Modular and Affordable Digital Accordion

ECE 445 Final Report - Spring 2025

Project # 13

Guangyang Sun, Henry Zhang, Zhuoer Zhang

Professor: Michael Oelze

TA: Jiankun Yang

Contents

Introduction

Problem

For a traditional accordion, there are some considerable problems. For instance, the sound quality is sensitive to the environment such as temperature and humidity, and there is a steep learning curve. In addition, the cost of a digital accordion is more than $7,000, which is not friendly to the beginners. With the presence of these problems, those lead to the need of an affordable,beginners-friendly, and modular digital accordion.

Solution

We intend to make a low-cost (less than $150), beginner-friendly, and modular digital accordion. This design replicates the sounds and functionalities of a traditional accordion using modern electronics while offering improved durability and ease of maintenance.

Visual Aid

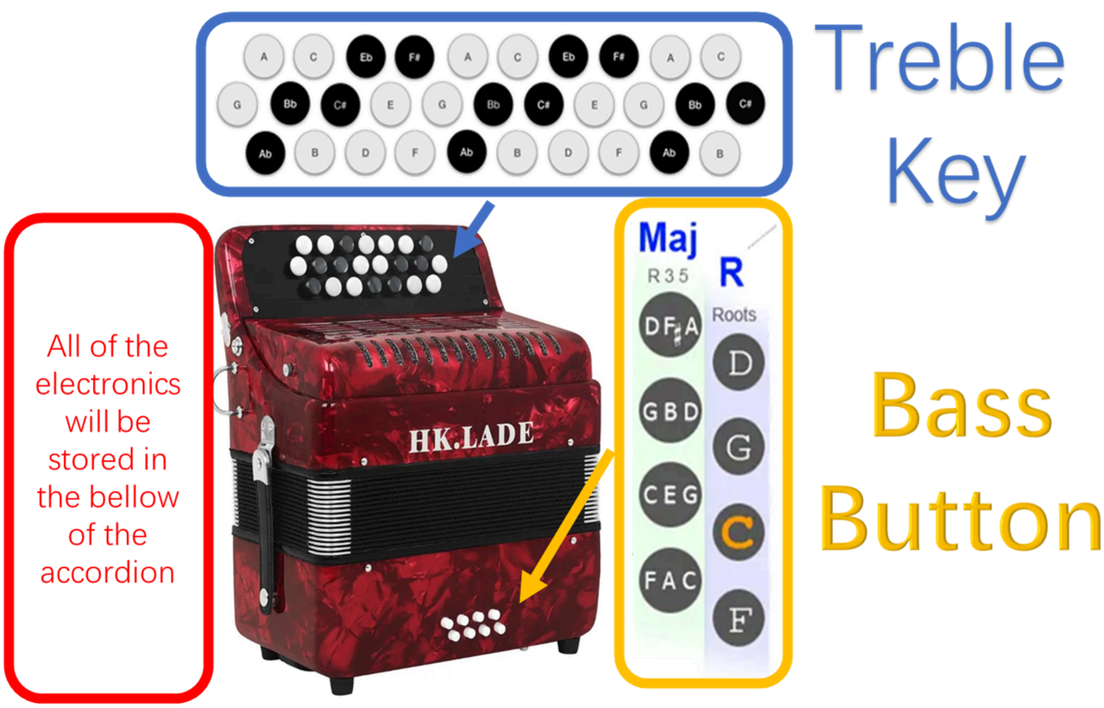


Figure 1. Visual Aid about Bayan Accordion’s Button Layout

Block Diagram

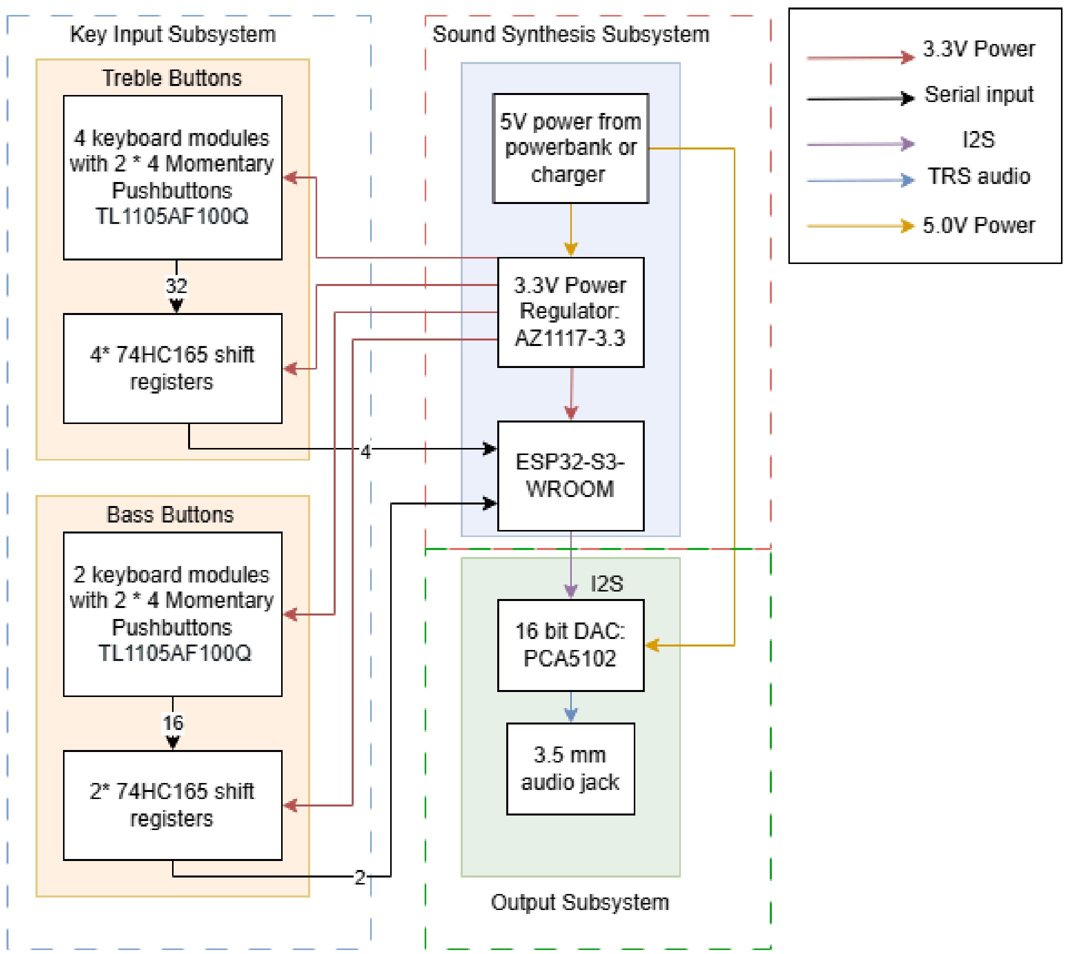


Figure 2. Block Diagram of the Design

There are three subsystems in our design: Key Input Subsystem, Sound Synthesis Subsystem, and Output subsystem. The input subsystem consists of low-latency buttons that allow user's input, and the parallel-in serial-out shift registers will send the input to esp32. The Sound Synthesis Subsystem is powered by 5V from the power supply and regulated to 3.3V for powering esp32. The esp32 will take the outputs from the Key Input Subsystem and synthesize the sounds by the functions programmed by the software. This will eventually be sent to the Output Subsystem using DAC and speaker, and therefore an accordion sound is delivered.

Design

Software

To ensure modularity, low latency, and high audio fidelity, we leverage the ESP32-S3's dual-core architecture and FreeRTOS task scheduling to execute keyboard scanning and sound rendering in parallel. Two FreeRTOS tasks are pinned to separate cores: one scans the keyboard and renders the first half of the audio buffer, while the other prepares the synthesizer, processes the second half, and transmits the complete buffer to a PCM DAC via I2S. This dual-core pipeline ensures that input processing does not interfere with audio output, enabling real-time performance with minimal jitter or latency.

The input subsystem is encapsulated in a class named ShiftRegisterInKeyboard, which interfaces with six parallel 74HC165 shift registers to scan 48 buttons. It manages serial communication by toggling the LOAD and CLOCK control pins and reading 8-bit data values serially from six data lines. During each update cycle, the software compares the current button states with the previous ones to detect rising and falling edges, which correspond to key press and release events. These events trigger corresponding callback functions. This polling-based design avoids interrupt-based timing issues and keeps the input process synchronized with the audio rendering thread.

