EE 344 Design Review Report
Wideband Audio Acquisition Using an Electret Microphone

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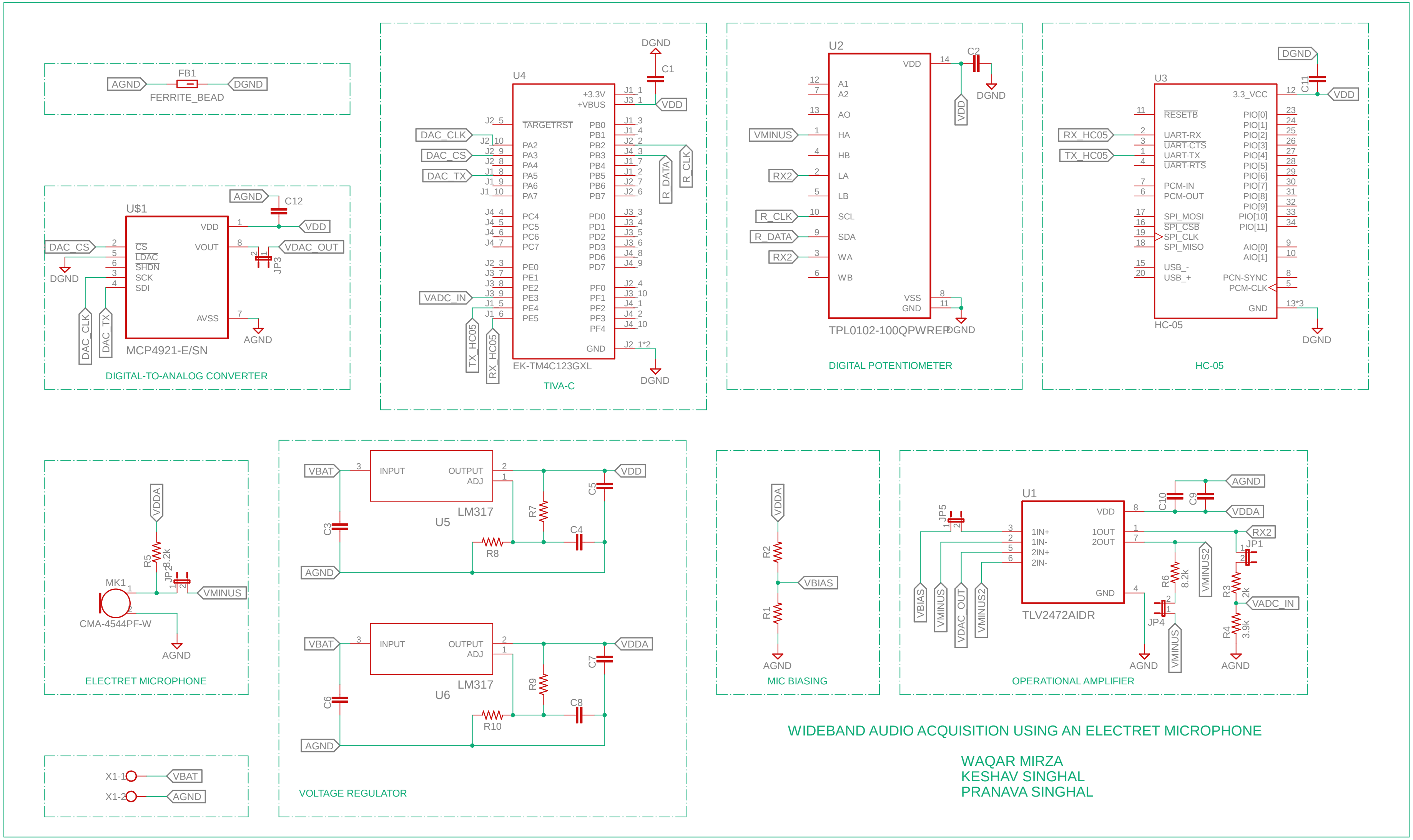

