Toy Piano

Introduction

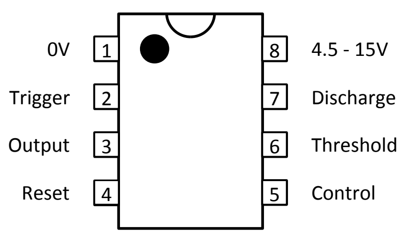
The main objective of this project is to try to replicate the sounds of a piano or electronic keyboard using as few components as possible. Additional features such as volume controls, individually tuneable notes, pitch control, vibrato, etc. could quite easily be added, but I wanted to keep it nice and simple! This document will take you through step by step how it works and the design stages used in the development of the final product.

555 Timer

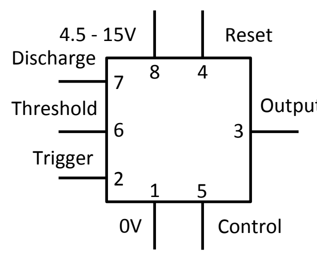
The circuit's main component is the wonderful 555 timer! So… before I delve into how the circuit works, perhaps I should give you a little bit of background on the 555 timer?

The 555 timer is a very versatile 8 pin DIL (Dual in Line) IC (Integrated Circuit). It is also available as a 556 and a 558 timer, which are dual and quad 555 timers respectively.

The 555 timer may be drawn to show its pin outs or as a circuit symbol:



Pin Out



Circuit Symbol

Notice the little notch in the top and the black dot? This shows where pin one is located. Also notice how the pin out is shown with pin 1 on the top left and numbered in an anticlockwise direction? This is how all DIL ICs are numbered. The different connections on the circuit symbol may appear in any order, without labels as long as they still have pin numbers.

It can be wired up in four different configurations, as an:

- Astable - no stable state, used to generate a square wave
- Monostable - one stable state, used for timing and generating a single pulse
- Bistable - two stable states, a form of memory that can be set and reset
- Buffer - an inverting buffer, sometimes referred to as a NOT gate or trigger

For this circuit we want to generate a signal that can be fed into a speaker, therefore an astable configuration will be suitable.

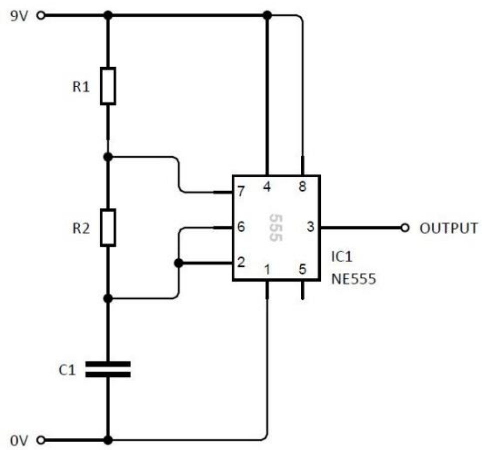
Astable Configuration

The astable configuration is essentially the 555 timer, a couple of resistors and a capacitor, how simple is that hey? By using different combinations of R_1, R_2 and C_1 we can change the properties of the output signal.

The properties of the output signal are:

- T - the time period, how long is the signal in seconds?
- T_m - the mark time, how long is the signal high for in seconds?
- T_s - the space time, how long is the signal low for in seconds?
- f - frequency of the signal, how many times does the signal repeat per second?
- Duty cycle - the proportion of time the signal is high, usually given as a percentage

Below I have included a copy of the circuit diagram, sometimes referred to as a schematic:



So now we have seen the basic setup of an astable, we will look at how we can calculate the different output signal properties...