When a key press is detected, the system maps the corresponding key index to a MIDI note or function using a lookup table. This array enables each physical key to produce a specific pitch, chord, or control command. Values below 100 are interpreted as single-note MIDI pitches, values between 200 and 210 correspond to predefined chords, and higher values are reserved for future functional extensions. For example, a key mapped to 200 triggers a C major triad by activating notes 60, 64, and 67 simultaneously. Note handling is managed by a Voice structure, which tracks the active state, MIDI note value, and the timestamp of last use. Upon receiving a note-on event, the system allocates an available voice slot—or replaces the oldest one if all are in use—to maintain smooth polyphonic playback.

The audio synthesis engine uses the AMY synthesizer library configured at a 96 kHz sample rate and 16-bit resolution, delivering audio through an I2S interface. This configuration ensures a signal-to-noise ratio sufficient for high-quality musical output.

Hardware

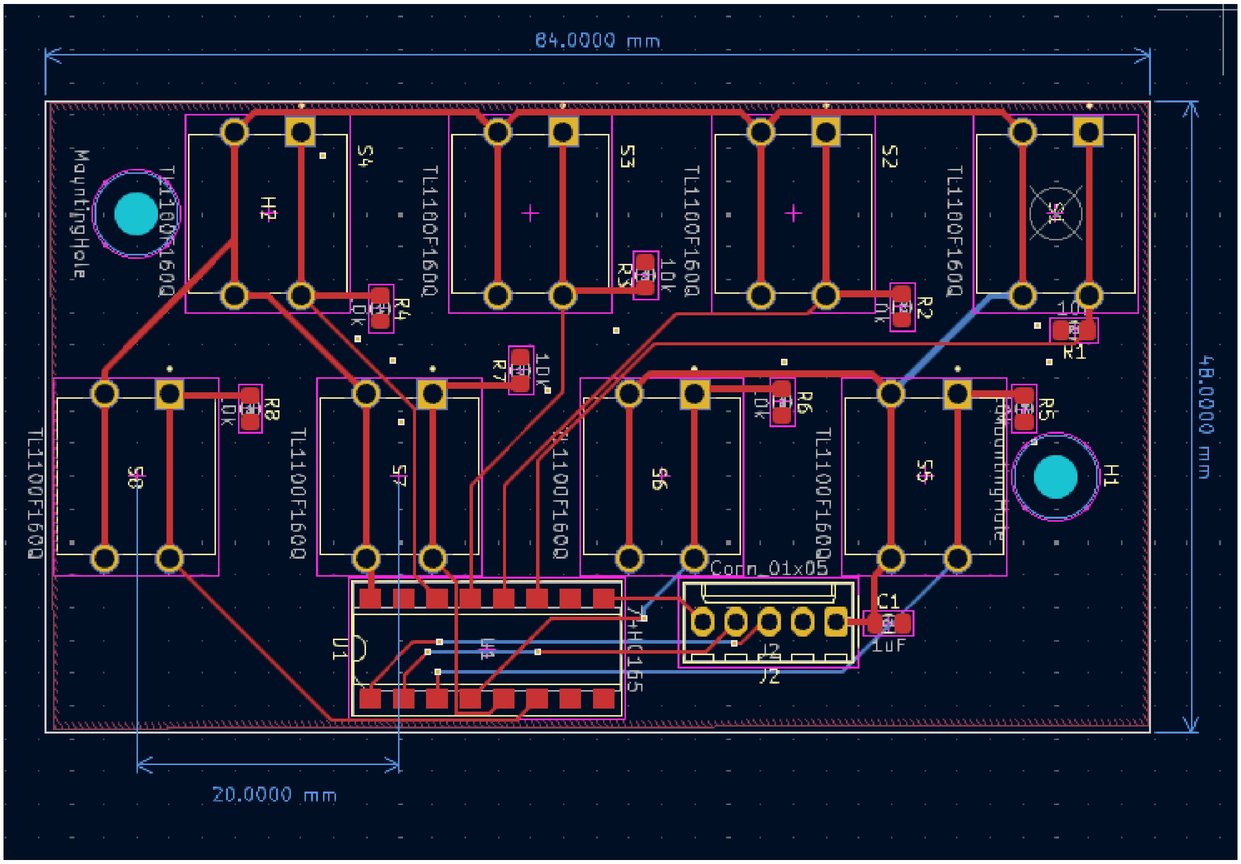


Figure 3: PCB Layout for the Keyboard

As shown in Figure 2, it is our keyboard design for the digital accordion. The buttons are offset horizontally so that adjacent rows do not line up. That wider “key pitch” makes it easier for players to reduce accidental presses.

