“I CAN TEACH MUSIC”

Prototype Design

Patent Owner:

Arelis J. Galavis

Patent Number

US9006550B2

Assisted by:

Sergio Espinal

MEng. Electrical and Computer Engineer

(Carleton University)

Ottawa, ON Canada Final Document February, 2016

Briefing

The document describes the steps taken for fabricating the electronic circuit for the patent US9006550B2 "I CAN TEACH MUSIC". It provides the schematics, bill of materials, and describes the decisions made during the design and fabrication. The complete description of the patent can be found at **[1]**. All rights goes to the author of the patent.

Purpose of the device "I CAN TEACH MUSIC"

The prototype is described as a two-player electronic device, aimed for learning how to read musical notes and associate them with their corresponding audio keynotes.

It employs flashcards that contain piano keynote symbols, associated with Bass and Treble clefs. The prototype also plays the desired piano keynote sound.

The game flow is described as follows:

- The "teacher" picks a flashcard. The flashcard is placed inside a determined compartment, depending if the card belongs to the bass or treble clef. This will trigger a light for the clef compartment, and the start of a new game.
- The student must press the button of the keynote shown in the flashcard.
- After the corresponding keynote button has being pressed, a light will turn on associated to the keynote that has being selected by the student.
- The teacher will press the button for the "green light" if the keynote is the right one. Else the teacher will press the button for the "red light" if it is the wrong keynote.
- Then, the teacher will press the button corresponding to the "correct" keynote, and the audio of the keynote will be heard.
- The student must press either the green or red button from his side, depending if the answer was right or wrong.
- After this, the current game ends, and a new card can be inserted to start a new game.

Circuit Design

The “I CAN TEACH MUSIC” electronic circuit design is composed by the following elements:

- Microcontroller
- Memory unit
- Digital-to-Analog converters
- Audio Amplifier
- Power Supplies
- Infra-Red Sensors
- Analog-to-Digital converter

Microcontroller

The **PIC16F1719** microcontroller from Microchip was used for this project. It controls each LED and IR emitter present. It has an Analog-to-Digital converter peripheral which is used to sense a set of 8 unique buttons, one at a time, through one single pin. It includes an SPI peripheral, suitable for communication with SPI operating IC devices like the Flash memory and the DAC unit. It can operate with 3.3V and has maximum instruction frequency of 8 MHz.

Finally, it can be programmed with the **PICKit 3** from Microchip using Low-Voltage Programming at 3.3V.

For further details refer to **[2]**.

Memory

The model selected was the **SST25VF016B** from Microchip. It communicates via SPI, has 2MB or 16Mbits of flash memory, and can operate at 3.3V. It is a good option since the total amount of data space required for the audio is less than 1.5MB.

For further details refer to **[3]**.

Digital-to-Analog Converters

The **AD5662** from Analog Devices was selected. It can operate at 3.3V, it has a resolution of 16-bits, and clocks as high as 30 MHz, just enough for a good audio resolution. Even though this is a general purpose DAC, it can be adapted for audio purposes and have a good performance.

For further details refer to **[4]**.

Two R-2R ladder resistors, **4610X-R2R-103LF**, were used to sense 16 buttons, 8 buttons per ladder. The voltage output is fed into the pin of the microcontroller, configured as the ADC module input.

Audio Amplifier

For the audio amplifier, **TPA2005D1** from Texas Instruments was selected. It is a class-D audio amplifier with an efficiency of 79% or more for an 8-Ω speaker. It can operate at 3.3V, and requires 5 extra passive components.

For further details refer to **[5]**.

Power Supplies

The voltage regulator selected for the circuit was the **TL2575-3.3** from Texas Instruments. It is a step-down switching voltage regulator, delivering 3.3 V and 1 A of load current. It requires several components, like a Zener diode, electrolytic capacitors and an inductor.

For further details refer to **[6]**.

For the audio amplifier only, the **AAT1217CA-1.2-T1** from Skyworks Solutions was selected. It is a step-up voltage converter, with an adjustable voltage output between 2.5V to 5.5V. The voltage selected was 5V for the audio amplifier.

Infrared Sensors

Two IR LED emitters (**OP265FAA**) were paired with two IR phototransistors (**OP599A**). They were selected to work around a wavelength of 890nm. These sensors are used to sense the incoming flash card, which will trigger a new game. They are located outside of the Bass and Treble clef card slots.

Analog-to-Digital Converter

The ADC comes embedded in the **PIC16F1719** microcontroller. It has a resolution of 10 bits, and it can be configured to be available over several pins.

<u>Criteria for Component Selection</u>

The key points for component selection is described as follows:

- Small size
- Low cost-per-unit
- Through-hole package (if available)
- Voltage requirement
- Low current requirement
- Low power dissipation
- Simple to operate

In the case of IC's, following the previous criteria: it must contain as many required peripherals as possible, with enough memory space (Flash), being fast enough, and the least-extra active/passive component required by the IC (i.e. step-down converter).

<u>Software used for the Project</u>

- The **MPLAB-X** compiler was used for programming the microcontroller in Assembly language.
- For piano keynote recording, the **Wispow Free Piano 2** application for Windows.
- **Matlab** and **Audacity** for the audio processing and formatting.
- **Eagle CadSoft** was used for the schematic design.

Schematics

The following figures represent the schematics of the prototype. Note that each track is labeled, where tracks with the same label are part of the same node.