Time Period:

$$T = 0.7 \times (R_1 + 2 \times R_2) \times C1$$

Where R_1 and R_2 are the values of the resistors in ohms (R) and C_1 is the value of the capacitor in farads (F). It is important to ensure that the correct base is used; otherwise your final calculation will be wrong. Remember:

CAPACITORS	$1\mu F$	$0.000{,}001F\ (\times 10^{-6})$
	$1nF$	$0.000{,}000{,}001F\ (\times 10^{-9})$
	$1pF$	$0.000{,}000{,}000{,}001F\ (\times 10^{-12})$
RESISTORS	$1K$	$1{,}000R\ (\times 10^{3})$
	$1M$	$1{,}000{,}000R\ (\times 1{-}^{6})$

Mark Time:

$$T_m = 0.7 \times (R_1 + R_2) \times C_1$$

Again where R_1 and R_2 are the values of the resistors in ohms (R) and C_1 is the value of the capacitor in farads (F).

Space Time:

$$T_s = 0.7 \times R_2 \times C_1$$

Again where R_2 is the value of the resistor in ohms (R) and C_1 is the value of the capacitor in farads (F).

Frequency:

Frequency is calculated as 1 divided by the time period, which gives this formula:

$$f = \frac{1}{0.7 \times (R_1 + 2 \times R_2) \times C_1}$$

Duty Cycle:

Ideally we want a duty cycle of 50% which means the signal is on for the same amount of time that it is off; however this isn't always possible in practice. The duty cycle is calculated by dividing the mark time (on time) by the total time (time period), which gives the following formula:

$$Duty\ Cycle = \frac{T_m}{T_m + T_s} = \frac{R_1 + R_2}{R_1 + 2 \times R_2}$$

For further information on the operation of the 555 timer and explanations of the other configurations, I would highly recommend visiting: www.electronicsclub.info/555timer.htm

Piano Circuit Design

So, now we have the basis of a circuit that will produce a signal. All we need to do now is connect a speaker to the output and vary a few values to give different notes. To keep things simple I decided that it would be easiest to vary the value of R_2. As the value of R_2 increases, the frequency of the output decreases and this will give a lower note. By connecting a stylus to pins 2 and 6 of the 555 and leaving one end of R_2 disconnected I can turn the output on and off. If I connect lots of resistors in series I will be able to touch the stylus at different points along the chain of resistors and this should give different notes!

We could just pick a random value of resistor… say 1K and keep adding 1K onto the total resistance of R_2, but this isn't going to give very accurate notes. To produce more accurate notes we need to do a little bit of Math. For this I chose to use Excel and was able to calculate the different resistor values needed for 25 different notes! That's two octaves! The table below shows the scientific note name (C4 is middle C), the real frequency, the resistor we will be using, the actual frequency we will get and the percentage deviation from the real frequency.

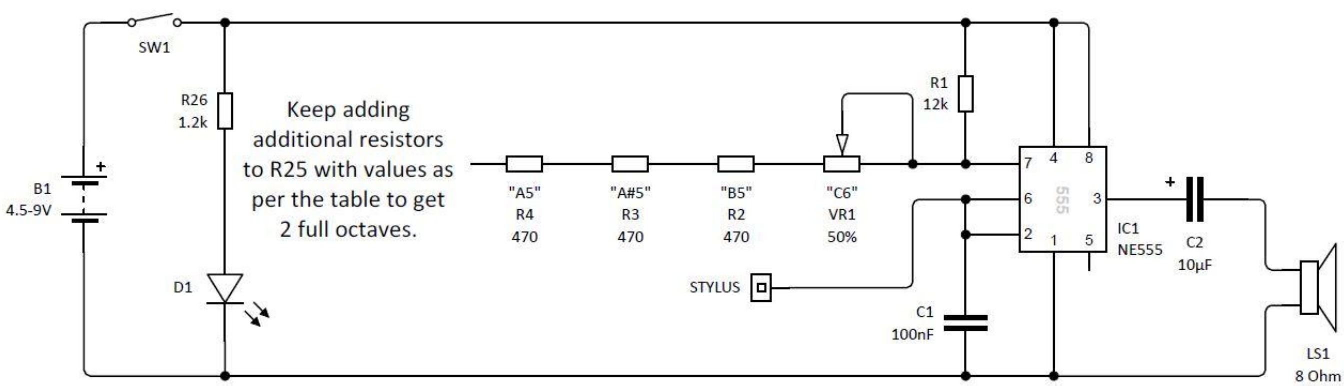
Note Name	Real Frequency (Hz)	R2 Value	Actual Frequency (Hz)	Percentage Deviation
C6	1046.500	928 - Use Pre-set	1046.500	0.000%
B5	987.767	470	980.014	0.785%
A#5/B♭5	932.328	470	921.471	1.165%
A5	880.000	470	869.528	1.190%
G#5/A♭5	830.609	470	823.129	0.901%
G5	783.991	560	773.923	1.284%
F#5/G♭5	739.989	560	730.269	1.314%
F5	698.456	560	691.276	1.028%
E5	659.255	560	656.236	0.458%
D#5/E♭5	622.254	680	618.186	0.654%
D5	587.330	680	584.307	0.515%
C#5/D♭5	554.365	680	553.949	0.075%
C5	523.251	820	521.288	0.375%