WIDEBAND AUDIO ACQUISITION USING AN ELECTRET MICROPHONE

WAQAR MIRZA
KESHAV SINGHAL
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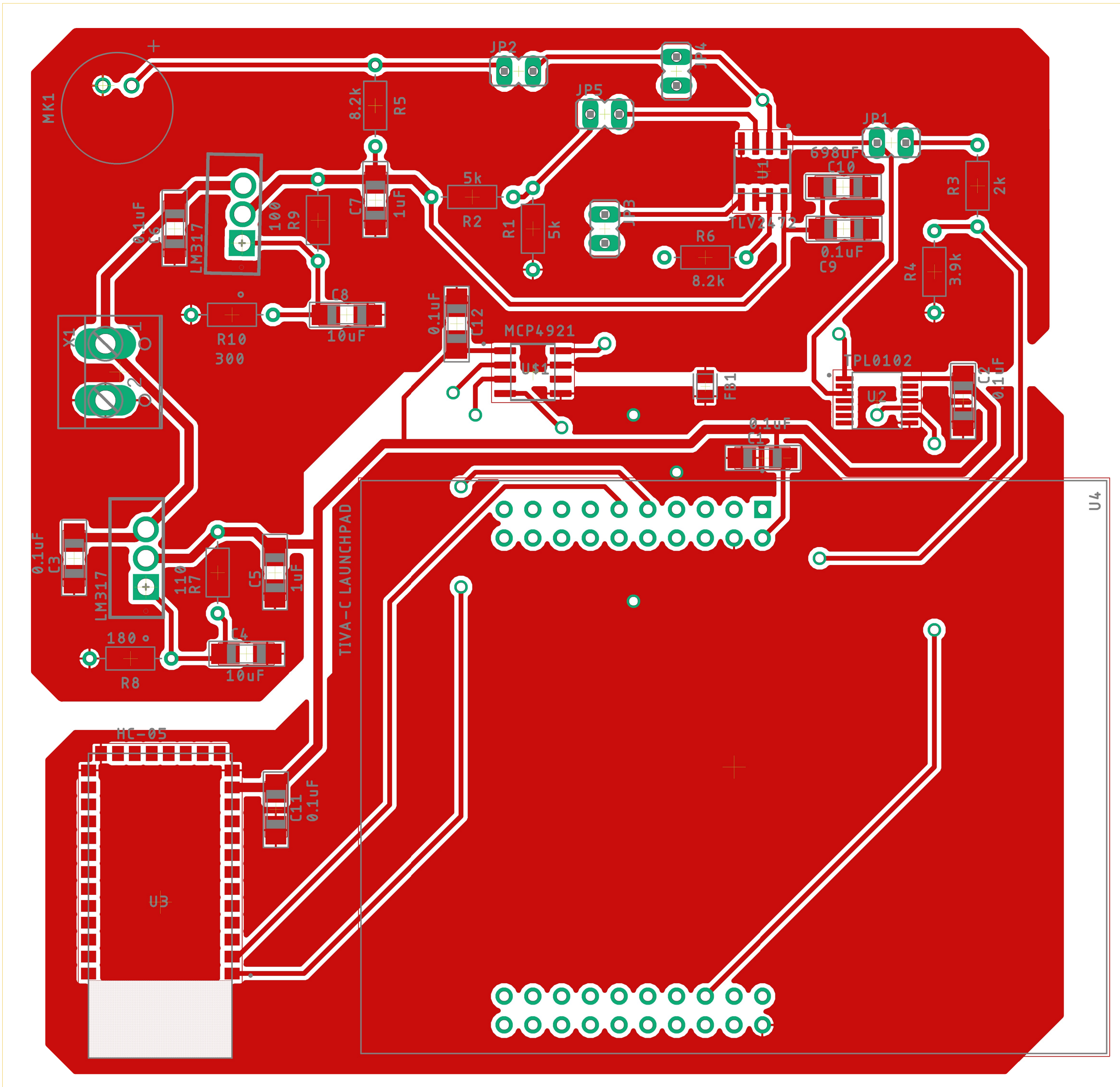
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JP4
JP5
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8.2k
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C7
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JP3