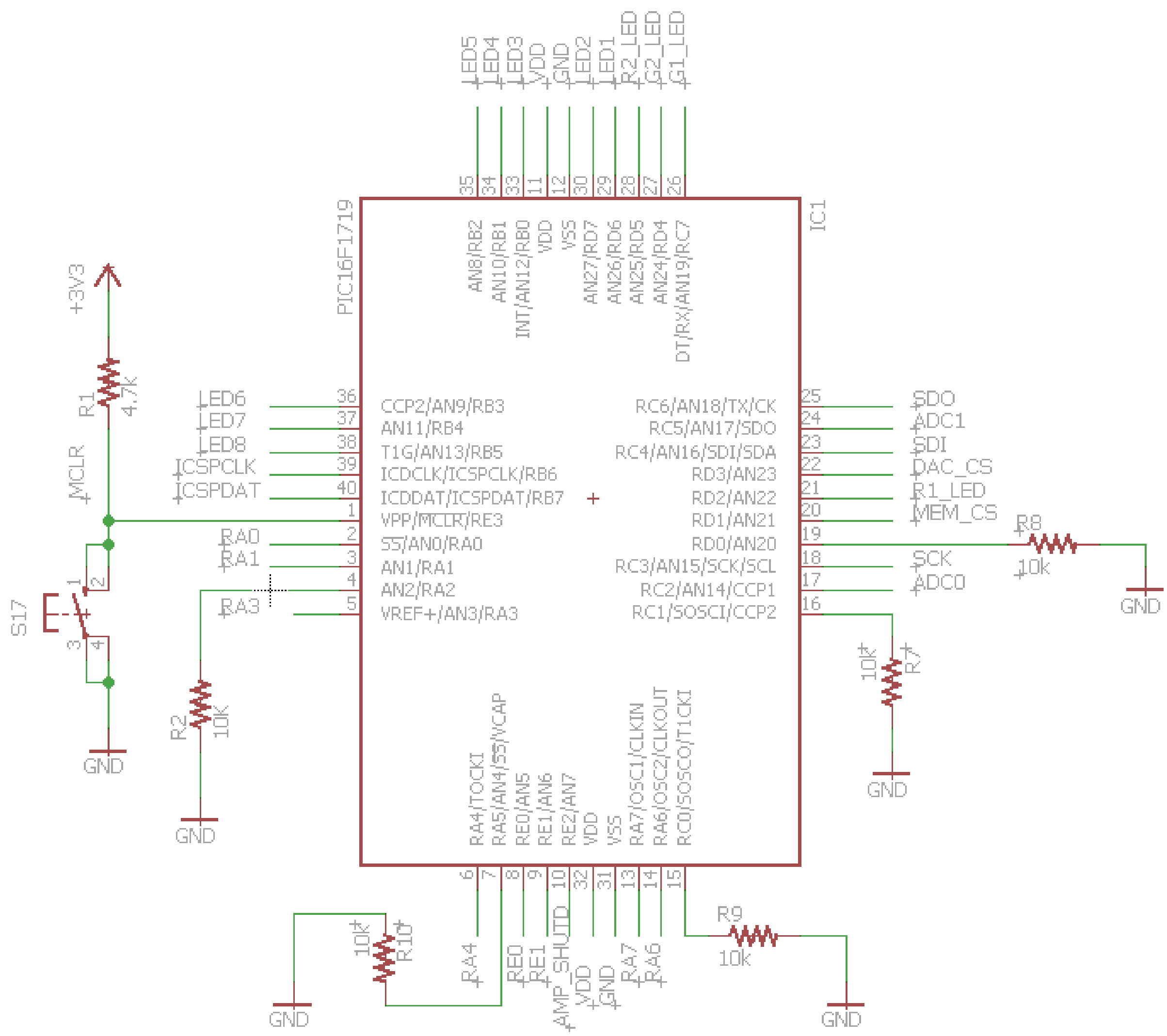


Figure 1. PIC16F1719 Microcontroller.

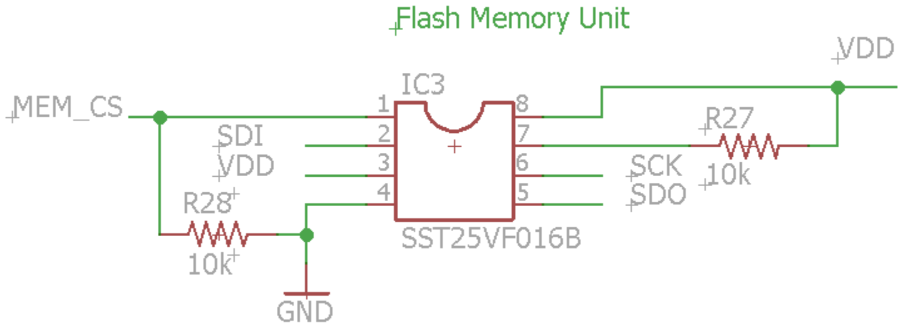


Figure 2. SST25VF016B Flash Memory unit.

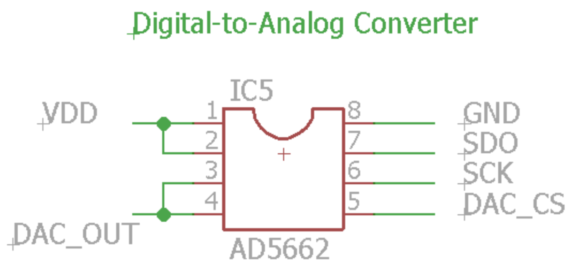


Figure 3. AD5662 Digital-to-Analog Converter. Note that SDO node is connected to the SDI pin of DAC.

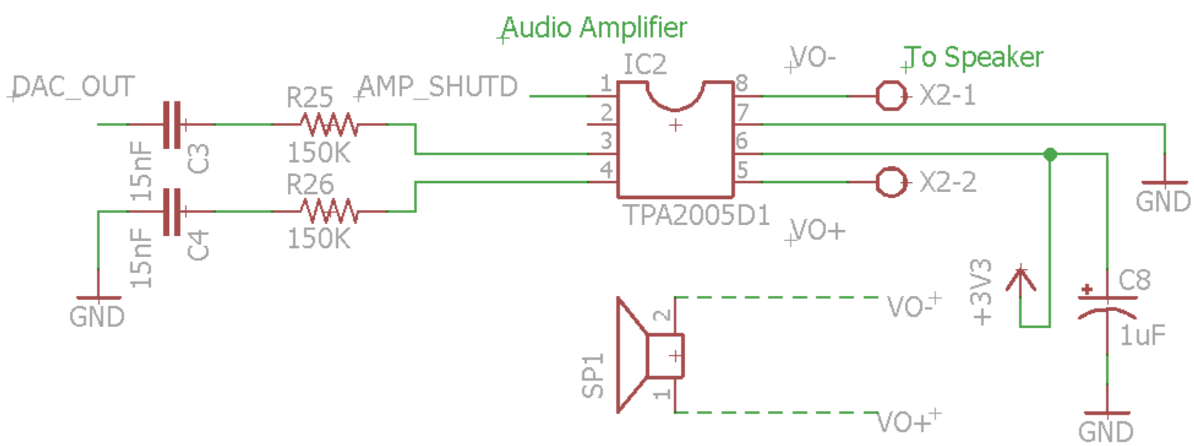


Figure 4. TPA2005D1 Audio amplifier. Note that the X2 component is a 2-position terminal block.

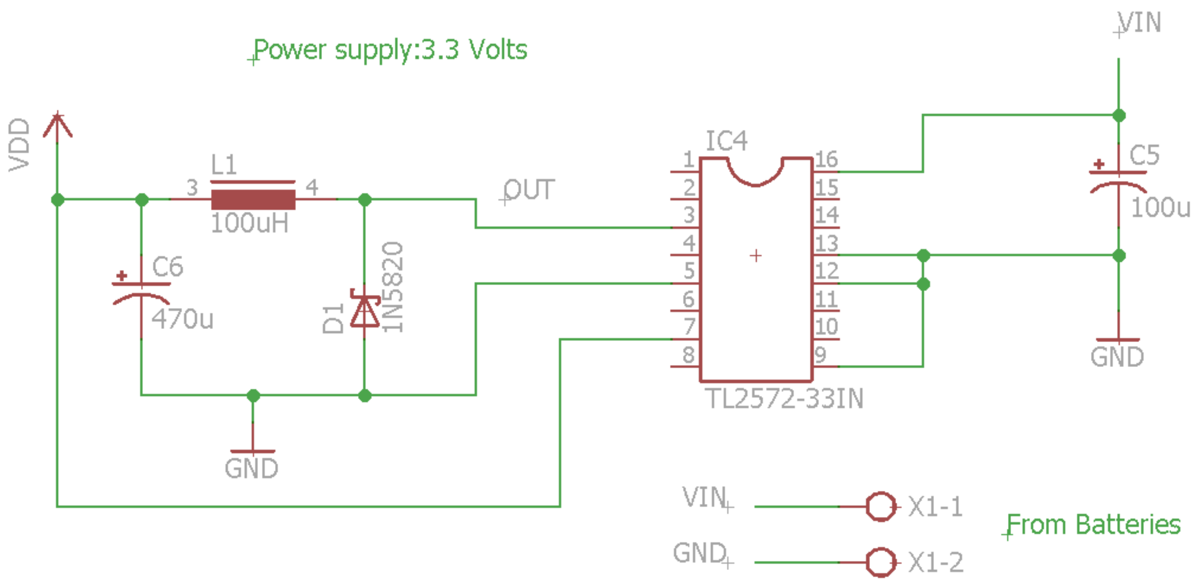


Figure 5. TL2572-33IN Power Supply.