Note Name	Real Frequency (Hz)	R2 Value	Actual Frequency (Hz)	Percentage Deviation
B4	493.883	820	492.264	0.328%
A#4/B♭4	466.164	820	466.302	0.030%
A4	440.000	1000	438.123	0.427%
G#4/A♭4	415.305	1000	413.156	0.517%
G4	391.995	1000	390.881	0.284%
F#4/G♭4	369.994	1000	370.885	0.241%
F4	349.228	1200	349.434	0.059%
E4	329.628	1200	330.328	0.212%
D#4/E♭4	311.127	1200	313.204	0.668%
D4	293.665	1500	294.143	0.163%
C#4/D♭4	277.183	1500	277.269	0.031%
C4	261.626	1500	262.226	0.230%

As you can see, I have used a pre-set (variable) resistor for the first value, which means the piano can be tuned to make the first note an accurate frequency. On the whole, all bar a few values are accurate to within 1% of the actual notes. This isn't too much of a problem, because the resistors won't be exact values anyway and for such a small amount you won't be able to hear the difference.

Schematic

Now we have discussed the circuit design, let's have a look at the schematic:



A suitable power supply for the circuit is either 3 x AA batteries (4.5V) or a PP3 (9V) battery, depending on how loud you want the piano to be. I have found during testing that 4.5V is sufficient.

R_{26} and D_1 provide a power indicator. D_1 is an LED (Light Emitting Diode) as can be seen from the little arrows pointing away from the symbol. R_{26} protects the LED and stops too much current from flowing through it which might damage it. R_{26} may be adjusted depending on the specifications of the LED (here I'm using a low current LED, hence the relatively high resistor value).

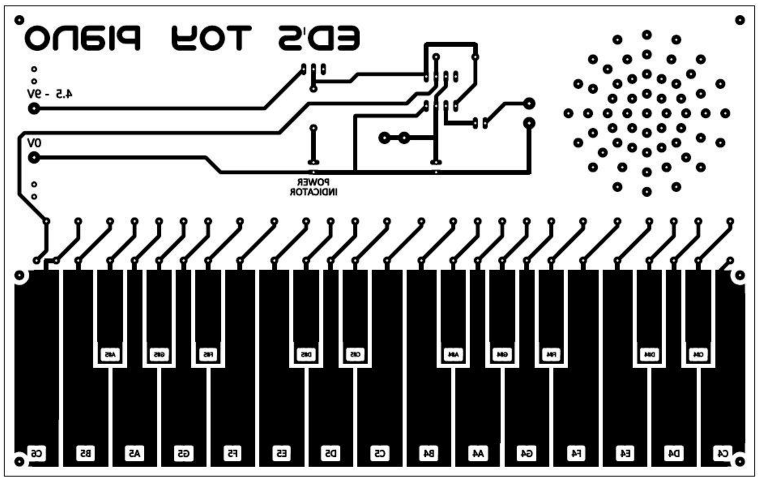
VR_1 and $R_2 - R_{25}$ are our R_2 in the calculations. As can be seen by touching the stylus at different points in the chain different total resistances for R_2 can be selected.

C_2 is used to protect the loudspeaker. It blocks the DC component of the output signal allowing the AC component to pass.