We use TL1100F tactile switches because they are compact and inexpensive, ideal for a low-cost digital accordion for beginners. In addition, every button is in series with a 10 kΩ resistor, which limits inrush current if a key is shorted or wired incorrectly and forms an RC network with the decoupling capacitor that suppresses contact bounce. You might change to other switches for a smaller size or higher quality based on preferences.

A value of 10 kΩ balances static power draw with reliable logic-level switching. If lower electromagnetic interference or faster edge times are required, you could drop to 4.7 kΩ; for ultra-low standby current, you could rise to 47 kΩ based on the design preferences.

The 1 µF capacitor helps in 2 ways:

1. Power decoupling: supplies burst current when several keys close at once, preventing VDD droop.

2. Hardware debounce: f_c = 1/[2pi*R*C] =1/[2pi*(10 kΩ)(1 μF)] = 16 Hz, which attenuates millisecond-scale contact chatter without slowing the 1 kHz keyboard-scan routine.

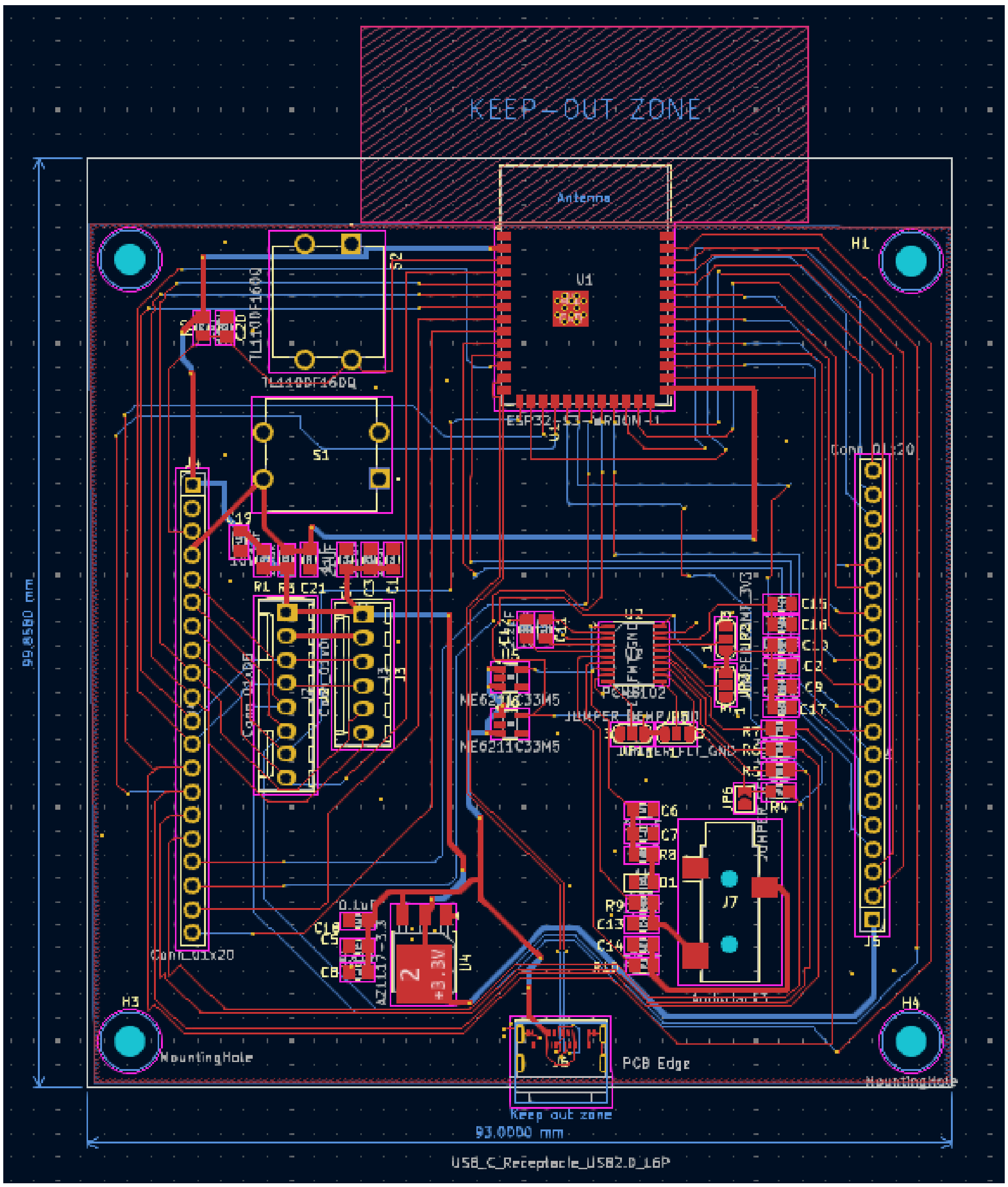


Figure 4: PCB Layout for the Control Board

As shown in Figure 3, the 93 mm × 93 mm motherboard consolidates every major function of the digital accordion onto a two-layer stack. The upper half carries an ESP32-S3-Mini-1 module, it processes the input signal and performs the process. USB-C delivers 5 V to a TPS563201 buck converter that generates the 3.3 V digital rail, while a low-noise MCP1700 LDO produces an isolated 3.3 V-analog rail for audio. Each rail is followed by a Pi-filter and local 10 µF + 0.1 µF Capacitor pairs to keep ripple below 5 mV pp (delta V_C = (Vin - Vout)/[8*Cout*f_sw^2]). I2S signals leave the MCU on the top layer, travel only 20 mm to a PCM5102A DAC, then exit as length-matched differential traces to a board-edge 3.5 mm jack.

All passives are 0603, and every IC sits in SOIC, TSSOP or QFN packages, so assembly remains low-cost and each block can be upgraded without respinning the board.

A MAX98357A class-D DAC-amplifier can replace the PCM5102A when an on-board speaker is desired; the 3.5 mm jack can be swapped for a JST header or panel-mount connector; the ESP32 module can give way to an RP2040-WiFi or ESP32-C6 to reduce cost; and the buck-plus-LDO power tree can be exchanged for a single ultra-low-IQ buck or a Li-ion boost-charger if portable operation becomes a priority. This modular hardware foundation therefore meets the present cost and performance goals while leaving clear paths for future enhancement.