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TLV2472
698uF
C10
0.1uF
C9
R3
2k
R4
3.9k
R6
8.2k
LM317
100
R9
0.1uF
X1
R10
300
C8
10uF
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C12
MCP4921
FB1
TPL0102
U2
C2
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U4
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C3
LM317
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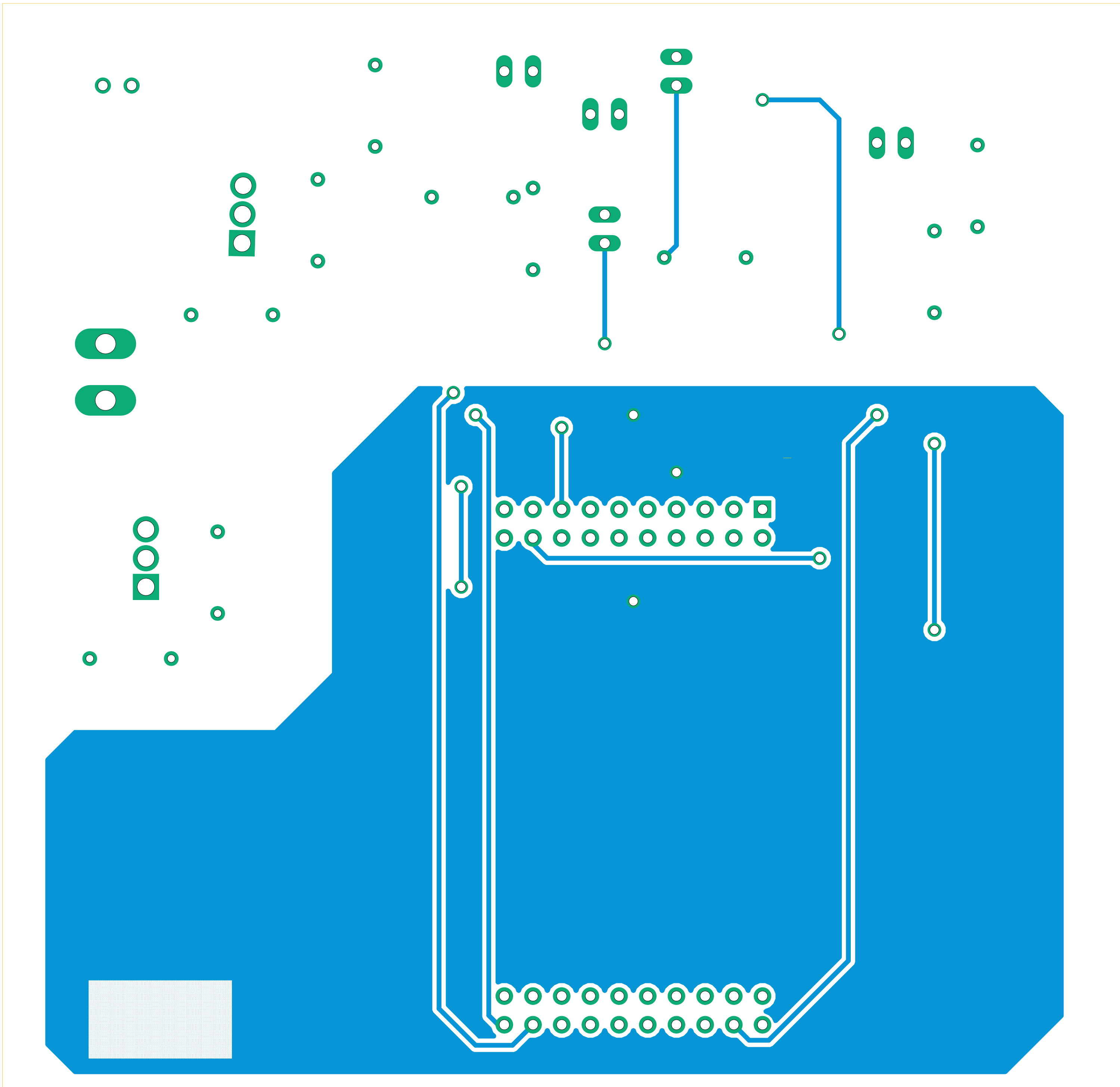