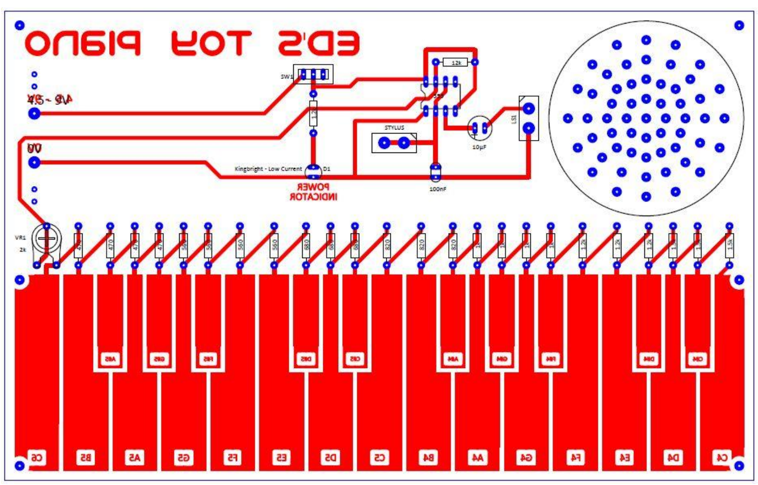
PCB Design

That's all of the boring theory bit out of the way, so now let's move on to the PCB (Printed Circuit Board) design. We could just connect the components together with pieces of wire but this would be messy and joins may break. To prevent this we need to fix the components to a substrate and then connect them together. For this we use a PCB, this is a material called either FR4 (glass reinforced epoxy laminate) or FR2 (SRBP - Synthetic Resin Bonded Paper). It is laminated with a copper layer which we use to join the components together.

Not only does the PCB need to be big enough to mount all of the components it also needs to provide a 'playing surface' to touch the stylus on.



This is the artwork for the PCB. All areas that are black will be copper on the PCB and it is used as a mask when etching the board. As can be seen, the power connections are marked along with the power indicator.



This is the normal view of the PCB. It shows the outlines and values for the different components and is used during the assembly process. The blue pads for the speaker are used as drilling guides to make a grille.

Notice how they are both the wrong way round? This is important because they are showing the board from the component side. Also when the toner mask is applied to the copper it will be the correct way up.

Don't worry about changes to the title etc. these can be done later on. I will also explain in full the process used for manufacturing a PCB in another hand-out.

ASSEMBLY

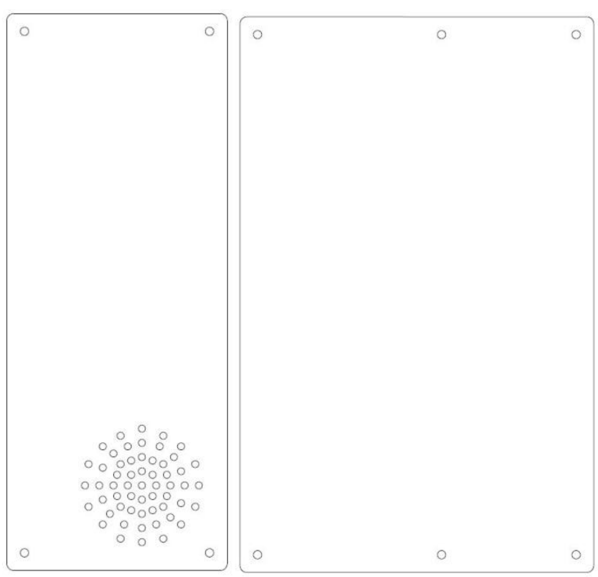
Just a few short notes on assembly:

1. Some components are polarized (have a positive and negative lead). If connected the wrong way, they won't work and more importantly they may **explode** or become **damaged**. The components that must be connected the correct way round are: the battery, the 555 timer, the power indicator LED and also C_2. The battery clip should have a red lead for positive and black for 0V. The IC holder for the 555 should have a notch in it that aligns with the notch on the diagram. The LED should have a longer positive lead; this connects to the top contact, coming from the resistor R_{26}. Finally C_2, again should have a longer positive lead and also a negative band clearly marked on the component (the + on the diagram indicates the positive lead). If you are unsure how to place any component in the board, **PLEASE** ask. I am more than willing to help and explain if you don't understand something.
2. I find it is easiest to solder the lowest profile components first and then work my way up to the biggest components. A sensible order might be… all of the resistors first, followed by the variable resistor and the capacitor. The DIL IC holder and the switch, the two connectors for the speaker and stylus and finally C_2.
3. You might have noticed that I missed out the LED from the list above. This is because I mounted the LED on the opposite side of the PCB, you might want to do this or you may want to solder wires to the board and mount the LED in a case?
4. To fix the battery clip, firstly feed the wire from the component side, through to the solder side, and then back through to the solder side. This gives the leads some strain relief and will stop the joint from breaking. The battery pack is simply stuck to the board using adhesive foam pads.
5. The speaker is glued to the back of the board over the previously drilled grille.

CASING

I will leave the casing design to you. I chose to cut two pieces of Perspex using a laser cutter and 'sandwich' the board between the two using six brass mounting pillars.

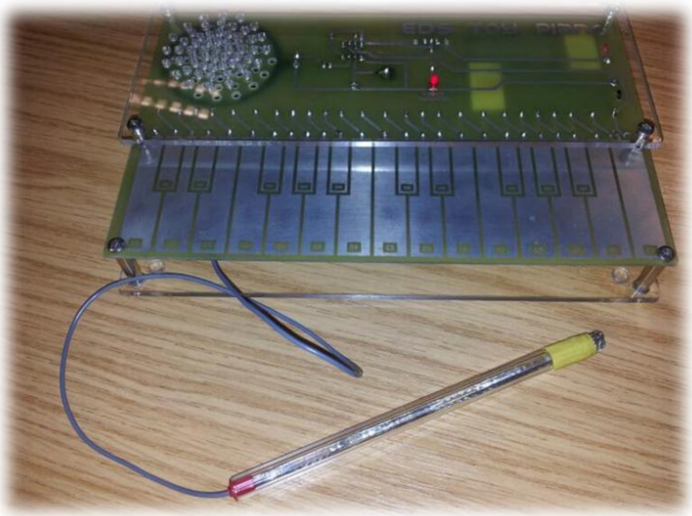
The files were drawn in a program called '2D Design Tools' and then exported as a DXF to the laser cutter program:



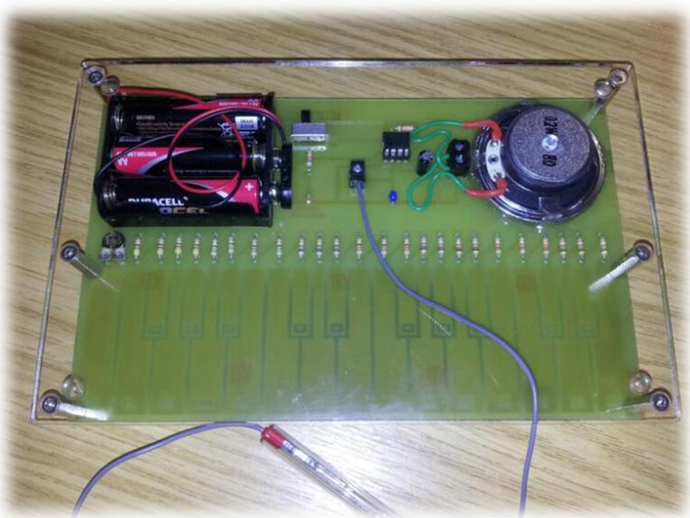
The two pieces shown are the top and the bottom. The top has a grille cut into it to match the grille on the PCB.

Final Product

To help in assembling your toy piano I have included a couple of pictures of the final product. A stylus was made using an old pen tube, a piece of wire and a short piece of heat-shrink. You can make one of these too if you like, or you can just use a piece of wire.



Toy piano as viewed from the top. Notice how the 'playing surface' is left exposed to allow you to play each note?



Toy piano as viewed from the bottom. Instead of cutting the battery leads short I decided to coil the wires up. Also notice the four little clear rubber feet? These stop the bottom getting scratched and they stop it from slipping on shiny surfaces.