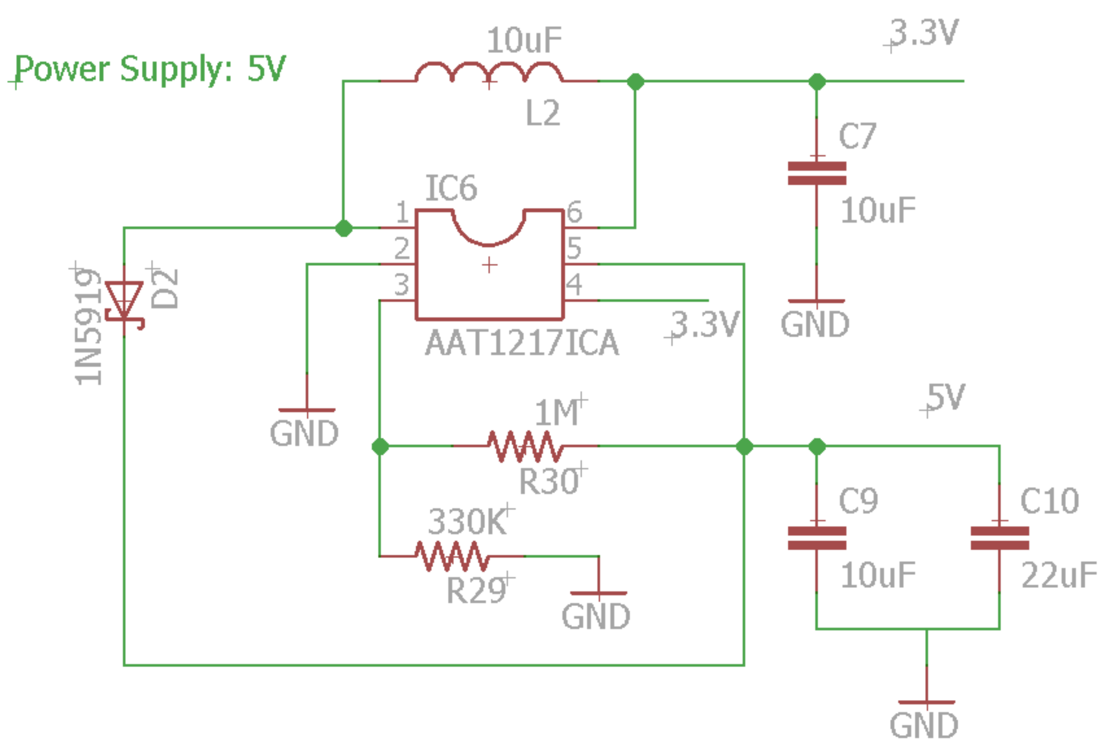


Figure 6. AAT1217ICA Power Supply.

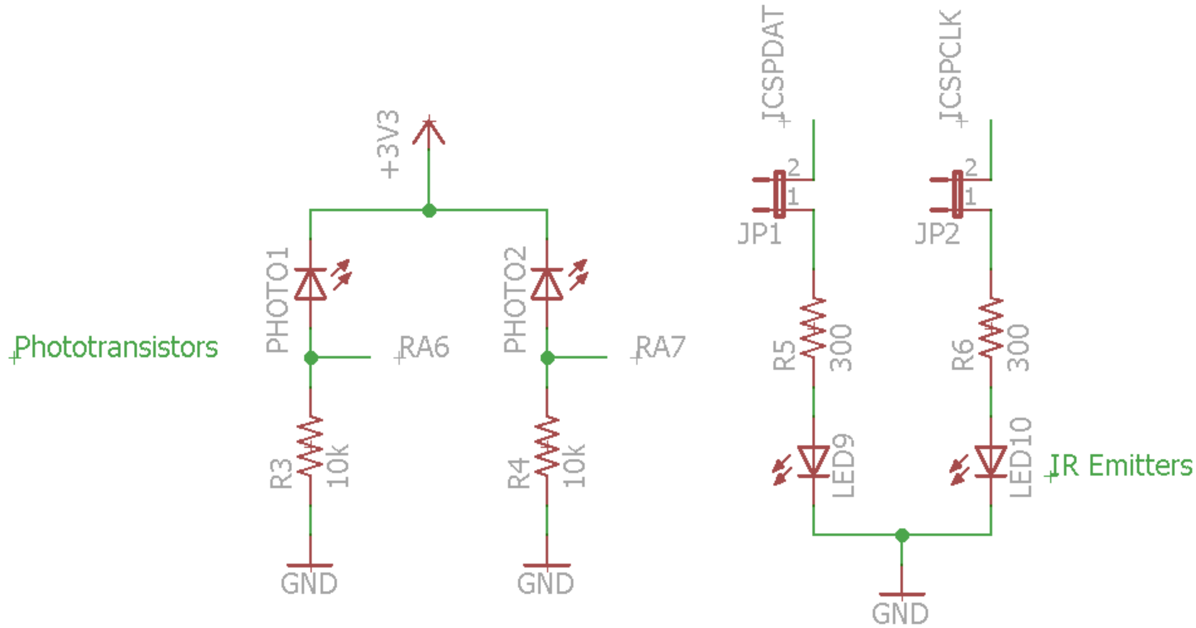


Figure 7. IR sensors: emitters and phototransistor.

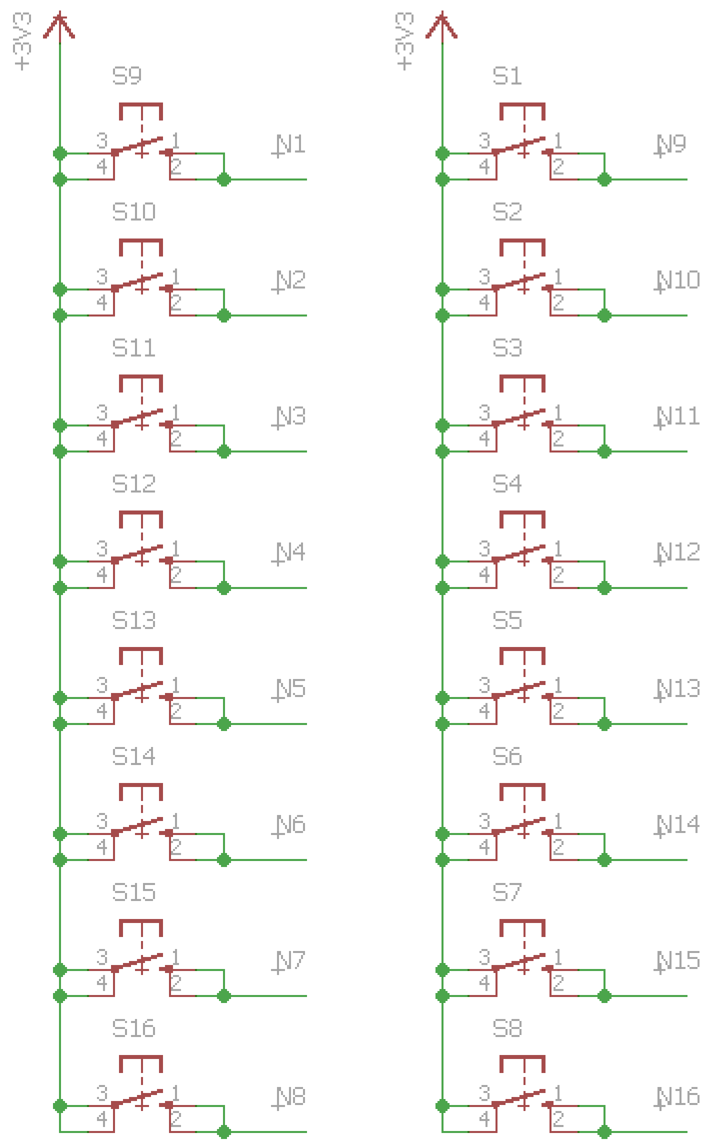


Figure 8. Keynote pushbuttons for ADC input.

