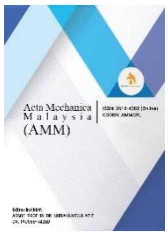
ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2616-4302 (Online)
CODEN: AMMCFL

Acta Mechanica Malaysia (AMM)

DOI: http://doi.org/10.26480/amm.02.2023.76.82



CrossMark

RESEARCH ARTICLE

DESIGN AND IMPLEMENTATION OF A 36-NOTE LOW-COST CUSTOMIZED DIGITAL MUSIC BOX

Md. Ibrahim Al Imran[a*], Fahmida Ahmed Antara[b], Bidya Debnath[c], Adrita Anika[c]

[a]Department of Biomedical Physics and Technology, University of Dhaka, Dhaka, Bangladesh, Email:
[b]Department of Electrical and Electronic Engineering, Daffodil International University, Dhaka, Bangladesh,
[c]Department of Electrical and Electronic Engineering, Bangladesh University of Engineering And Technology, Dhaka, Bangladesh, ,
[*]Coressponding Author Email:imran.bmpt@du.ac.bd

ARTICLE DETAILS

Article History:

Received 03 May 2023
Revised 07 June 2023
Accepted 10 July 2023
Available online 01 August 2023

ABSTRACT

The purpose of the current study was to design and build a music box with digitally produced notes. The input command sheet allows anybody to create any melody from the octave, making it possible to think of it as a small version of a musical instrument. This instrument is capable of producing frequencies in all three octaves, i.e., the lower, the middle, and the higher octaves. This music box may therefore play any tune, no matter how short or lengthy the note is. There is no need to alter the frequencies over time because no string is used in the creation. It can play any song to one's heart's content if the song's music sheet is accessible. In an epitome, this music box can be viewed as a very simple musical instrument with digitally created tones. There is no need to customize the strings over time like with traditional mechanical musical instruments owing to tones produced digitally. The ability to generate a vast variety of tones, the ease with which it can be adjusted, the convenience with which anyone may have their desired notes customized, and the low cost at which it was produced are the most notable advantages of this digital music instrument. Due to its low price, it can be simply incorporated, altered, slightly improved, and produced at a considerably reduced cost for commercial use.

KEYWORDS

Digital music box, octave, melody, frequencies, notes.

1. INTRODUCTION

The most direct way to portray beauty is via music since it is the purest form of art, having a single, uncomplicated soul and being least burdened by superfluous elements. One of the several forms of communication that have emerged as a result of social and biological interactions is music. It can play a necessary part in how the modern human mind develops (Cross., 2001).

Pitch and pitch range are significant concepts in music theory that are related to musical Notes and intervals (Hörschläger et al., 2015; Will., 2011). The variation in pitch between two Notes is known as an octave when one Note is twice as frequent (measured in hertz) as another Note. A note will sound similar but can be lower or higher if it is played twice at different pitches separated by an octave. Logically, an octave consists of twelve unique pitches (or Notes) spaced equally apart (T. S. S. O. M., 2022.).

The pitch of a sound reveals whether it is typically high or typically low, or in the center (like Middle C). The 440Hz global tuning standard, which corresponds to the musical Note of A, allows musicians to tune their instruments uniformly (above Middle C) (Gribenski, 2020). A 440Hz piano tuned in Boston will therefore sound the same as a 440Hz piano tuned in China. Based on the alphabetical letters A, B, C, D, E, F, and G, there are 12 tones (or pitches). A certain pitch is denoted by a musical note. The following five Notes are created by adding symbols to the letters that either raise or lower the pitch of the natural Note. Depending on the circumstance, an A natural (written as A) can alter in pitch to become an A sharp (written as A# on the musical staff) or a flat (written as A) (Schmidt-Jones, 2021).

The idea of a music box is so creative since songs may be generated anyway the heart desires. The most common kind of music boxes are mechanical ones, which make sound by striking a precisely tuned comb with a set of pins (Music Box Attic, 2022; Lesko, 2020). It is constructed similarly to a standard piano or string instrument, but on a small scale. Some mechanical music boxes are limited to playing a single tune, while others may play any song. In an optical rotatory encoder, microcontroller, and necessary software were designed for an E-music box, where cyclical rotatory movement was transformed into a musical song (Novembre, 2015). The melody's pace was decided by the rotation's speed (Chen, 2022).

To build a digital music box, the first and foremost task is to develop a frequency synthesizer. There has been developed a digital fractional frequency synthesizer (Stork, 2016) where an array of digital circuits, including flip-flops, registers, AND gates, and monostable multivibrators were utilised. The setup made it feasible to generate frequencies between 137Hz and 2740Hz. A 555 timer may, however, also be employed as a steady multivibrator to create octaves (Kumar, 2013).

