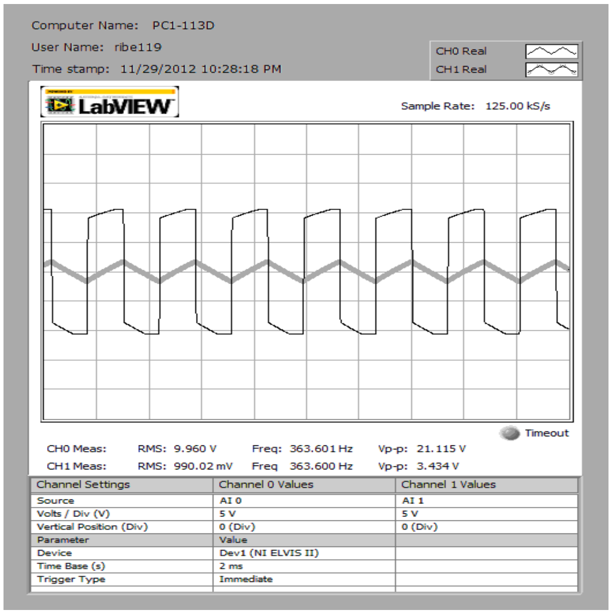

Fig. 7. Output and capacitor voltage waveforms for key F

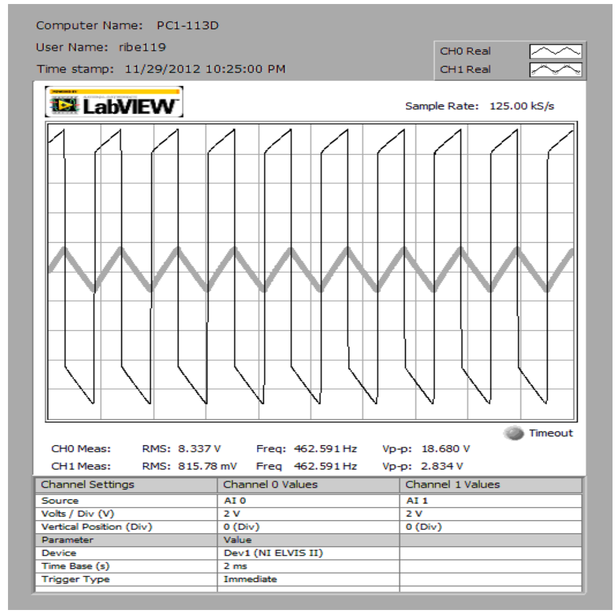

Fig. 9. Output and capacitor voltage waveforms for key A

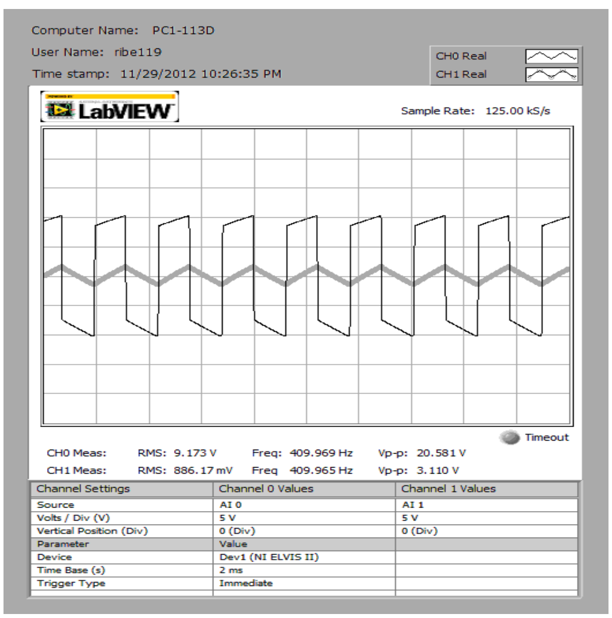

Fig. 8. Output and capacitor voltage waveforms for key G

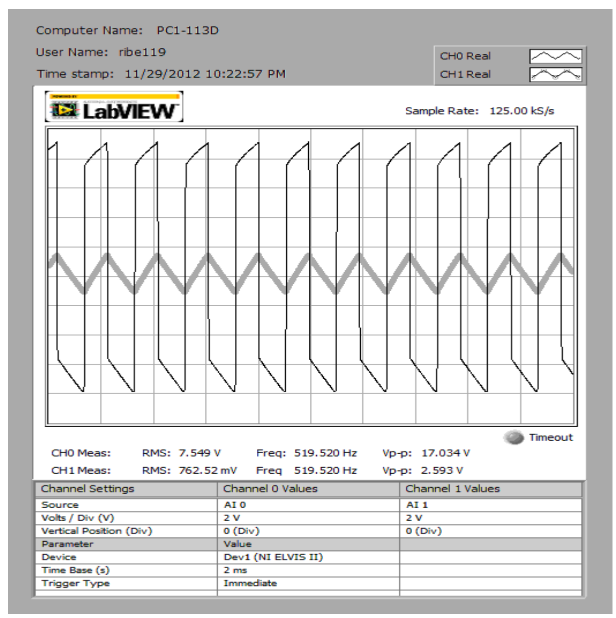

Fig. 10. Output and capacitor voltage waveforms for key B

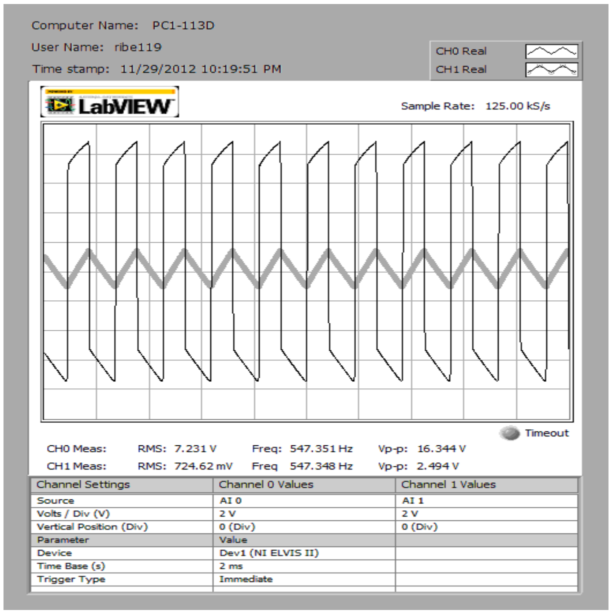

Fig. 11. Output and capacitor voltage waveforms for key C

VI. Conclusion

In this paper an electronic piano based on the relaxation oscillator was presented. Eight discreet frequencies were synthesized using tuned resistors. The circuit will be susceptible to temperature variations due to the finite temperature coefficients of the resistors. High quality resistors could be used to mitigate the effect of this. Selective filtering could also be used to vary the timbre of the sound produced in future work

VII. References

[1] http://en.wikipedia.org/wiki/Piano_key_frequencies
[2] Edgar Sanchez Sinencio,ECEN-457 Lecture notes, Lecture 7