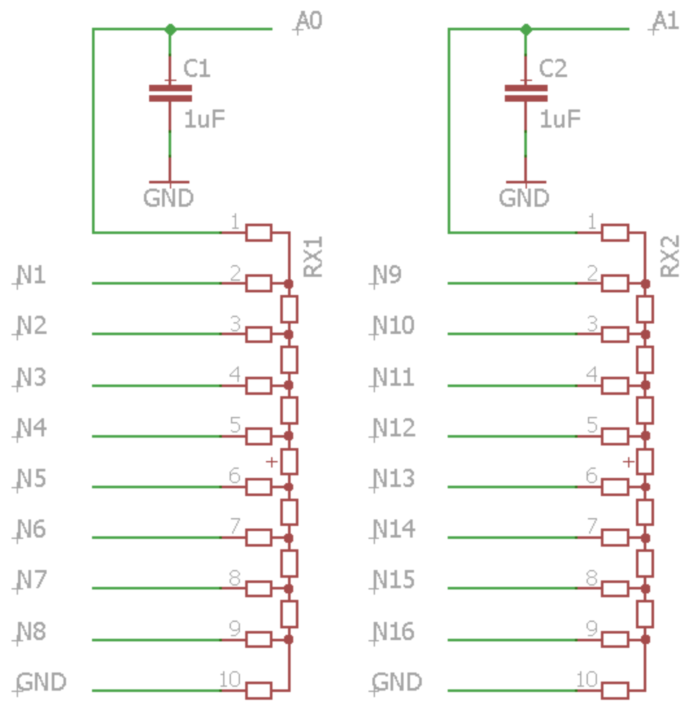


Figure 9. Resistor ladder (R-2R) for ADC input.

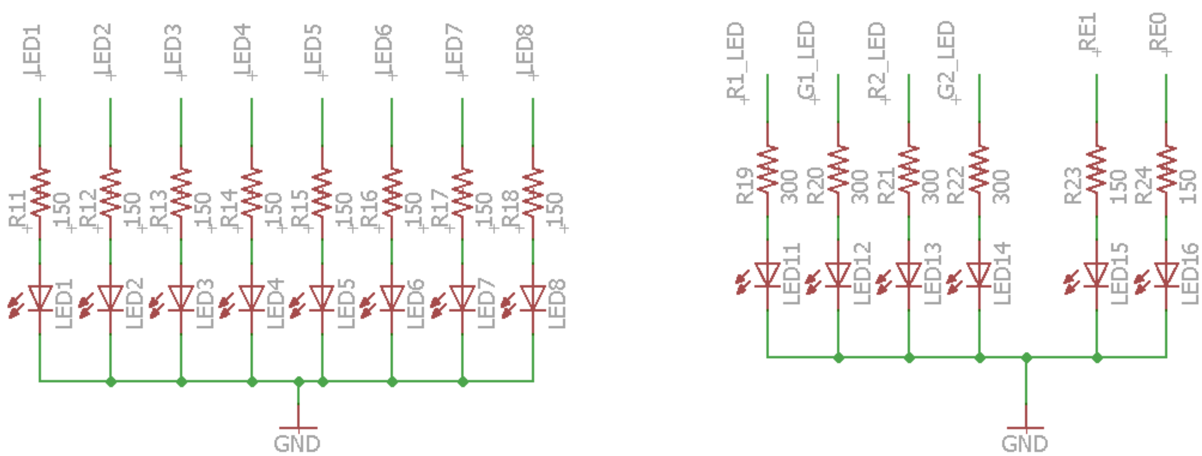


Figure 10. Keynote LEDs, Red and Green LEDs, Bass and Treble Clefs LEDs (RE1 and RE0, respectively).

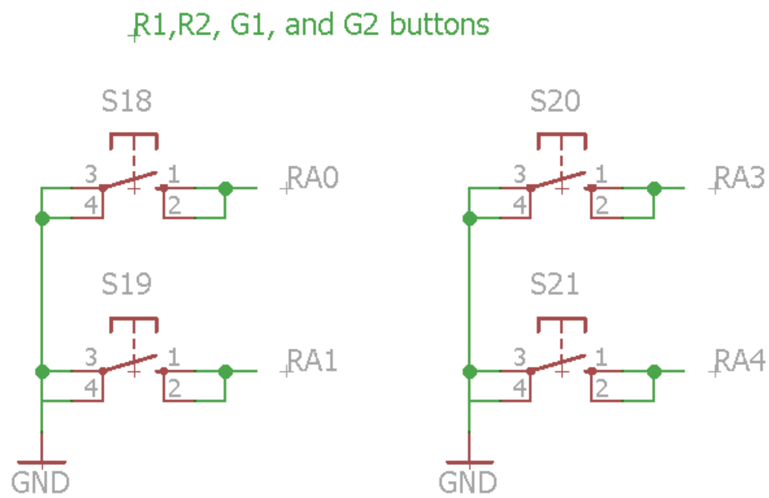


Figure 11. Pushbuttons for triggering Red and Green LEDs.

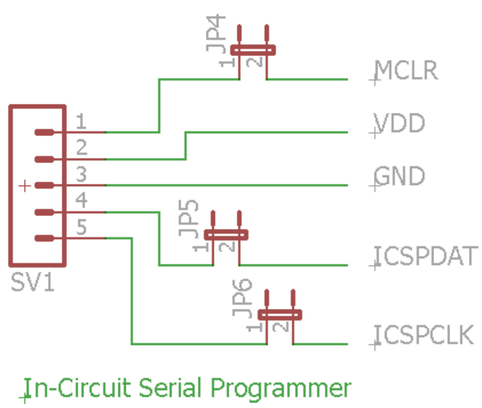


Figure 12. In-Circuit Serial Programmer pin setup.

Label	Name	Description
IC1	PIC16F1719-I/P	Microcontroller, 40-DIP
IC2	TPA2005D1DGNR	Audio amplifier, 1.4W @ 5V
R1-R4, R7-R10, R27-R28	CF14JT10K0	10KΩ resistor, 1/4 Watt
R25, R26	MFR-25FBF52-100K	100KΩ resistor, 1/4 Watt
(in series w/previous)	PR01000105102JR500	51KΩ resistor, 1/4 Watt
C1, C2	N/A	1uF Ceramic Capacitor
C8	FK28X7R1C105K	1µF capacitor X7R
C7, C9	FK26X7R1C106K	10µF capacitor X7R
C10	FK20X7R1A226M	22µF capacitor X7R
C3, C4	FK28X7R1H153K	0.015µF capacitor X7R
IC3	SST25VF016B-50	Flash Memory 16Mbit 50MHz, SOIC-8
IC4	TL2575-33IN	3.3 V, 1A step-down voltage regulator
IC6	AAT1217ICA	5V, 0.7A Step-up voltage regulator
D1	1N5820G	Schottky diode 3A
D2	1N5819	Schottky diode 1A
L1	12LRS104C	100µH inductor, shielded
L2	RLB0914-100KL	10µH inductor, shielded
C6	UHD1E471MPD6	470µF capacitor
C5	B41868W7107M	100µF capacitor
LED12, LED14	LTL2R3KGD-EM	Green LED, 2mA, 1.8V
LED11, LED13	LTL2R3KRD-EM	Red LED, 2mA, 1.8V
LED1-LED8	N/A	White LED
LED15, LED16	WP7113LVBC/D	Blue LED, 2mA 2.65V
R5, R6, R19-R22	CFR-25JB-52-300R	300Ω 1/4W carbon film
R11-R18, R23, R24	MFR-25FBF52-150R	150Ω 1/4W metal film
R29	CF14JT330K	330KΩ 1/4W carbon film
R30	CF14JT1M00	1MΩ 1/4W carbon film
LED9, LED10	OP265FAA	IR LED emitter, 1.8V
PHOTO1, PHOTO2	OP599A	IR Phototransistor
IC5	AD5662ARMZ	16bit DAC, 8-MSOP
S1-S16, S18-S21	B3F-4050	Push Button
S17	B3F-1000	Push Button
SV1	PRPC020SFAN-RC	Pin Header, male
X1, X2	N/A	2-position terminal block
SP1	CDS-25148	8Ω 1.5W speaker
RX1, RX2	4610X-R2R-103LF	R2R Ladder, 25k, 50k

Table 1. Components with their respective labels.