In this project our objective is to develop a digital music box that can play any song. There is a distinction between this music box and others. The Notes in a digital music box are not produced by striking strings as they would be in a traditional music box. Digital components like the 555 timer IC are instead used to create various frequencies. Using a timer IC, all 12 frequencies that make up an octave are created. The octaves this instrument can play are lower, middle, and upper (Kuyken et al., 2015;

Quick Response Code	Access this article online	
	Website: www.actamechanicamalaysia.com	**DOI:** 10.26480/amm.02.2023.76.82

Cite the Article: Md. Ibrahim Al Imran, Fahmida Ahmed Antara, Bidya Debnath, Adrita Anika (2023). Design and Implementation of A 36-Note Low-Cost Customized Digital Music Box. *Acta Mechanica Malaysia, 6(2): 76-82.*

Matos et al., 2003). Instead of using staff notation, the music sheet is produced for this device. By creating the music sheet, any desired song may be played and experienced the unadulterated joy of music.

2. Materials and Methodology

The prototype is developed using amplifiers, timer IC and digital logic gates. For the input, a memory device is required for which a black-and-white patterned sheet of the specific melody was used.

***A**. Required Components*

The list of the required components with their specifications is as follows,

- **i.** Operational amplifier (IC LM358)
- **ii.** NE555 Timer
- **iii.** NOT gate (IC 7404)
- **iv.** TCRT5000
- **v.** OR gate (IC CD4072BE)
- **vi.** Resistance and Capacitance
- **vii.** 16:1 MUX (IC 74150)
- **viii.** 12V Battery
- **ix.** Dual D Flip-Flop (IC CD4013)
- **x.** Speaker
- **xi.** Dual 2:1 MUX (IC 74153)
- **xii.** Wires etc.

***B**. Theory:*

The tools are deployed to create the prototype, and then a patterned black and white sheet was used to create our memory device. As the wheel of the spinning sheet would pass beneath the TCRT5000 IC, a stepper motor was employed to provide torque to drive the wheel (Jinasena, and Meegama, 2011).

The TCRT5000 is a reflecting sensor that features phototransistors as receivers and IR-emitting diodes as transmitters inside a lead-free housing that blocks visible light. Both the transmitter and receiver have integrated lenses (Semiconductors, 2022). Two mounting clips are included in the box. The musical notation on our musical score is picked up by this sensor.

Figure 1: TCRT5000 sensor

An integrated circuit (chip) called the 555 timer is utilized in several oscillators, timers, and pulse generator applications. The 555 may be used as an oscillator, a D Flip-Flop component, and to produce time delays. The timer is used in the project to create multiple frequencies by varying resistances in an astable condition since it may be used as a multivibrator in astable, bistable, and monostable modes. The timer doesn't need input while it's in astable mode. Because of this, it is often referred to as a free running oscillator (Bohare, 2021).

A comparator op-amp is the LM358. The LM358 is made up of two separate operational amplifiers with high gain and inbuilt frequency compensation that were created expressly to run off of a single power source and function across a broad variety of voltages. It is also feasible to run on separate power supplies, and the low power supply current drain is unaffected by the size of the power supply voltage.

IC4050BE was used as buffer since there was a voltage drop, which prevented the components from functioning. A CMOS Hex non-inverting buffer/converter with logic-level conversion utilizing just one supply voltage is the CD4050BE (V_{CC}) (Farhan Khalid, and Khalid, 2014). When these devices are used for logic-level conversions, the input-signal high level (VIH) might be higher than the V_{CC} supply voltage.

Static frequency dividers are a typical benchmark to check the D flip-flops used in high-speed digital circuits and to assess high-speed technologies (Foster, 2010; Awny, 2010). In this project, the frequency of sounds is divided into half using a D flip-flop IC (CD4013BE) to create the middle and lower octaves from the higher octave. The monolithic CMOS IC CD4013B dual D Flip-Flop is built using N-channel and P-channel enhancement mode transistors. Each D flip-flop has separate inputs for data, set, reset, and clock as well as outputs for "Q" and its complement.

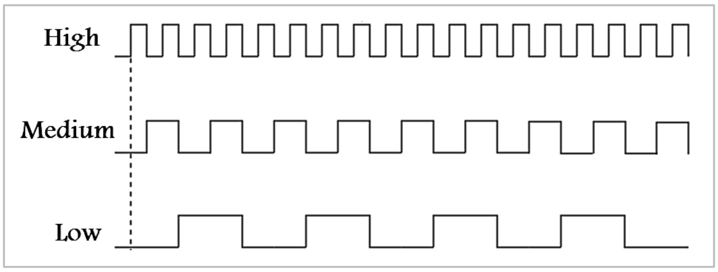


Figure 2: Plot of the Output Signals of an Asynchronous Counter Using D Flip-Flop IC CD4013BE Showing High, Medium and Low Frequencies

A power amplifier called the LM386 was created for low-voltage consumer applications. The gain is initially set to 20 to reduce the number of external parts, but by adding an external resistor and capacitor between pins 1 and 8, the gain may be increased to any value between 20 and 200. While the output is automatically biased to half the supply voltage, the inputs are grounded referenced. This portion is exclusively utilized in our sound amplification section.