1 Design Description

1.1 Electret Microphone

The CMA-4544PF-W electret microphone is a suitable choice for this experiment for several reasons.

- It has a small form factor of 9.7 x 4.5 mm^2, which is important for compact circuit designs.
- It has a high signal-to-noise ratio, which is crucial for capturing clean audio signals.
- It has a wide frequency response range that covers frequencies from 50Hz to 20KHz, making it suitable for capturing a broad range of sounds.
- It has low power consumption, which is advantageous for battery-powered applications.
- Finally, it is affordable, making it a cost-effective option for experimental setups.

The CMA-4544PF-W offers a good balance of performance and practicality, making it an excellent choice for this experiment.

1.2 Microcontroller

The TIVA C TM4C123GH6PM microcontroller has the following properties which make it a suitable choice for this experiment.

- It has a 32-bit ARM Cortex-M4F core, which provides high-performance computing and DSP capabilities, making it well-suited for audio signal processing.
- It has a high clock speed of up to 80 MHz, which allows for fast data processing and high sampling rates.
- It has a built-in ADC, which are essential for capturing analog signals.
- It has 4 SPI communication interfaces, which allows for easy data transmission to other devices using Bluetooth.
- It has a low-power mode, which is important for energy-efficient applications, especially in battery-powered systems.
- It has a robust software development kit (SDK), which makes it easy to develop and test applications using a range of programming languages and development tools.
- Finally, it has a rich set of peripherals and I/O ports, which makes it highly configurable and customizable for various experimental setups.

Overall, the TIVA C TM4C123GH6PM offers a good balance of performance, power efficiency, and flexibility, making it an excellent choice for this experiment.

1.3 Bluetooth Microcontroller Interface

The following reasons make LAUNCHXL CC2640R2F a suitable choice for this experiment.

- It is a low-power, high-performance microcontroller, which is essential for energy-efficient applications, particularly in battery-powered systems.
- Second, it has a built-in Bluetooth 5.1 Low Energy (BLE) module, which allows for wireless data transmission to other devices, making it easy to integrate into a wider range of systems.
- It has a variety of interfaces, including 1 UART, 2 SPI, 1 I2C, and 1 I2S which make it easy to communicate with other devices or sensors.

- It has 28 KB of RAM, which is sufficient for data processing and storage for the proposed experiment along with a 12 bit ADC.
- It has a compact form factor, which is important for space-constrained applications.
- Finally, it has a low cost, making it an affordable option for experimental setups.

In summary, the LAUNCHXL CC2640R2F is a cost-effective and versatile option that strikes a good balance between performance, power efficiency, and flexibility, making it a highly suitable choice for our experiment.

1.4 Digital Potentiometer

The following reasons make TPL0102-EP a suitable choice for this experiment.

- It provides a high-resolution 256-tap adjustment for fine-grained gain control in the audio acquisition circuit.
- It has an I2C interface, which enables easy digital communication with the microcontroller, simplifying the integration of the digital potentiometer into the circuit.
- It has a low-power consumption, making it an energy-efficient option for battery-powered applications.
- The evaluation module provides a convenient way to test and evaluate the performance of the TPL0102 digital potentiometer, which helps streamline the design process.

Overall, the TPL0102 digital potentiometer with I2C interface evaluation module offers a high level of functionality, accuracy, and convenience.

1.5 Digital to Analog Converter (DAC)

The MCP4921 DAC with SPI interface is a suitable choice for this experiment for several reasons.

- It has a high resolution of 12 bits, which ensures accurate digital-to-analog conversion.
- It has a fast settling time, which is important for applications where rapid changes in the output voltage are required.
- It has a compact form factor, which is important for space-constrained applications
- It has a wide input voltage range, which makes it suitable for a variety of input signal levels.
- It has an SPI interface, which enables easy digital communication with the microcontroller, simplifying its integration into the circuit.

The MCP4921 DAC with SPI interface offers reliable and efficient operation, making it an excellent choice.