Primary Tasks of the Microcontroller

The microcontroller will perform the following tasks:

- Sense which button is being pressed by means of analog and digital signals (i.e. interrupts).
- Sense the signaling of the phototransistors by means of a logic transition as an interrupt, indicating a flashcard has being inserted (a new game has started).
- Control the White LEDs of the board, depending on the keynote buttons being pressed. The Blue LEDs indicate which clef is being triggered, and the Red and Green LEDs are used for the evaluation.
- Communicate with the Flash memory unit via SPI bus in order to fetch the audio data at the moment of playing the keynote.
- Send the audio data to the DAC via SPI bus.
- Turn ON and OFF the Audio Amplifier when required.

Design Considerations

Using Matlab for Audio data formatting

The audio data was recorded using “Wispow Free Piano 2” program as WAV file format. Then, each audio file was converted to **PCM 16-bit 16KHz mono unsigned** using Audacity software. Finally, the data is formatted with values ranging from 0 to 65535, and its Header chunk removed using Matlab. This is suitable for the DAC, at the audio output, to process.

The piano keynotes selected were the following:

Bass Clef	Treble Clef
C3	**C4 – Middle C**
D3	D4
E3	E4
F3	F4
G3	G4
A3	A4
B3	B4
C4 –Middle C	C5

Table 2. Selected Bass and Treble piano keynotes for the project.

Each audio data sample is composed by a Low-byte and a High-byte. Together they give a resolution of 16 bits.

The size of each audio data file (without header) was calculated, and this information was used to determine the memory space allocations.

A function was coded in Matlab such that it streamed each audio sample (two bytes each) through the Serial Port, byte-by-byte, into the microcontroller: first the Low-byte, then the High-byte.

The microcontroller firmware implemented a function that receives the data and immediately saves each byte in the flash memory module via SPI bus. This function was available only by flashing the microcontroller with the correct firmware, where this particular function was active and the rest of the functions were "commented".

A USB-to-Serial adapter was used for this task, the **Prolific PL2303**. It delivers 0 to 5VDC output (TTL), but it was regulated down to 3V using a potentiometer for the use of the microcontroller.

As a consequence, a pin (RA2) on the microcontroller was later designated for a dual function: as a voltage source for one of the IR emitters during normal operation, and as the Rx in the Serial Protocol transmission when receiving the audio data from the computer. Again, the function and the pin were configured depending on the firmware being programmed in the microcontroller.

The serial adapter was linked to the microcontroller through two wires, one for the TX and another for Ground, inserted in a 2x1 Female Header. This was an adaption in the late design stage.

Power source

The power source is delivered by **4 x AA batteries connected in series**, and fed into the step-down switching voltage regulator to deliver 3.3 V for the whole circuit. A **SPST switch** was connected in series, between the positive lead of the batteries and the input of the voltage regulator.

The only component that required a dedicated power supply of 5V is the TPA2005D1 audio amplifier, which translate into higher power output to the speaker when using a power source of 5V instead of 3.3V.

SMD to Through-hole adapters

Since the AD5662, TPA2005D1, and SST25VF016B are not in a through-hole package, SOIC-8 and MSOP-8 to DIP package adapters were necessary. The AAT1217 required a SOT23-6 to DIL adapter.

About the ADC module and pushbuttons

In order for the ADC peripheral in the microcontroller to sense the keynote buttons, a couple of resistors ladders were employed, one for each set of keynote buttons.

The output impedance of the resistor ladder (seen by the ADC) is of 100KΩ, and it was greater than the maximum impedance allowed by the ADC, for a maximum of 10KΩ.

In order to reduce the impedance seen by the ADC peripheral, and to reduce the Acquisition time, a capacitor was connected in parallel with the input pin based on the principle of charge sharing.

For reading the pushbuttons' voltage, a loop function was implemented. On each iteration, 16 samples were taken, and then averaged in order to deliver a consistent value. The cycle repeated until a known (hard-coded) value was found.

Irradiance of the LEDs

For the White and Blue LEDs, resistors of 150Ω were used. The voltage and current were supplied by individual pins of the microcontroller where they LEDs were connected to.

The irradiance of the Blue LEDs was too bright for the eyesight, and it was reduced thanks to a PWM signal supplied to them with a duty cycle less than 40%. For the White LEDs, this was not possible due to microcontroller internal design constraints.

For the IR emitters, the Red and Green LEDs, resistors of 300Ω were used. The irradiance delivered was satisfactory.

Battery case

Since the size of the screws were bigger than the holes on the battery case, the battery case had to be “trimmed” in order to fit the screws and attach it to the acrylic layer. This was improvised and not part of the intended design.

Using a Perfboard instead of making a PCB

There were no circuit tracks pre-designed for this prototype. The distribution of the components was performed “on-the-fly” and soldered using hook-up cable.

This was done in order to avoid using etching chemicals to make the copper tracks of the Printed Circuit Board, where the working station was not suited for dealing with chemical waste and fumes. Also, corrections and rework can be performed faster in a perforated board than on a PCB.

About the Firmware Code

The program was coded in C language initially, following a flow chart of how the prototype was supposed to work. But, it was found that the XC8 compiler from Microchip was generating inefficient machine code. And timing control was required.

So, the C code was adapted into a customized ASM code. This enabled to have control of every line and generate adequate delay functions.

The microcontroller ran using an integrated PLL as a clock source. The PLL was set to run at 32 MHz. That leaves 8 MHz of instruction frequency (Tcyc = Fosc/4), or 125ns per instruction cycle.

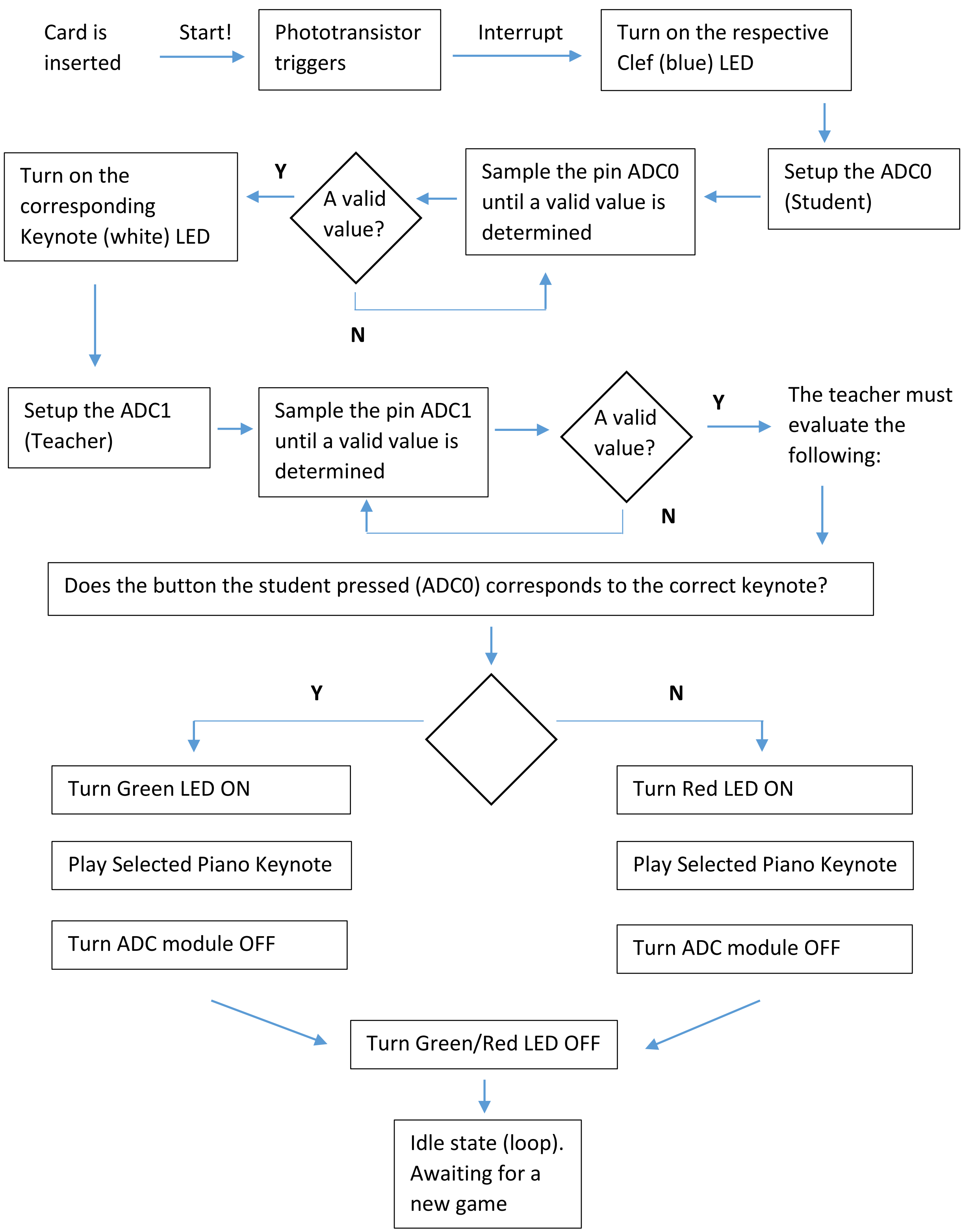
The audio sampling rate was of 16 KHz, or 62.5µs.