The IC 7404 is a NOT gate. It has six inverters, each of which does a logical invert action. An inverter's output is the inverse of the logic state of its input, meaning that when the input is high, the output is low, and vice versa.

Four input OR gates: CD4072BE. The CD4072BE gate is an addition to the family of CMOS gates and offers the system designer a direct implementation of the positive-logic OR function. The SN74150N is a data selector or multiplexer that compels the strobe's W-output to be high and Y-output to be low. The device only has an inverted W-output. This IC is used to create Boolean functions.

A 4:1 MUX is the SN74HC153N. It can operate between 2 and 6 volts. It only uses up to 80 A of power (Suzuki, 2007). A speaker that functions effectively in a variety of audio applications was employed. The speaker has a 0.5W power rating and a 4 Ω resistance which worked pretty well. However, voltage dips were seen, thus an amplifier circuit was initially used. The circuits that will be covered later require capacitors and resistors of various values.

The black-and-white page was used as its memory in the project.

A. *Truth Tables*

Actually, TCRT5000 uses the black area of the page as the input source. Here, a diode and an LED are present in the TCRT5000.

The light is reflected when a white part passes over the LED, and the diode then absorbs the reflected light. A dark part prevents light from reflecting. When it is black, it indicates high voltage, and when it is white indicates low voltage. Therefore, the output of the comparator circuit is inverted using a NOT gate. In this procedure, ten circuits are built to produce the letters C, D, E, F, G, A, B, H, L, and #.

Figure 4 depicts the order of the higher octave Notes employed in this circuit. Here, pins C, D, E, F, G, A, and B were connected to the 8 to 3 encoder's input, and logic 0 was obtained from the left pin, which is indicated in Table 01 with a blue mark. The 8 to 3 Encoder receives the following signals from this source: C, D, E, F, G, A, and B.

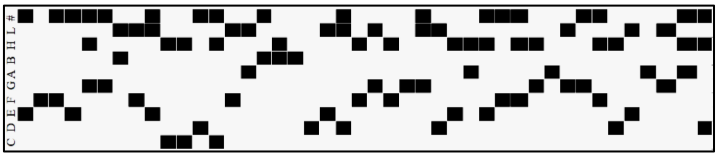


Figure 3: The Black and White Page Used as The Memory Device

Figure 4: The Sequence of Octave Notes Used in The Device

Table 1: Modified Truth Table of the 8 To 3 Encoder Used in the Device

B	A	G	F	E	D	C	0	y2	y1	y0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	1
0	0	0	0	0	1	0	0	0	1	0
0	0	0	0	1	0	0	0	0	1	1
0	0	0	1	0	0	0	0	1	0	0
0	0	1	0	0	0	0	0	1	0	1
0	1	0	0	0	0	0	0	1	1	0
1	0	0	0	0	0	0	0	1	1	1

y0, y1, and y2 were the 8 to 3 encoder's outputs. Again, we used y3 as the 16:1 MUX's selection input from the black and white patterned paper. The output of our modified 8 to 3 encoder was defined using the logic equations listed below.

$y0 = C + E + G + B$

$y1 = D + E + A + B$

$y2 = F + G + A + B$

$y3 = \#$

The 16:1 MUX uses y0, y1, and y2 as its control inputs. The output of the TCRT5000 circuit marked with # is used as the fourth control input. The various frequencies produced by the 555timer IC are the input to the 16:1 MUX. Table 2 displays the amended truth table for the control input and output from the 16:1 MUX.

The D Flip-Flop is used to convert the higher frequency output of the MUX to medium and lower frequencies. The signal with a low, medium or high frequency is now delivered to the output using a 4:1 MUX. H and L are utilized as the control inputs for the 4:1 MUX. The truth table for the 4:1 MUX's control input and output.

Table 2: Truth Table of the 16:1 MUX Used in the Device

y3	y2	y1	y0	Output of the 16:1 MUX	Output Note
0	0	0	0	C0	-
0	0	0	1	C1	C
0	0	1	0	C2	D
0	0	1	1	C3	E
0	1	0	0	C4	F
0	1	0	1	C5	G
0	1	1	0	C6	A
0	1	1	1	C7	B
1	0	0	0	C8	-
1	0	0	1	C9	C#
1	0	1	0	C10	D#
1	0	1	1	C11	-
1	1	0	0	C12	F#
1	1	0	1	C13	G#
1	1	1	0	C14	A#
1	1	1	1	C15	-

Table 3: Truth Table of the 4:1 MUX Used in the Device

H	L	Output of the 16:1 MUX
0	0	Medium
0	1	Low
1	0	High
1	1	(x)No such input

There won't be any such input on the control side that will result in output, as shown by the 'x' symbol because there are no realistic analog musical instruments that can play these Notes. Because of the circuit's voltage loss, the 4:1 MUX's output needs to be amplified. An amplifier circuit is then used to increase the output.