1.6 Operational Amplifier

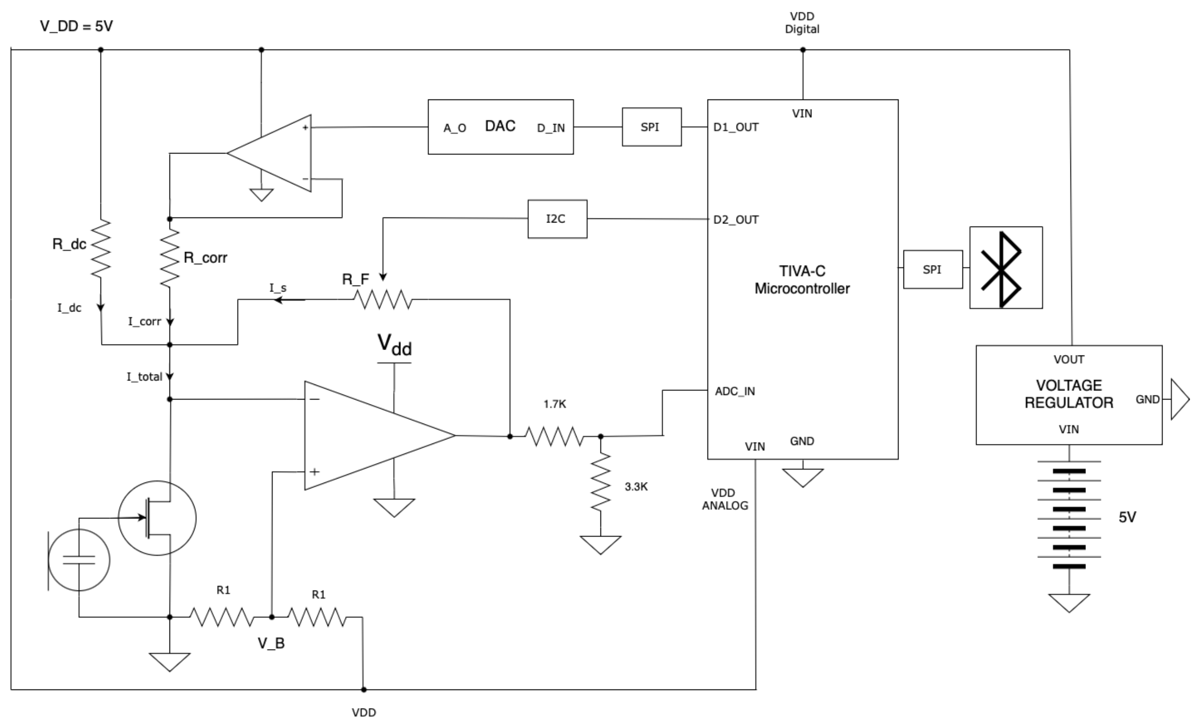
The selection of TI TLV2472 operational amplifiers for this project is based on several factors.

- The Op-amp provides reliable and accurate signal acquisition, which is essential for high-quality audio recording as the amplifier supports rail-to-rail operation, which enables precise acquisition of signals across the full input range.
- This feature is particularly important in low-voltage applications, where the voltage range can be limited.
- Furthermore, the Op-amp has low input noise and low offset voltage, which ensures that the acquired signal is free from unwanted noise and distortion.

- The amplifiers also has a high gain bandwidth product, which allows for fast signal processing and ensures that the acquired signal is faithfully represented in the output.

Overall, the TI TLV2472 operational amplifiers provide a robust and reliable solution for signal acquisition in this project, which is crucial for obtaining high-quality audio recordings.