Cost and Schedule

Schedule

Week of 2/10: Project approval
Week of 2/17: Project Proposal and order parts
Week of 2/24: Drawing schematics and CADs and order parts
Week of 3/3: Building breadboard and working on design document
Week of 3/10: Soldering PCBs
Week of 3/17: Spring Break
Week of 3/24: Continuing soldering PCBs
Week of 3/31: Debugging and checking requirements
Week of 4/7: Working on mechanical parts
Week of 4/14: Final debugging and get prepared for the mock demo
Week of 4/21: Mock demo and modifications for final demo
Week of 4/28: Final demo and prepare for final presentation
Weed of 5/5: Final presentation

Cost of Labors

Using a salary of about $40/hour, each of us work on this project for about 30 hours, so the cost of the labors for each of us therefore would be 40 x 30 x 2.5 = $3000

Cost of Components

Description	Manufacturer	Part Number	Quantity	Unit Cost ($)	Total Cost ($)
Switch Tactile SPST-NO 0.05A 12V	E-Switch	EG1821-ND	40	0.4388	17.55
IC 8-Bit Shift Register 16-DIP	Texas Instruments	296-8251-5-ND	5	1.1800	5.90
Capacitor Ceramic 10uF 25V X5R 0805	Samsung Electro-Mechanics	1276-2891-1-ND	11	0.0840	0.92
Resistor SMD 10 Ohm 1% 1/8W 0805	Vishay Dale	541-3976-1-ND	39	0.0410	1.60
USB 2.0 Type C 24P SMD RA	Amphenol CS	664-124019772112ACT-ND	1	1.9000	1.90
Capacitor Ceramic 0.1uF 10V X7R 0805	YAGEO	311-3556-1-ND	7	0.2000	1.40
Capacitor Ceramic 1uF 16V X7R 0805	KEMET	399-C0805C105K4RACTU-ND	3	0.1200	0.36
Capacitor Ceramic 2.2uF 10V X7R 0805	KEMET	399-C0805C225K8RACTUCT-ND	4	0.2000	0.80
Capacitor Ceramic 22uF 6.3V X5R 0805	KEMET	399-C0805C226M9PACTU-ND	1	0.1700	0.17
LED Orange Clear 25mcd	Kingbright	754-1860-1-ND	1	0.3300	0.33
Connector Header 20POS 2.54MM	Sullins Connector Solutions	S1011EC-20-ND	2	0.6000	1.20
Connector Header 6POS 2.54MM	Molex	WM2748-ND	1	1.1300	1.13
Connector Header 8POS 2.54MM	Molex	WM50016-08-ND	6	0.3000	1.80
Connector Jack Stereo 3.5MM SMD	Same Sky	CP1-3523N-ND	1	0.980	0.98
Resistor SMD 100K Ohm 1% 1/8W 0805	Vishay Dale	541-3978-1-ND	2	0.1000	0.20
Resistor SMD 22 Ohm 1% 1/8W 0805	Vishay Dale	541-4151-1-ND	4	0.1000	0.40
Resistor SMD 470 Ohm 1% 1/8W 0805	Vishay Dale	541-4147-1-ND	2	0.1000	0.20
IC DAC 16/24/32BIT 384K 20TSSOP	Texas Instruments	296-36707-1-ND	1	4.4300	4.43
RF TXRX MOD Bluetooth U.FL SMD	Espressif Systems	1965-ESP32-S3-WROOM-1U-N4CT-ND	1	5.0600	5.06
IC REG Linear 3.3V 800MA SOFT223	STMicroelectronics	497-3504-1-ND	1	0.3400	0.34
IC REG Linear 3.3V 150MA SOT23-5	STMicroelectronics	497-3504-1-ND	2	0.7500	1.50