B. *Circuits Constructions*

Below is a schematic diagram of the input circuit using the TCRT5000 IC. Here, the black LED serves as the receiver while the blue one transmits.

The formula from the NE555 timer IC datasheet is used to compute the levels of resistance needed to produce certain frequencies in the upper octave. The Table 4 below lists the resistances that were employed in this device.

Making a frequency calculation utilizing a 555 timer IC in astable mode, frequency is created. The capacitor charges through resistors R_1 and R_2 in astable mode, but only R_2 is used for discharge. As a result, although T_{OFF} depends just on R_2, T_{ON} depends on R_1 and R_2 (Chien et al., 2020).

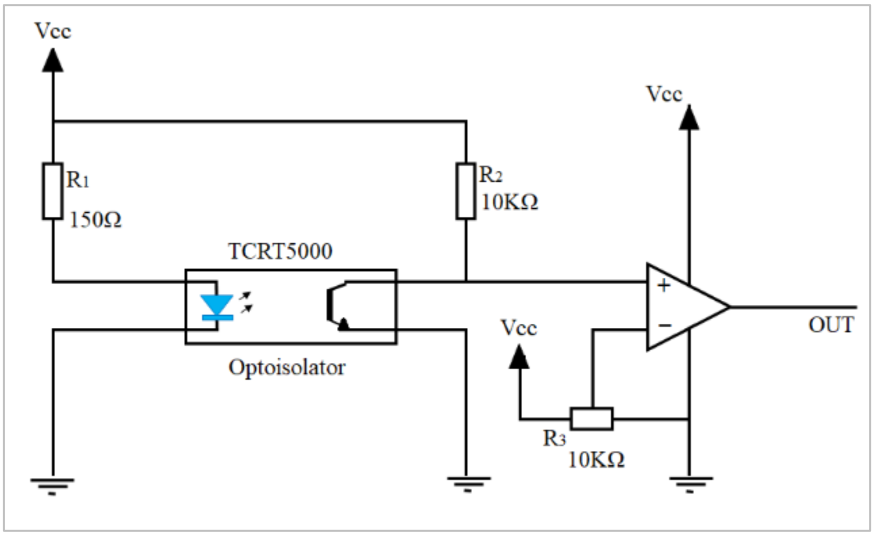


Figure 5: Schematic Diagram of the Input Circuit Using TCRT5000 IC

$$T = \frac{1}{frequency}$$

$$T = T_{ON} + T_{OFF}$$

$$T_{ON} = 0.693C(R_1 + R_2)$$

$$T_{OFF} = 0.693C(R_2)$$

$$Duty\ cycle, D = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

We took the duty cycle to be 70% for all the frequencies except A# and B.

The value of capacitance was taken, C = 1μF for all except E and F frequency.

This device employed the astable mode of the NE555 timer. Here, in Figure 6, two NE555 timer IC set up in astable mode is shown. The left one generates a signal having frequency of approximately 987.77Hz which is denoted by the B Note, shown in Figure 7. The right setup generates a signal having frequency of approximately 523.25Hz which is denoted by the C Note of the High frequency octave, shown in Figure 7. In the circuit, 15V served as the biasing voltage. Capacitance of 1μF is utilized as the capacitor.

Table 4: Calculation of the Resistances Used in the Device

Note	1st Octave frequencies (Hz)	T (sec)	T_{ON} (sec)	T_{OFF} (sec)	R_1+R_2 (Ω)	R_2 (Ω)	R_1 (Ω)
C	523.25	0.001911	0.001338	0.000573	1930.44	827.33	1103.11
C#	554.37	0.001804	0.001263	0.000541	1822.07	780.89	1041.18
D	587.33	0.001703	0.001192	0.000511	1719.82	737.07	982.753
D#	622.25	0.001607	0.001125	0.000482	1623.3	695.7	927.602
E	659.25	0.001517	0.001062	0.000455	1532.2	656.66	875.541
F	698.46	0.001432	0.001002	0.00043	1446.18	619.79	826.39
F#	739.99	0.001351	0.000946	0.000405	1365.02	585.01	780.011
G	783.99	0.001276	0.000893	0.000383	1288.41	552.18	736.235
G#	830.61	0.001204	0.000843	0.000361	1216.1	521.18	694.912
A	880	0.001136	0.000795	0.000341	1147.84	491.93	655.91
A#	932.33	0.001073	0.000751	0.000322	1083.42	464.32	619.095
B	987.77	0.001012	0.000709	0.000304	1022.61	438.26	584.347