2 Principle of Operation



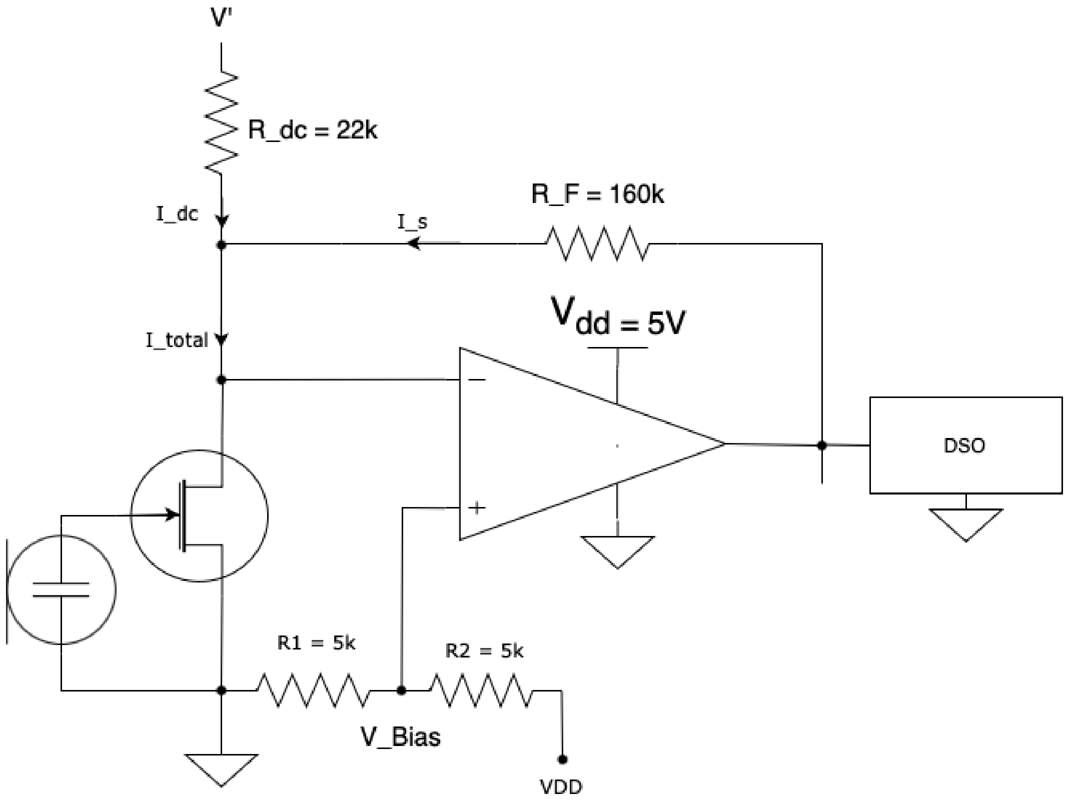
2.1 Bias Current Compensation

The principle of operation of the experiment involves the conversion of incoming sound signals into voltage signals using an electret microphone. This voltage signal is then fed into the gate of the FET, and a negative feedback opamp configuration sets the voltage at the drain to V_B. A current $I = I_{bias} + i_{in}$ flows into the drain of the FET, where i_{in} is the small signal component carrying the sound signal information, and I_{bias} needs to be compensated.
To compensate for the bias current, compensating currents from the sources I_DC and $I_{correction}$ are brought in. The current I_C cancels most of the bias current and is fixed, while $I_{correction}$ is a variable output of the microcontroller, which handles small variations in the bias current. The TIVA C muC and the MCP4921 DAC with an SPI interface are used to efficiently convert the digital input to analog output for DC bias compensation.
The microcontroller uses a digitized version of the opamp output as input to control the gain R_F and decide $V_{control}$ in a feedback loop. The digitized signal is also transmitted to an external device through a Bluetooth module, where further operations may be performed on the signal. The TPL0102 256-tap dual-channel digital potentiometer with an I2C interface evaluation module is used to set the voltage $V_{control}$, which controls the gain of the opamp. The LAUNCHXL CC2640R2F Bluetooth microcontroller interface is used to transmit the digitized signal to external devices.
Finally, the TI TLV2472 operational amplifiers are used in the circuit to support rail-to-rail operation, ensuring precise acquisition of signals. Overall, the principle of operation of the experiment

involves integrating various components and techniques to ensure the accurate acquisition and transmission of sound signals while compensating for DC bias.

3 Microphone Amplifier Interfacing

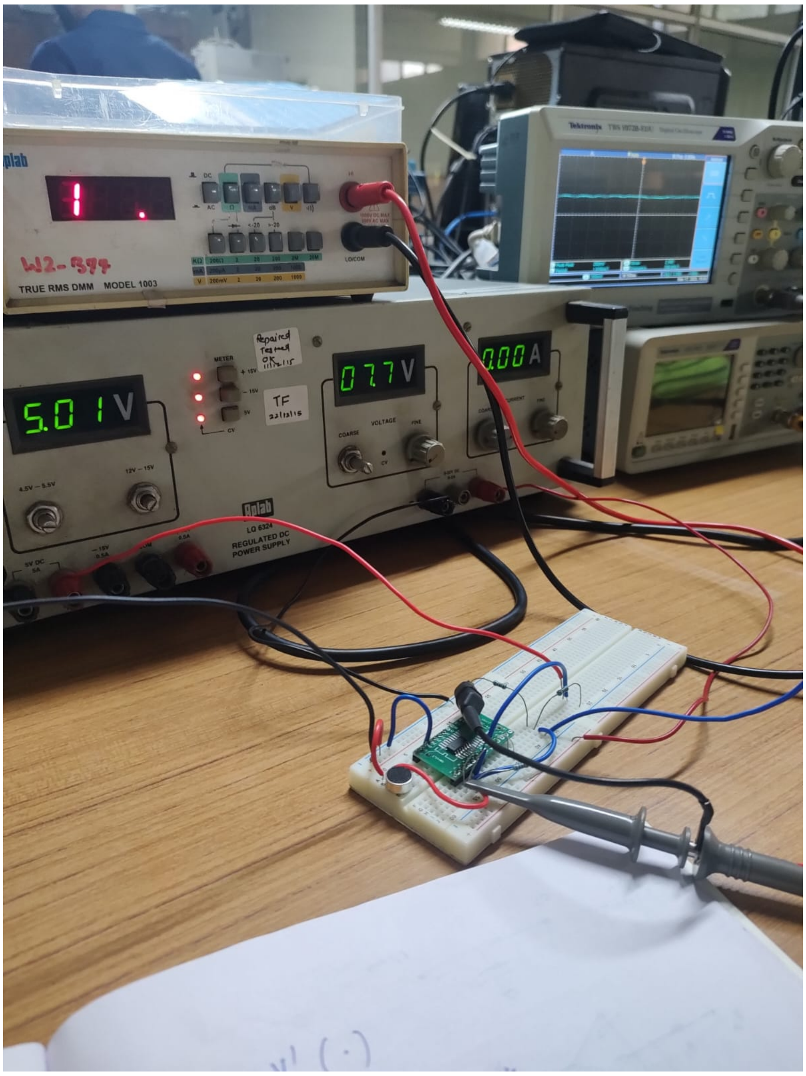
3.1 Description of Test Setup and Method



