FREQUENCY ADJUSTABLE SIMPLE PIANO USING 555 TIMER

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ABSTRACT

This project includes an explanation of the circuit built to simulate a simple piano. It also includes a review of the material used and a detailed analysis of how the 555 IC timer works. Then, it shows the mathematical methodology used to determine the values of some components, based on the frequency of the notes we want to play. Finally, expected results are explained and compared with the actual results. Further development and possible improvements are also mentioned.

INTRODUCTION

The objective of this project is to replicate the sounds produced by a piano or an electronic keyboard using basic circuit components. Additional features such as volume controls, individually tuneable notes, pitch control, vibrato, etc. could quite easily be added, but we wanted to keep it simple. The key part of this circuit is the IC 555 timer. The 555 timer is a very unique 8 pin DIL (Dual in Line) IC (Integrated Circuit) chip. IC 555 timer can be used in three mode, monostable, astable and bistable, which will all be explained later. Audible frequency range of humans is from 20Hz to 20KHz, so we wanted to generate frequencies in this range using 555 timer and feed it to the loudspeaker.

PROBLEM DEFINITION

To build the simple piano, we used a list of material that consisted of: a 9V battery, an assortment of 8 resistors - of values 1487Ω, 1328Ω, 608Ω, 1115Ω, 994Ω, 886Ω, 406Ω, and 6825Ω -, a 10kΩ potentionmeter, a Piezo Buzzer, 8 push buttons, a 100nF capacitor and a 10nF capacitor, a 555 IC timer and jumper wires.

The 9V battery is used because the 555 IC timer can only handle ranges of voltage comprised between 5V and 15V. Moreover, we thought it was more convenient to use a simple 9V battery than to use a generator that would involve more complex connections. The values of the resistors will be explained later in the report. In general when using 555 IC timer, people use a simple resistor instead of the potentiometer but we thought it would be more challenging and interesting to use a potentiometer, since it would enable us to change the frequency. We chose its value to be 10KΩ so the change in frequency wouldn't be too abrupt while contributing to a considerable change in frequency when the potentiometer value would be turned all the way to 10kΩ. The Piezo Buzzer acts as a speaker for our piano. We chose a Piezo Buzzer because it was the only type of speaker available on the simulation software we used. The push buttons act like switches, and were chosen to reflect that idea of a keyboard that is present for every piano. The 10nF capacitor has a value that is commonly used for the 555 timer setup we built our circuit on. For the 100nF capacitor, we decided to pick this capacitance because a different value would impact the output voltage, which we didn't need to personalize. The jumper wires used on the simulation have different colors to help with differentiating them.

To design the circuit around the 555 timer, we first needed to determine what mode would be used. There are three modes the 555 timer can be used with. The first one is monostable. The monostable mode is used to output a pulse with adjustable duration. That would be useful to build an alarm for example that would consist of one long sound. The second mode is astable and is used to output an oscillating pulse with a tunable frequency. This mode was used in our circuits since we wanted to output desired pitches. Finally, the last mode is Bistable and that could be used for a more complex wave generator.

The way we built the circuit was following the schematics for the astable mode. Consequently, we connected the pin 1 to ground. The pin 2 was connected to the pin 6. The pin 3 was the output so it was connected to the Piezo Buzzer. The pin 4 was connected to the voltage source. The pin 5 was connected to a grounded 10nF capacitor. The pin 6 was connected to the pin 2, and also to a grounded 100nF capacitor and to the second leg of a resistor that we named Rb. The pin 7 was connected to the first leg of the Rb resistor and to the second leg of the potentiometer that we called Ra, which was then connected to the voltage source. Finally, the pin 8 was connected to the voltage source.

The output of the 555 timer following this mode will be a square wave. The reason why the output is a square wave will now be explained. The inside of the 555 timer consists of 2 comparator, whose output will be the input of a RS flip flop. The output of the flip flop will go to an output stage and to a transistor. If the output of the flip flop is zero, the output stage will output the high state of a square wave. If the flip flop's output is one, the output stage will output the low state of a square wave and the transistor to which the flip flop is connected will be turned one and will ground the pin 7. After the pin is grounded, the voltage will be drained from the capacitor so this phenomenon will act backward and repeat itself with a frequency determined by the values of Ra and Rb. The reason why the frequency is determined by the values of Ra and Rb will be explained in the mathematical methodology.