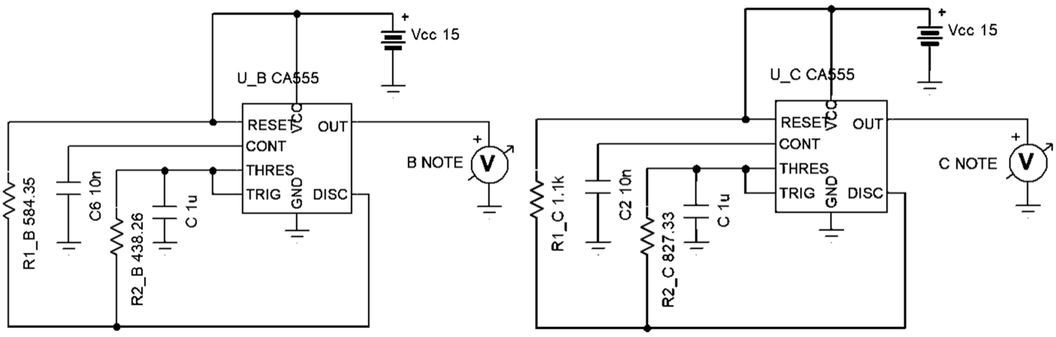


Figure 6: Schematic diagram of the 555 timer IC working in the Astable Mode generating B Note and C Note of the high frequency Octave

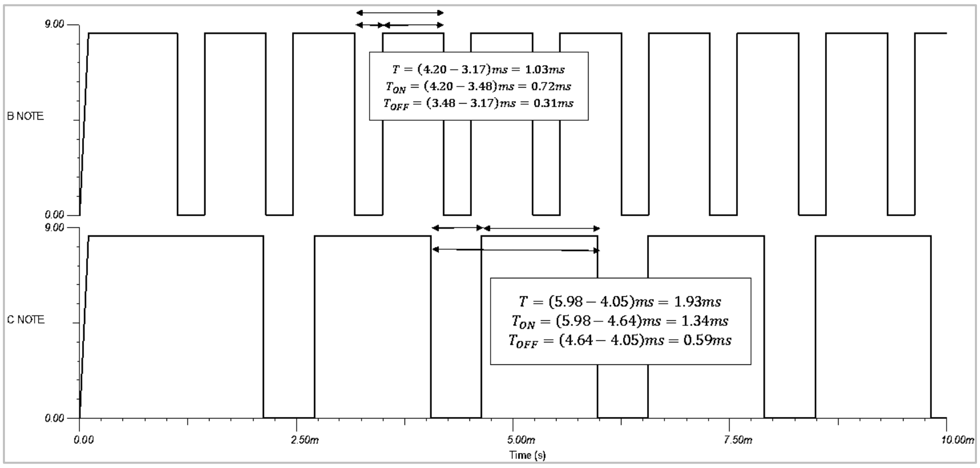


Figure 7: Output plot of the 555 timer IC working in the Astable Mode generating B Note and C Note respectively

Output plot of the 555 timer IC working in the astable mode generating B Note and C Note is shown in Figure 7. The 1st one denotes the B Note generated from the circuit shown on the left and the 2nd one denotes the C Note generated from the circuit shown on the right of the Figure 6.

From the plot the duty cycle and the frequency of the signal was calculated.

For B Note,

$$T = (4.20 - 3.18)ms = 1.02ms$$

$$T_{ON} = (4.20 - 3.48)ms = 0.72ms$$

$$T_{OFF} = (3.48 - 3.18)ms = 0.30ms$$

$$Duty\ cycle, D = \frac{0.72}{1.02} = 0.7058$$

$$Frequency, f = \frac{1}{1.02} \times 1000\ Hz = 980.39Hz$$

For C Note,

$$T = (5.98 - 4.05)ms = 1.93ms$$

$$T_{ON} = (5.98 - 4.64)ms = 1.34ms$$

$$T_{OFF} = (4.64 - 4.05)ms = 0.59ms$$

$$Duty\ cycle, D = \frac{1.34}{1.93} = 0.6943$$

$$Frequency, f = \frac{1}{1.93} \times 1000\ Hz = 518.13Hz$$

From Figure 7 taking two points from the graph the frequency was calculated. For the B Note, the frequency is approximately 980.39Hz. And, for the C Note, the frequency is approximately 518.13Hz**.**

Taking the values from the graph, it can be seen that the generated frequencies are very close to our expected frequencies.

The whole circuit diagram's creation is shown in Figure 8 below. Here, it can be seen that the outputs of the ten NE555 timed ICs, marked as C0 to C15, was utilized as the input of the 16:1 MUX, and the input from the patterned memory device was used as the input of the sequenced TCRT5000.