Table 1. Bill of Materials

Requirements & Verification

High Level Requirements

To ensure high-fidelity audio output, the system was required to achieve a signal-to-noise ratio (SNR) of at least 40 dB. This was verified using Audacity, where a synthesized note was compared against background noise in a quiet environment. The RMS difference between the foreground (−13.33 dB) and background (−61.86 dB) measured 48.53 dB, confirming compliance with the requirement.

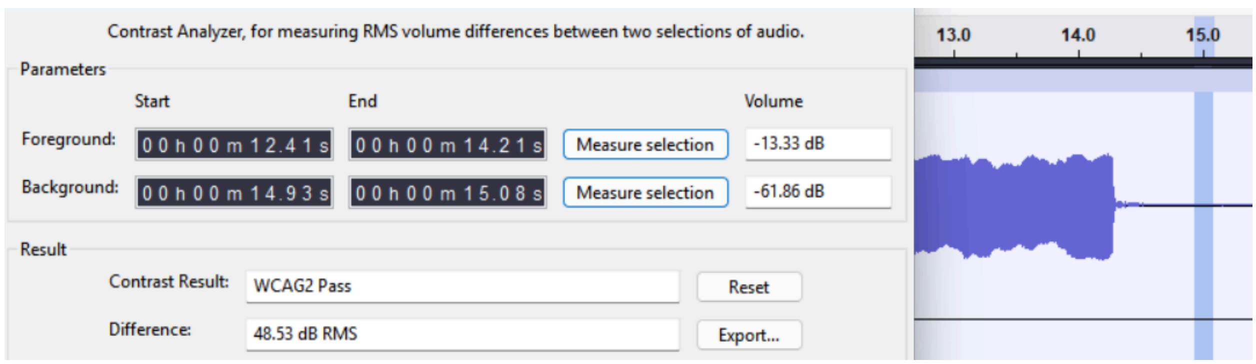
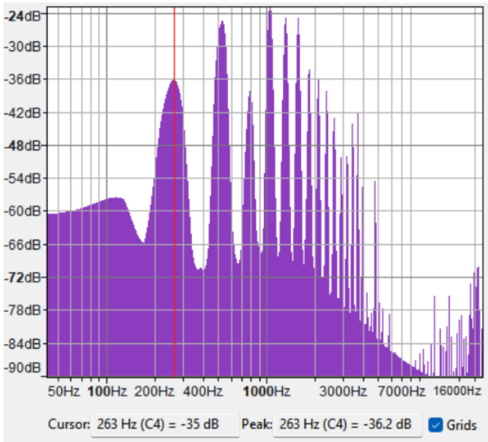


Figure 5. SNR Measurement

Another requirement was that the synthesized sound faithfully replicate the spectral characteristics of a traditional accordion, including the fundamental frequency and its harmonic overtones. Using Audacity's frequency analysis tool, we captured and plotted the frequency response of our synthesized tones and compared them with reference plots from recordings of an acoustic accordion. The harmonic structure, spacing, and roll-off pattern were comparable, confirming that the output closely matches the expected timbre of the instrument.