In order to generate the audio output, two functions had to be completed under 62.5µs:

- Fetch the two bytes of each sample from the flash memory module
- Send the two bytes per sample to the DAC module

At then end, both functions together took 57.5 µs, leaving about 5 µs headroom in instruction cycles.

Program Flow



A rough description of the functions inside the program is described as follows:

START

- Setup_All
- Super_Function

Super_Function

- Setup_ADC
- Read_ADC_Input
- Check_ADC_Result
- Play_Keynote
- LED_Shutdown

MyISR

- _TMR0_ISR
- _IOC_ISR
- _OSFIF_ISR
- _SSPIF_ISR
- _TMR2IF_ISR

Setup_All

- Setup_Oscillator
- Set_IO_Pins
- Set_Interrupts
- Setup_Timer0
- Setup_SPI
- PWM3_for_IR

Program_Flash

Other function and attributes include:

- Custom delay functions (in µs)
- Comparison of two values (1, 2 and 3 byte long)
- Calls to one instance functions instead of rewriting that same piece of code
- Use of variables as flags (i.e. mutual exclusion)
- Recycling of variables

START is the main function. **Setup_All** encapsulates different functions that configure the microcontroller peripherals, as well as the clock. **Super_Function** works as an "idle" function, but still allowing the program to be sensible to the interrupts.

MyISR handles all the interrupt calls (Interrupt-on-Change, Timer overflow, etc.) that were configured to be active during the initial setup.

There is another function called **Program_Flash**. This function receives the audio data being sent by the Matlab application through the Serial Port.

NOTE: Since the ASM code is close to 3K lines, it is excluded from this document, and present in a separate file "as is".

Bill of Materials

The following is a list of items that were bought through "Digi-Key **[7]**" electronic component supplier.

Name	Description	Quantity	cost p/u	Subtotal
PIC16F1719-I/P	Microcontroller, 40-DIP	1	3.7	3.7
TPA2005D1DGNR	Audio amp	1	1.76	1.76
1528-1071-ND	SMT ADAP 6 PK 8SOIC/MSOP/TSSOP	1	7.13	7.13
BOB-00717	SOT23-6 to 6DIL adapter	1	1.42	1.42
MFR-25FBF52-100K	100K resistor, 1/4 Watt	2	0.14	0.28
PR01000105102JR500	51K resistor, 1/4 Watt	2	0.53	1.06
CF14JT330K	330KΩ 1/4W carbon film	1	0.16	0.16
CF14JT1M00	1MΩ 1/4W carbon film	1	0.16	0.16
FK28X7R1C105K	1µF capacitor X7R	1	0.46	0.46
FK28X7R1H153K	0.015µF capacitor X7R	2	0.42	0.84
SST25VF016B-50	Flash Memory 16Mbit 50MHz, SOIC-8	1	2.56	2.56
TL2575-33IN	3.3 V , 1 A voltage regulator	1	2.95	2.95
1N5820G	Schottky diode 3A	1	0.65	0.65
12LRS104C	100µH inductor	1	1.02	1.02
UHD1E471MPD6	470µF capacitor	1	0.6	0.6
B41868W7107M	100µF capacitor	1	1.05	1.05
LTL2R3KGD-EM	Green LED, 2mA, 1.8V	2	0.43	0.86
LTL2R3KRD-EM	Red LED, 2mA, 1.8V	2	0.43	0.86
WP7113LVBC/D	Blue LED, 2mA 2.65V	2	0.81	1.62
CFR-25JB-52-300R	300Ω 1/4W carbon film	6	0.15	0.9
MFR-25FBF52-150R	150Ω 1/4W metal film	10	0.14	1.4
OP265FAA	IR LED emitter, 1.8V	2	1.24	2.48
OP599A	IR Phototransistor	2	0.88	1.76
AD5662ARMZ	16bit DAC, 8-MSOP	1	8.71	8.71
335-1149-ND	Screw Phillips M3	10	0.667	6.67
36-4708-ND	Hex nut, M3 steel	10	0.221	2.21
B3F-1000	Push Button	1	0.5	0.5
AE10784	Hex-standoffs M3 brass 18mm	16	0.68	10.88
S101031SS03Q	Switch SPST	1	2.81	2.81
4610X-R2R-103LF	R2R Ladder, 25k, 50k	2	1.41	2.82
V2009-ND	6.00" x 4.00" (152.4mm x 101.6mm)	2	16.59	33.18
AAT1217ICA	5V, 0.7A step-up voltage regulator	1	0.66	0.66
RLB0914-100KL	10µH inductor, shielded	1	1.4	1.4
CDS-25148	8Ω 1.5W speaker	1	7.03	7.03
FK26X7R1C106K	10µF capacitor X7R	2	0.67	1.34
FK20X7R1A226M	22µF capacitor X7R	1	0.94	0.94

Table 3. List of items bought through "Digi-Key" supplier.

The Subtotal in **Table 3** is: 114.83 CAD.

The following is a list of items that were bought through “Active Tech” **[8]**:

Name	Description	Quantity	cost p/u	Subtotal
150-340W	AA Batter Holder, 4 cells	1	1.6	1.6
801X100F	22AWG H/U wire, s/core BLUE, 100’	1	13.99	13.99
4880-18G	Sn63/Pb37, 22AWG 0.032” Solder	1	4.20	4.20
ST7	Conical tip, Weller WP Series	1	6.8	6.8

Table 4. List of items bought through “Active Tech” supplier.

The Subtotal in **Table 4** is: 26.59 CAD.

The following is a list of items that were bought through TNC Electronics S.A.S (Colombia)

Name	Description	Quantity	cost p/u	Subtotal
N/A	2-Pos terminal block	2	0.17	0.34
N/A	40-pos Header, male single row	1	0.21	0.21
N/A	40-pos Header, female single row	1	0.26	0.26
N/A	40-pin DIP socket	1	0.04	0.04
N/A	10K resistor, 1/4 Watt	10	0.00856	0.0856
N/A	10K resistor, 1/4 Watt	2	0.00856	0.01712
N/A	White LED	8	0.06	0.48
N/A	1 µF Ceramic Capacitor, Disc	2	0.04	0.08
N/A	10 nF Ceramic Capacitor, Disc	2	0.04	0.08
1N5819	Schottky diode 1A	1	0.12	0.12

Table 5. List of items bought through TNC Electronics S.A.S.

The Subtotal in **Table 5** is: 1.7127 CAD.

The following is a list of items that were bought through ATM Store S.A.S (Colombia):

Name	Description	Quantity	cost p/u	Subtotal
N/A	Push Button	20	0.22	4.4
N/A	Caps pushbutton	20	0.22	4.4

Table 6. List of items bought through ATM Store S.A.S.