MATHEMATICAL METHODOLOGY

We found online the frequencies of the notes we wanted the piano to play. We decided that the piano would play notes from C5 to C6 because the frequency gap between two notes gets smaller as you go down in pitch. Therefore, this choice enabled us to work with greater resistances, enabling the error margin to be more flexible. After finding the frequencies, we analyzed the formula of the output frequency:

$$frequency = \frac{1}{.7\,(R_A + 2R_B)\,C}$$

We were able to modify the equation in order to calculate Rb, since we knew the values of the frequency for each note. The resulting equation was:

$$R_B = \frac{1}{2}\left(\frac{1}{.7C \times frequency} - R_A\right)$$

Since we're using a potentiometer of known value for Ra, we decided to set the initial resistance of Ra to ≅ 0Ω. The value of Ra can't be exactly 0 since it would change the properties of the 555 timer used in astable so we just put assigned it to 0 for calculation but it would actually be a very small value for the simulation. The value of C is also known, since we chose to use a 100nF capacitor. To calculate the resistance of Rb, it is necessary to first understand what Rb represents. Rb is a group of resistors in series. When a button is pressed, it closes the circuit to enable the current to flow through the resistor at the same location on the breadboard. The resulting Rb will thus be the sum of all the resistance of the resistors located between that button and the pin 6. Using the formula above, we were able to calculate the total resistance Rb needed to produce each individual notes. From that, we worked our way from C6 to C5 to calculate the required resistance of each resistor in order to obtain the total resistance that we calculated. The method is illustrated on the chart below:

Note	**freq. (Hz)**	**R_B(Ω)**	**Resistor(s)**
C6	1046.5	6825	6825Ω
B5	987.8	7231	6825Ω + 406Ω
A5	880.0	8117	6825Ω + 406Ω + 886Ω
G5	784.0	9111	6825Ω + 406Ω + 886Ω + 994Ω
F5	698.5	10226	6825Ω + 406Ω + 886Ω + 994Ω + 1115Ω
E5	659.3	10834	6825Ω + 406Ω + 886Ω + 994Ω + 1115Ω + 608Ω
D5	587.3	12162	6825Ω + 406Ω + 886Ω + 994Ω + 1115Ω + 608Ω + 1328Ω
C5	523.3	13649	6825Ω + 406Ω + 886Ω + 994Ω + 1115Ω + 608Ω + 1328Ω + 1487Ω

According to the formula, the speaker will emit a sound of the frequencies calculated for each button pressed when Ra is set to approximately 0. Since the frequency is inversely proportional to Ra, increasing the resistance of the potentiometer will result in a lower frequency.

RESULTS

The results of the simulation were exactly as wanted. The frequency emitted matches perfectly with the desired frequencies. In addition, the potentiometer enabled to lower the frequencies emitted in a noticeable way.

DISCUSSION

In our circuit design, the size of the breadboard limits the number of buttons placed thereby limiting the number of musical notes that can be played. This can be improved in the future by designing a similar circuit in a bigger breadboard or using multiple breadboards of the size used in this project. After running our simulation, we found that our design had a bad timbre (timbre refers to the character or quality of a musical sound or voice as distinct from its pitch and intensity) and produced some static sounds. The timbre can be corrected by passing the circuit through a sound simulator and the sound quality can be improved by using good quality loudspeakers instead of a Piezo buzzer which was used in our design. The use of a single IC 555 timer limits the number of buttons that can be pressed simultaneously. This is because the IC 555 timer can only produce one square pulse per input. So, when multiple buttons are pressed at a time the frequencies get mixed up and ends up producing a completely different musical note than the one desired. In our follow up design, we plan to introduce parallelism to enable several buttons to be pressed simultaneously. This could be possible by assigning each button a separate IC 555 timer.

CONCLUSION

All things considered, to design the circuit in this project we first determined how to emit pitches from pulses, then we calculated the values of the resistances in the circuits and put all information collected together to simulate the circuit. To conclude, the topic of this project was definitely good. It challenged us and pushed us to learned beyond the material covered in the circuit analysis class, while enabling us to apply content and knowledge viewed in class. Finally, the process we went through to figure out the design got us a greater understanding of circuits.

REFERENCES

http://www.phy.mtu.edu/~suits/notefreqs.html

http://www.doctronics.co.uk/555.htm

https://www.youtube.com/watch?v=WqGq9Yv1d_U

APPENDIX

The HIGH and LOW times of each pulse can be calculated from:

$$\text{HIGH time} = 0.69(R1 + R2) \times C$$

$$\text{LOW time} = 0.69(R2 \times C)$$

The duty cycle of the waveform, usually expressed as a percentage, is given by:

$$\text{duty cycle} = \frac{\text{HIGH time}}{\text{pulse period time}}$$

An alternative measurement of HIGH and LOW times is the mark space ratio:

$$\text{mark space ratio} = \frac{\text{HIGH time}}{\text{LOW time}}$$