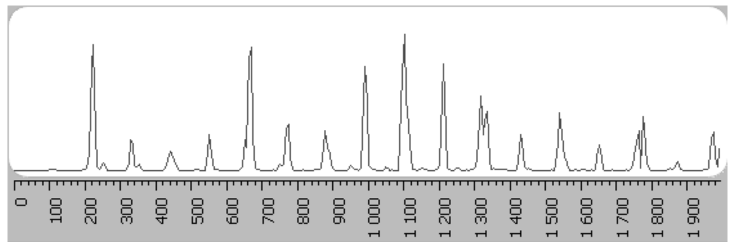


Figure 6 & 7 Frequency Response from Our Digital Accordion and Traditional Accordion

Lastly, the system was required to support polyphonic playback, with at least three notes playing simultaneously without audio dropout or timing issues. This was demonstrated in our final demo, where the synthesizer successfully handled up to 16 concurrent voices with no noticeable artifacts or latency, validating the polyphony requirement far beyond the minimum threshold.

Subsystems

To ensure responsiveness, sound quality, and robustness, we defined quantitative requirements for each subsystem and verified them through a combination of measurement, calculation, and observation.

In the key input subsystem, the debounce time for button presses was required to be less than 7 milliseconds to guarantee a responsive and stable playing experience. Using Scopy, we measured the voltage transition timing and observed that the signal stabilized within approximately 0.395 milliseconds—well within the acceptable range.

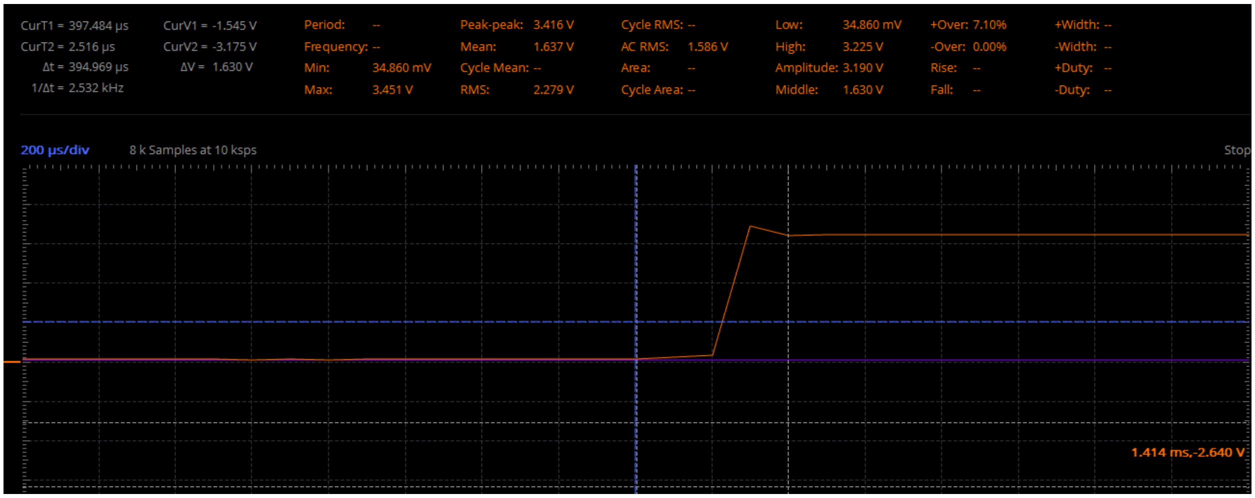


Figure 8: Debounce Time Measurement

In addition to debounce, total readout latency for all 48 keys needed to be below 10 milliseconds to support real-time musical performance. This latency includes the serial data acquisition across all six shift registers, along with associated control delays.

$$t_{readout} = 8 \times (t_{bit} \times 4 + t_{load} \times 2 + t_{delay} \times 2) = 8 \times (6 \times 4 + 3 \times 2 + 1 \times 2) = 256\ \mu s = 0.256\ ms$$

To ensure signal stabilization and avoid noisy transitions, we conservatively set the system's actual readout cycle to 0.8 milliseconds, which still meets the real-time requirement comfortably.

In the sound synthesis subsystem, two primary criteria were established: digital audio resolution and I2S communication speed. High audio fidelity demanded a DAC output of at least 16-bit resolution. Our design meets this with the PCM5102A DAC, which outputs at 16 bits. To ensure that audio data is transmitted without loss, the I2S interface was required to operate above 1 MHz. Given our configuration of a 96 kHz sample rate and 16-bit mono output, the resulting I2S clock rate is approximately 1.54 MHz—satisfying the bandwidth requirement.