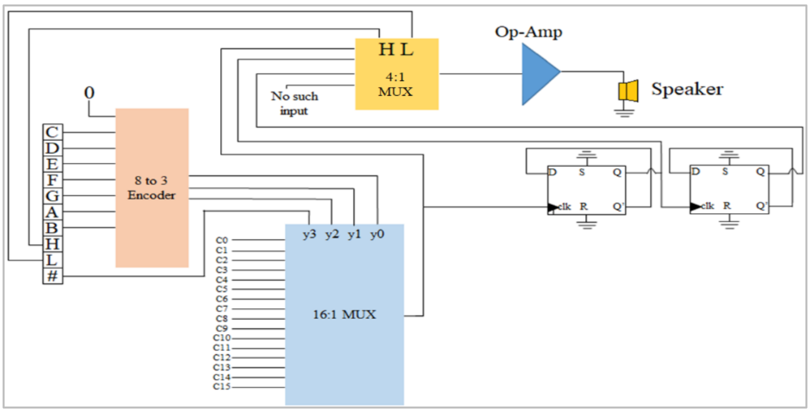


Figure 8: Block Diagram of the Circuit Used in The Device

The 16:1 MUX's selection pins, y0, y1 and y2 come from the encoder's output, whereas y3 came straight from the patterned memory sheet. The generated notes from the NE555 timer IC i.e. C0 to C15 goes to the input pins of the 16:1 MUX and the output is then sent to the counter circuit so that the middle octave and lower octave frequencies can be generated (Watanabe, 2004) [23]. These three output signals go to the 4:1 MUX where the selector pins H and L are taken from the patterned sheet. The selector pins H and L are taken according to the Table 3. There was no such input when both H and L pins are high.

3. Result

The experimental setup of the circuit is show below in the Figure 9.

C. Output

A higher octave frequency signal is produced by the 16:1 MUX. However, the frequencies were altered using the counter circuit to produce the middle and lower octave frequencies, yielding a total of 36 distinct frequencies. The selector pins of the 4:1 MUX, H and L were used to give the expected output at the final stage.

The frequencies produced by the device are shown in Table 5 as the first, second, and third octaves. An operational amplifier was then used to boost the output signal before being routed to the speaker. The speaker's resistance is merely 4Ω. The speaker revealed the desired outcome.

D. Cost calculation

The device's cost computation is shown below. The chart shows that the overall cost is not excessive, and since the device may be tailored to the user's preferences, this expense is justified.

The device has a lot of room for improvement and cost reduction because it is still in the early stages of development.

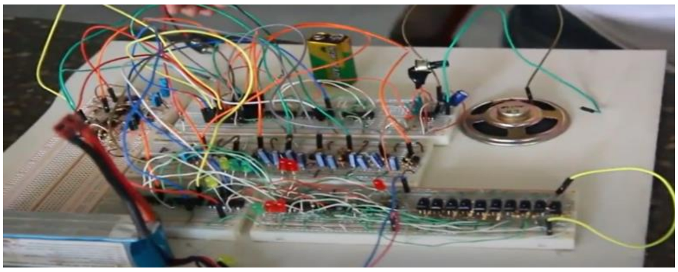


Figure 9: The experimental setup of the circuit

Table 5: List of the Generated Frequencies Using the Counter Circuit

Note	1st Octave frequencies (Hz)	2nd Octave frequencies (Hz)	3rd Octave frequencies (Hz)
C	523.25	261.625	130.8125
C#	554.37	277.185	138.5925
D	587.33	293.665	146.8325
D#	622.25	311.125	155.5625
E	659.25	329.625	164.8125
F	698.46	349.23	174.615
F#	739.99	369.995	184.9975
G	783.99	391.995	195.9975
G#	830.61	415.305	207.6525
A	880	440	220
A#	932.33	466.165	233.0825
B	987.77	493.885	246.9425

Table 6: Total Cost Calculation

Component	**Quantity**	**Unit Pack (USD)**	**Price (USD)**
TCRT5000	10	0.20	2
LM358	5	0.05	0.25
NE555 timer	12	0.50	6
CD4072 (4 input OR gate)	2	0.50	1
CD7404 (NOT gate)	1	0.10	0.1
SN74HC150 (16:1 MUX)	1	0.98	0.98
SN74HC153 (4:1 MUX)	1	0.40	0.4
LM386	1	0.05	0.05
Flip-Flop 4013	1	0.29	0.29
Buffer 4050	1	0.01	0.01
Resistors	200	0.01	2
Capacitors	30	0.01	0.3
Speaker (4Ω)	1	0.01	0.01
Breadboard	5	0.50	2.5
5V stepper motor with driver	1	0.60	0.6
			Total =16.49

4. Analysis

E. Main findings

This machine produces all 36 frequencies or three octaves of frequency. It receives input from a black and white sheet made using the music's notation. This item can be transformed into a little piano. Then the switch may be utilized as reeds for the input. It was employed to filter out noise and block the DC signal coming from the output capacitor. The 16:1 MUX's output was too low to serve as the D Flip-input. Flop's Therefore, a buffer was employed before the IC 74150 to maintain a high enough output voltage. An amplifier circuit was used to boost the output of the final 4:1 MUX so that it could be utilized as the speaker's input voltage (Farhan, 2020).