The Subtotal costs in **Table 6** is: 8.8 CAD.

The total cost for the components, from **Table 3** to **Table 6**, is: **151.9327 CAD.**

Tools and equipment bought:

Name	Description	Quantity	cost p/u	Subtotal
SP40NKUS	Soldering Iron Weller 40W kit	1	37.11	37.11
EROP7SA	Tweezer, stainless steel	1	6.11	6.11
480-001P	Multimeter (V,F,Ω,Hz)	1	49.72	49.72

Table 7. List of items bought through “Digi-Key” supplier.

Name	Description	Quantity	cost p/u	Subtotal
N/A	Solder Extractor	1	2.86	2.86

Table 8. List of items bought through TNC Electronics S.A.S.

Total sum for the tools (**Table 7 and Table 8**) is: **95.8 CAD.**

Total sum of components and tools: **247.7327 CAD**

Final prototype

The following image shows the final design of the prototype.

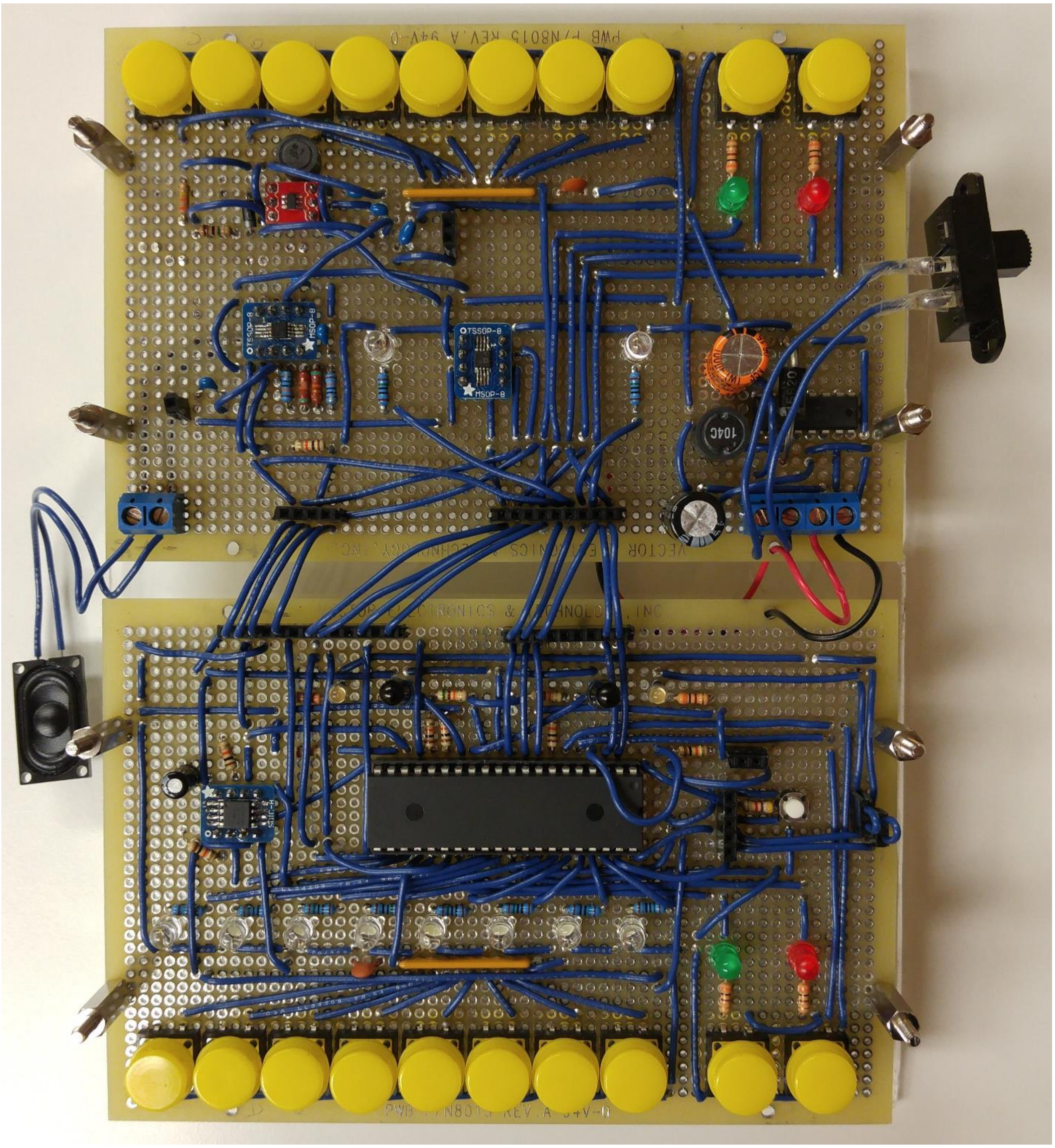


Figure 13. Top-side of the prototype without the acrylic layer

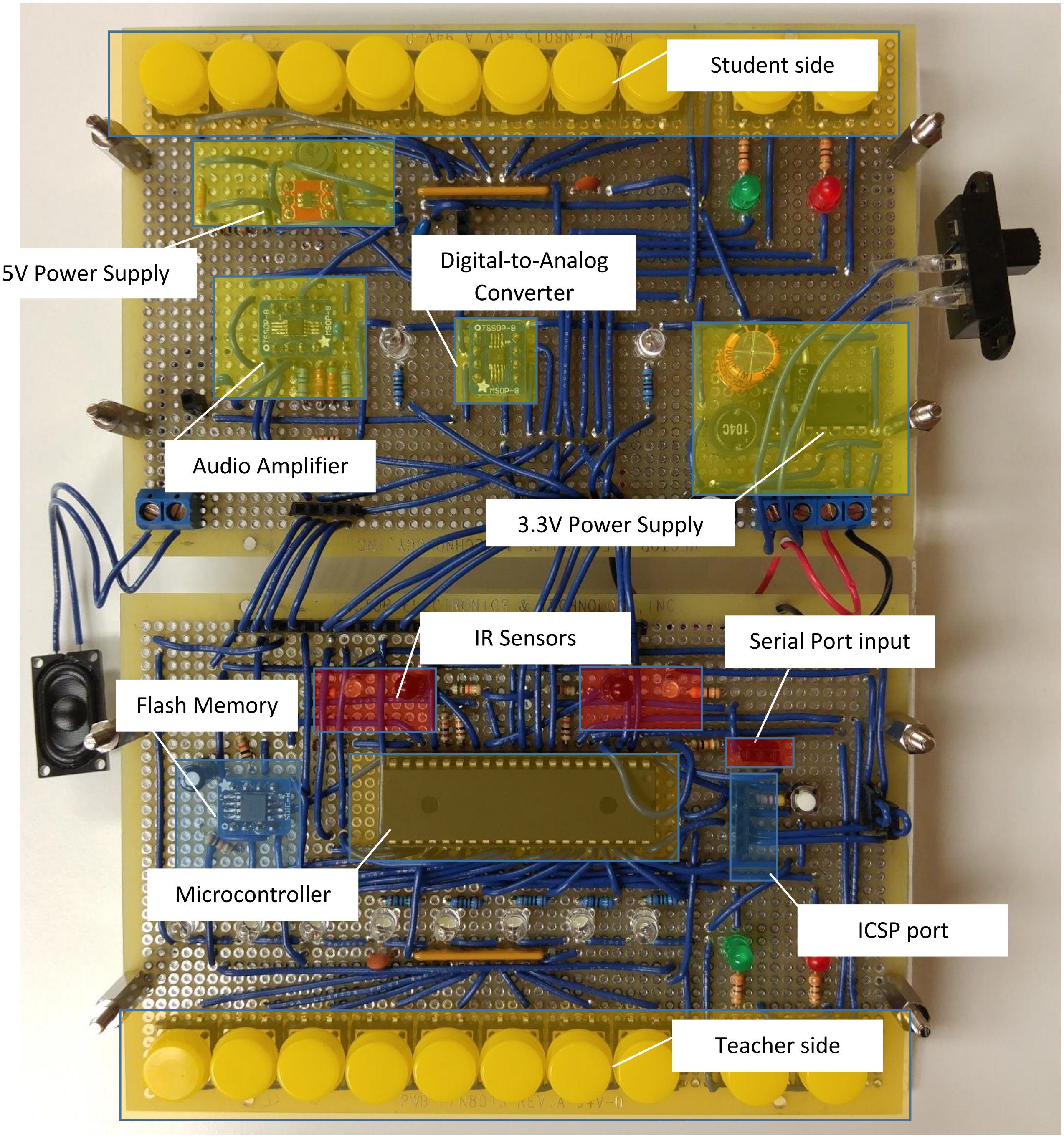


Figure 14. Sections of the prototype

The dimensions of the prototype is: 21.9 cm x 16.2 cm x 5 cm (L x W x H).