For the audio output subsystem, the system needed to produce a sound pressure level (SPL) of at least 85 dB at a distance of one meter, approximating the loudness of a traditional acoustic accordion. Using Audacity, we obtained an output SPL of 89 dB at full volume. The speaker also had to support at least 3 watts of output power to ensure clarity and dynamic range. Our final system uses an external 15-watt speaker, which not only satisfies this specification but also provides ample headroom for future enhancements.

All subsystems met or exceeded their target specifications, demonstrating that the design achieves its intended performance goals across responsiveness, fidelity, and output strength.

Subsystem	Requirement	Specified Value	Tested
Key Inputs	Button Debounce Time	< 7 ms	0.395 ms
	Total Button Readout Latency	<10 ms	8*(0.006 *4 +2 * 0.003 + 2 *0.001) = 0.256 ms
Sound Synthesis	DAC resolution	≥ 16 bits	16 bit
	I2S	≥ 1MHz	16*96000= 1.54MHz
Output	Sound	≥85 dB	89dB
	Speaker Wattage	≥ 3W	15 W

Table 2. Requirement and Verification Table

Conclusion

Accomplishments

We successfully designed the digital accordion keyboard as well as signal processing esp32. The high level requirements we have listed are also accomplished: the sound quality reaches the standard, the harmonic is accurate, and the polyphonic sounds could be played by pressing different keys simultaneously.

Uncertainties

The only part that we did not successfully implement was the on board DAC. The possible reason is that the DAC’s analog output may lack proper connection, preventing it from driving the audio jack and resulting in only 3 mV output. To solve this, we connected an external DAC.

Ethical Considerations

Issue 1: Intellectual Property Compliance

A key concern in developing a digital accordion is adhering to intellectual property laws, particularly when using MIDI sound banks or accordion samples. Many commercial sound libraries are copyrighted, and unauthorized use may lead to legal issues. To avoid this, we rely on open-source MIDI and synthesis libraries that are freely licensed for use and distribution. This ensures legal compliance while allowing flexible sound customization.

Issue 2: Hearing Protection & Volume Control

Prolonged exposure to high sound levels can damage hearing, making volume regulation essential. The main risk is that high speaker output could exceed safe thresholds. To prevent this, we integrate automatic gain control (AGC) to cap volume at 85 dB SPL. AGC maintains consistent audio levels and prevents sudden spikes, protecting users and improving usability across various environments.

Issue 3: Component Overheating

Parts like the voltage regulator and PCM5102 DAC produce heat during use, which can lead to failure or fire risk if unmanaged. Given the compact design, heat management is critical.

Solutions include passive heat sinks and active cooling fans to regulate temperature and maintain performance, ensuring component longevity.

Issue 4: Enclosure Ventilation

Beyond individual components, poor airflow in the enclosure can trap heat and worsen thermal issues. Proper ventilation—through slots or perforations near heat sources—helps dissipate heat effectively. Using thermally conductive materials in the housing can further aid cooling. These design strategies reduce overheating risks and ensure safe, sustained operation.

Future Works

Our design consists of two functionalities: play polyphonic sounds when pressing keys, and play songs/music with the synthesized accordion sounds. However, these two functions could not be done simultaneously. Therefore, one of the recommendations on the future work could be integrating these two functions.

In addition, our design is mainly based on achieving functionalities rather than ease of user's usage. Thus, another recommendation could be to utilize more effective components.

Citation

“Digital Accordions.” *KORG USA Official Store*, 2015, korgusshop.com/collections/digital-accordions?srsltid=AfmBOopGSvmTT7T8x1Wge-_88KWAqwRRjKBeOVJBosGmjlD89Gt5VXqW. Accessed 8 May 2025.

Hopkin, Bart. “OVERTONES HARMONIC and INHARMONIC | Bart Hopkin.” *Barthopkin.com*, 22 Feb. 2017, barthopkin.com/overtones-harmonic-and-inharmonic/.

Lucifero, Giovanni. “12 Bass Accordion Chart - Diagram, Bass Notes, List of Chords.” *AccordionChords.com*, 29 Dec. 2021, accordionchords.com/stradella-bass-layouts/12-bass-accordion-chart/. Accessed 8 May 2025.

“Tomasz Maciejewski.” *Homepage Tomasz Maciejewski | Old Bicycle Parts, VDO Speedometers Collection*, 14 Nov. 2013, maciejewski.com/en/analysis-of-the-accordion-sound/. Accessed 8 May 2025.