F. Limitations

Unfortunately, it turned out to be impossible to produce every frequency with extreme precision. The majority of the time, 1μF capacitors were utilized. However, it was later discovered that tuning capacitor is able to create more precise frequency as time constant of 555 timer is dependent on capacitor's value (Bohare, 2021; Abrar, 2017; Kasri, 2017). Here in the project, a capacitance of 0.1μF performed better.

5. Conclusions

In this article, a low-cost personalized digital music box is fabricated and utilized. The complete 36 Note production capabilities of the device may cover a sizable portion of the piano utilizing a memory sheet. In that sense, it may be called a little musical instrument. Additionally, the project's overall cost is estimated and found to be reasonable. However, this device can be converted into a real-time device with a relatively simple adjustment. The volume and tempo of the song may also be changed by varying the stepper motor's speed.

Initially, this prototype is developed for experimental purpose only. But as the device worked properly it can be produced and offered for sale at a commercial level. So, the manufacturing cost can be much lower. The frequencies can be varied by changing the value of the resistances. As changing the value of the capacitance gave a better result at the final stage, it should be done accordingly to generate tones with more precise frequencies. Although, the produced frequencies in the simulation was very close to the expected frequencies, but in the practical device the produced frequencies were at a deviation from the expected frequencies. The expected frequencies should be achieved in near future by varying the value of capacitance. The tones were generated using square wave signal as the signals are generated from the timer IC. But it can further be developed with sinusoidal signals by using different circuitry. The duty cycle was taken 70% in this prototype which can be varied to get a sweeter sounding tone keeping the frequency fixed. As the device is at its initial level of development, there is a huge opportunity to improve the device and lessen the cost.

Acknowledgment

The Department of Electrical and Electronic Engineering at Bangladesh University of Engineering & Technology (BUET) is very appreciative for allowing the authors to utilize their lab. The Department of Biomedical Physics and Technology at the University of Dhaka's Lutfun Nahar, an MS student, is acknowledged by the authors for her cooperation.

References

Abrar, M., 2017. Design and Implementation of Astable Multivibrator using 555 Timer," IOSR Journal of Electrical and Electronics Engineering, vol. 12, Pp. 22-29, 01/01, doi: 10.9790/1676-1201022229.

Awny, A., Thiede, A., Borngräber, J., Elkhouly, M., and Scheytt, J. C., Speed/power performance of D-type flip-flops in a 0.13μm SiGe:C HBT technology demonstrated by a 86 GHz static frequency divider, in German Microwave Conference Digest of Papers, Pp. 15-17 March 2010 2010, Pp. 24-27.

Bohare, A., 2021. Study of Timer IC 555.

Chen, K., Yu, S., Wang, C. i., Li, W., Berg-Kirkpatrick, T., and Dubnov, S., 2022. "Tonet: Tone-Octave Network for Singing Melody Extraction from Polyphonic Music," in ICASSP 2022 - 2022 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 23-27 May 2022 2022, Pp. 621-625, doi: 10.1109/ICASSP43922.2022.9747304.

Chien, Y.-F. P., Lee, C., Huang, K., and Liang, H., 2020. Timing jitter reduction of passively Q-switched solid-state lasers by coupling resonance between pumping and firing rates, Optics Letters, vol. 45, 04/27 2020, doi: 10.1364/OL.394613.

Cross, I. A. N., 2001. "Music, Cognition, Culture, and Evolution," Annals of the New York Academy of Sciences, https://doi.org/10.1111/j.1749-6632.2001.tb05723.x vol. 930, no. 1, pp. 28-42, 2001/06/01, doi: https://doi.org/10.1111/j.1749-6632.2001.tb05723.x.

Farhan Khalid, T. A., Khalid, A., 2014. Framework for Automated Dobby Based Fabric Design System, International Journal of Scientific & Engineering Research, Journal vol. 5, no. 8, Pp. 7, 2014. (Online). Available: file:///F:/IAI/Framework-for-Automated-Dobby-Based-Fabric-Design-System.pdf.

Farhan, H., Shahadi, H., Ahmed, S., Mohsin, S., and Taherinia, A., 2020. A Wireless Warning System using a Programmable Intelligent Computer,IOP Conference Series Materials Science and Engineering, vol. 671, p. 012049, 01/17 2020, doi: 10.1088/1757-899X/671/1/012049.