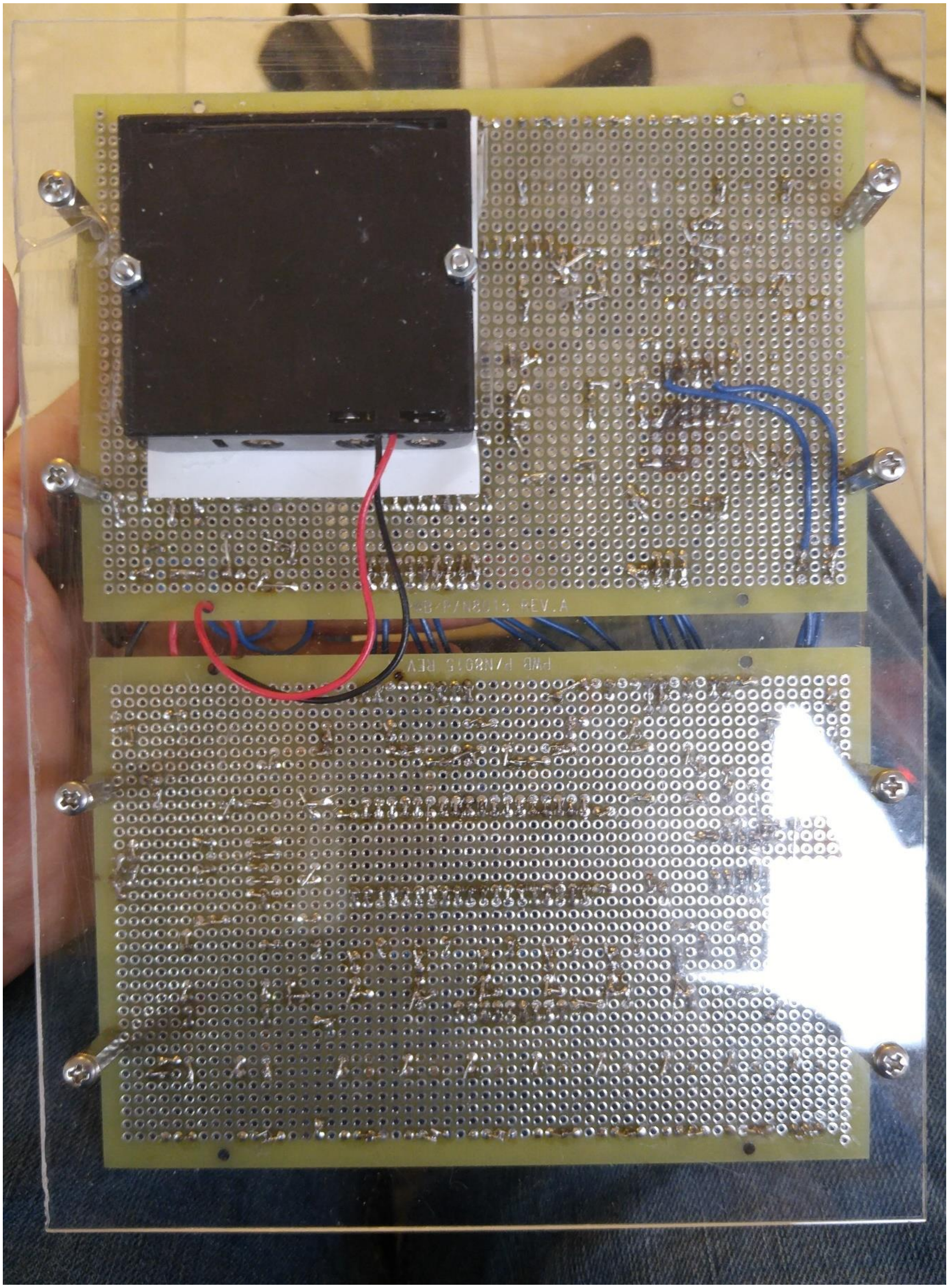


Figure 15. Bottom-side of the prototype

Observations and Conclusions

- The battery case that was available at the market had no lid. It would be adequate to buy a battery case with a cover lid.

- It was found that the irradiance was greater than estimated (too bright) for the Blue and White LEDs with a 150Ω resistor in series at 3.3V. A good value could have been between 400Ω to 5KΩ.

- Sometimes, when pressing a keynote pushbutton, the ADC may compute an (incorrect) analog voltage value and associate it to a different pushbutton. This may be due to the high resistance of the R-2R ladder available at that time, close to 100KΩ, affecting the Acquisition Time of the ADC for sampling. Also, it can be do the mechanical nature of the pushbuttons, generating variable voltage spikes when pressing or releasing it. Some possible solutions are: to use an R-2R ladder with an R value between 5KΩ and 10KΩ; to add a debouncing circuit for the pushbuttons; to change the sampling algorithm firmware.

- The cost of components was higher than expected for a single prototype unit. It can be reduced if an Integrated Circuit is found such that it has integrated most of the peripherals required for this prototype, reducing space and number of components. Also, a cheaper perforated board, or design a Printed Circuit Board which would require less wiring and space.

- The weight of the prototype can be reduced by: replacing the metal stand-offs with polymer material; use a rechargeable lithium ion polymer battery cell instead of 4 x AA batteries.

- For better results and better component selection, it would be required to design a full customized PCB.

- The IR sensors gets affected by sunny ambient and fluorescent lamp irradiance, rendering the sensors saturated, not being able to trigger the programmed function. It can be mitigated by modifying the resistors coupled with the phototransistors and applying an IR pass-filter to “box” the IR sensors.

References

[1] Patent: “I Can Teach Music”. Link: https://patents.google.com/patent/US9006550B2/en

[2] PIC16F1719, “Cost-Effective 8-Bit Intelligent Analog Flash Microcontrollers”. Microchip. Link: http://www.microchip.com/wwwproducts/Devices.aspx?product=PIC16F1719

[3] SST25VF016B, “16 Mbit SPI Serial Flash”. Microchip. Link: http://www.microchip.com/wwwproducts/Devices.aspx?product=SST25VF016B

[4] AD5662, “2.7-5.5V, 16-Bit nanoDAC® Converter in a Sot-23”. Analog Devices. Link: http://www.analog.com/en/products/digital-to-analog-converters/da-converters/ad5662.html

[5] TPA2005D1, “1.4-W Mono Class-D Audio Amplifier”. Texas Instruments. Link: http://www.ti.com/product/tpa2005d1

[6] TL2575-33, “1-A Simple Step-Down Switching Voltage Regulators”. Texas Instruments. Link: http://www.ti.com/product/tl2575-33/description

[7] AAT1217ICA, “Micropower Synchronous Step-Up Converter”. Skyworks Solutions. Link: http://www.skyworksinc.com/Product/1240/AAT1217

[8] “Digi-Key, World's Largest Selection of Electronic Components Available for Immediate Shipment!”. Link: http://www.digikey.ca/

[9] “Active Tech”. Link: http://www.active123.com/