Extension

Try holding the tip of the stylus in one hand and touching the notes with the other. What happens and can you explain why? Try this again using more than one person.

Can you think of any modifications that you could make to the circuit to make it operate differently?

Pricing

So finally, to finish, how much do you think it costs to build this little toy piano? I have included a parts list below with the order numbers from Rapid Electronics and also the price of all the parts.

Item Description	Rapid #	Quantity	Unit Price	Line Total	Line Total (Inc. VAT)
NE555 Bipolar Single Timer	82-0336	1	0.17800	£0.18	£0.22
8 Pin DIL Turned Pin Socket	22-1757	1	0.08950	£0.09	£0.11
Carbon Film 0.25W 470R Resistor	62-0362	4	0.00526	£0.02	£0.03
Carbon Film 0.25W 560R Resistor	62-0364	4	0.00526	£0.02	£0.03
Carbon Film 0.25W 680R Resistor	62-0366	3	0.00526	£0.02	£0.02
Carbon Film 0.25W 820R Resistor	62-0368	3	0.00526	£0.02	£0.02
Carbon Film 0.25W 1K Resistor	62-0370	4	0.00526	£0.02	£0.03
Carbon Film 0.25W 1K2 Resistor	62-0372	4	0.00526	£0.02	£0.03
Carbon Film 0.25W 1K5 Resistor	62-0374	3	0.00526	£0.02	£0.02
Carbon Film 0.25W 12K Resistor	62-0396	1	0.00526	£0.01	£0.01
Carbon Pre-set 0.1W 2K Resistor	67-0408	1	0.11100	£0.11	£0.14
Ceramic Capacitor 2.5mm 50V 100nF	08-1015	1	0.15800	£0.16	£0.20
Electrolytic Capacitor 10uF 25V	11-0220	1	0.04100	£0.04	£0.05
Kingbright Super Red 3mm Low Current LED	56-0415	1	0.14800	£0.15	£0.19
2 Way 16A Interlocking Terminal Block 5mm	21-1810	2	0.08400	£0.17	£0.21
50mm Ultraslim Loudspeaker 8R	35-0128	1	0.68300	£0.68	£0.85
Ultraminiature Right Angled Slide Switch	78-0691	1	0.25700	£0.26	£0.32
Procell AA Batteries 2700mAH	18-3350	3	0.26100	£0.78	£0.98
3x AA Battery Holder	18-0126	1	0.49800	£0.50	£0.62
Heavy Duty PP3 Battery Clip	18-0092	1	0.17600	£0.18	£0.22
Single Sided FR4 Copper Clad PCB (cm^2)	34-0365	260	0.00532	£1.38	£1.73
3mm Clear Acrylic Sheet (cm^2)	06-0600	420	0.00262	£1.10	£1.38
Pozi Pan Head M3 6mm	33-2300	6	0.00830	£0.05	£0.06
Pozi Countersunk Head M3 10mm	33-2952	6	0.01940	£0.12	£0.15
Hexagonal Male - Female Brass Spacer M3 5mm	33-3590	4	0.11640	£0.47	£0.58
Hexagonal Threaded Brass Spacer M3 20mm	33-3555	6	0.16160	£0.97	£1.21
Clear Feet 6mm Diameter X 1.9mm	31-0610	4	0.01964	£0.08	£0.10
			Totals:	£7.59	£9.49

The prices are in GBP (Great British Pounds). The line total is the cost of the items less tax and the column to the very right includes tax. At the current exchange rate this is about $15.

It is worth noting, that these prices are calculated per item and not all items may be bought individually. For example the resistors are sold in packs of 100. The cost of the sheet material is worked out per cm^2 however they are not sold in exact sizes.

If you were to go into production:

How much would you charge for this? Could the prices be reduced if bought in volume? Don't forget, you have additional costs such as those of the chemicals used to manufacture the PCB and initial costs for purchasing equipment. How many boards will a drill bit drill before needing to be re-sharpened or replaced? How long will the chemicals last for? Do they have a shelf life once mixed or opened?