Foster, A., Foster, M., Salem, R., Gaeta, A., and Lipson, M., 2010. Frequency conversion over two-thirds of an octave in silicon nanowaveguides, Optics express, vol. 18, Pp. 1904-8, 02/01 2010, doi: 10.1364/OE.18.001904.

Gribenski, F., 2020. Plenty of pitches," Nature Physics, vol. 16, no. 2, Pp. 232-232, 2020/02/01, doi: 10.1038/s41567-019-0707-1.

Hörschläger, F., Vogl, R., Böck, S., and Knees, P., 2015. Addressing Tempo Estimation Octave Errors in Electronic Music by Incorporating Style Information Extracted from Wikipedia.

Jinasena, T. M. K. K., and Meegama, G., 2011.Kasun Kosala, Ravinda Gayan Meegama, Design of a Low-cost Autonomous Mobile Robot, International Journal of Robotics and Automation (IJRA), March," International Journal of Robotics and Automation (IJRA), vol. 2, Pp. 1-13, 03/01 2011.

Kasri, N. F., and Piah, M. A. M., 2017. A compact and reliable pulse generator using dual 555-timer IC to produce PWM method, Pp. 100-104.

Kumar, R., Dahiya, S., Kumar, K., and Sonepat, B., 2013. Design and Implementation of Astable Multivibrator for Different Applications in Communication System, International Journal of Advances in Electrical and Electronics Engineering, vol. 2, Pp. 274-282, 07/31.

Kuyken, B., Ideguchi, T., Holzner, S., Yan M., Theodor, W., Hänsch., Campenhout, J. V., Verheyen, P., Stéphane F. L. C., Baets, R., Roelkens, Gunther., Picqué, N., et al.,2015. An octave spanning mid-infrared frequency comb generated in a silicon nanophotonic wire waveguide, Nature communications, vol. 6, Pp. 6310, 02/20 2015, doi: 10.1038/ncomms7310.

Lesko, D., Timmers, H., Xing, S., Kowligy, A., Lind, A. and Diddams, S., 2020. A six-octave optical frequency comb from a scalable few-cycle erbium fiber laser. 2020.

Matos, L., et al., 2003. "Direct frequency comb generation from an octave spanning prismless Ti:sapphire laser," in Conference on Lasers and Electro-Optics, 2003. CLEO '03., 6-6 June 2003 2003, Pp. 2

Music Box Attic, 2022. What Is A Traditional Movement? (2022). https://www.musicboxattic.com/what-is-a-traditonal-movement/. Music Box Attic.

Novembre, G., Varlet, M., Muawiyath, S., Stevens, C. J., and Keller, P. E., 2015. The E-music box: an empirical method for exploring the universal capacity for musical production and for social interaction through music, (in eng), R Soc Open Sci, vol. 2, no. 11,Pp. 150286, Nov 2015, doi: 10.1098/rsos.150286.

Schmidt-Jones, C., 2021.Pitch- Sharp, Flat, and Natural Notes, in Understanding Basic Music Theory (Schmidt-Jones): NICE CXone Expert.

Semiconductors, V., 2022. Application of Optical Reflex Sensors TCRT1000, TCRT5000, CNY70, vol. 2022, ed: https://www.vishay.com/.

Stork, M., 2016. Multiple outputs frequency synthesizer, in 5th Mediterranean Conference on Embedded Computing (MECO), 12-16 June 2016 2016, Pp. 238-241, doi: 10.1109/MECO.2016.7525750.

Suzuki, T., Kawano, Y., Nakasha, Y., Yamaura, S., et al., 2007. A 50-Gbit/s 450-mW Full-Rate 4:1 Multiplexer With Multiphase Clock Architecture in 0.13- $\mu{\hbox {m}}$ InP HEMT Technology," IEEE Journal of Solid-State Circuits, vol. 42, no. 3, Pp. 637-646, doi: 10.1109/JSSC.2006.891495.

T. S. S. O. M., 2022. Team "Introduction To The Pitch Range Of Musical Instruments." The Solan School of Music. https://sloanschoolofmusic.com/ (accessed October 24).

Watanabe, K., Koyama, A., Harada, T., M. Kuraishi et al.,2004. A low-jitter 16:1 MUX and a high-sensitivity 1:16 DEMUX with integrated 39.8 to 43GHz VCO for OC-768 communication systems," in 2004 IEEE International Solid-State Circuits Conference (IEEE Cat. No.04CH37519), 15-19 Feb. 2004, Pp. 166-520 Vol.1, doi: 10.1109/ISSCC.2004.1332646.

Will, U., 2011. "Two types of octave relationships in central Australian vocal music?," Musicology Australia, vol. 20, pp. 6-14, 11/24 , doi: 10.1080/08145857.1997.10415970.