We checked the interfacing of the microphone with amplifier. The key objectives of this experiment were to identify a suitable biasing voltage for the microphone, DC compensation resistance and the appropriate feedback resistance for the op-amp to get the desired output voltage swing. In order to perform this test we used the following circuit, where the microphone biasing voltage V_{bias} and the DC-compensation voltage $V^{'}$ were set using a variable voltage supply. Audio signal used is a 1KHz sinusoidal tone played using a mobile phone speaker at fixed volume at a particular distance from the microphone. The experiments were performed with low ambient noise (like people speaking) in the background.

The first part was aimed at identifying a suitable biasing point. The value of feedback resistance R_F was fixed initially. Even the resistor on the DC compensation branch, R_{dc} is constant. Thus, we tried different values of V_{bias} using the variable voltage source and for each value of V_{bias} we adjusted $V^{'}$ so that the DC current is close to zero on the feedback resistor. The output voltage fed to the oscilloscope (DSO in figure) is given by $V_{out} = V_{minus} + I_s \cdot R_F$. Thus, if the current I_s only carries the AC component of the signal, the output is centred around $V_{minus} = V_{bias}$. We use this knowledge to vary $V^{'}$ while observing the signal output on the oscilloscope until the **mean** of V_{out} is close to V_{bias} on the oscilloscope. Knowing $V^{'}$ at the biasing point and R_{dc} we also get to know the DC compensation current for this particular microphone I_{dc}.

For each value of V_{bias} we also note down the output peak-to-peak voltage swing while keeping the input audio signal identical at a fixed distance. We obtain similar waveforms and output swing for a large range of biasing values any of which can be used for operation. We choose a convenient middle value of $V_{bias} = 2.5V$. This simplifies design in a few key ways. First, the



output signal is centred around $2.5V$ which allows us to make best use of the op-amp output swing from 0 to $5V$. Moreover, in the final circuit, the control feedback from the DAC will have voltage outputs between 0 to $5V$ and using a biasing of $2.5V$ allows us to use equal range of positive and negative DC-compensating control currents, maximising the useful range of the DAC feedback. We generate this $V_{bias} = 2.5V$ using a resistive divider with $R_1 = R_2 = 5k\Omega$.
The second part of the experiment aims to identify a suitable range for the feedback resistance R_F in order to provide the necessary output voltage swing. In the final circuit R_F will be replaced by a digipot (digital potentiometer) which will allow us to vary the amplification factor based on the input loudness so that the op-amp output does not enter saturation. We fix $V_{bias} = 2.5V$ for the remaining experiments and try two different values of R_F which are $260k\Omega$ and $380k\Omega$ respectively. For a fixed value of R_F we vary the distance of our audio source from the microphone and observe the peak-to-peak swing of V_{out} on the oscilloscope. We also remove the audio source and observe the peak-to-peak swing due to ambient noise. This information will later help us design the gain-control algorithm, where we need to set a noise threshold before the gain control sets in. We take three different distances: placed on the microphone surface (nearest), roughly a centimetre from the microphone (near), and a comfortable speaking distance for a usual microphone (speaking distance). With our output centred around $2.5V$, the amplifier allows for a swing of 0 to $5V$. However, we want to keep some headroom for the signal in our design so that clipping doesn't happen. Thus, we would ideally like to have a peak to peak variation of $4V$ keeping $0.5V$ of headroom for the signal on both sides.

3.2 Test Results

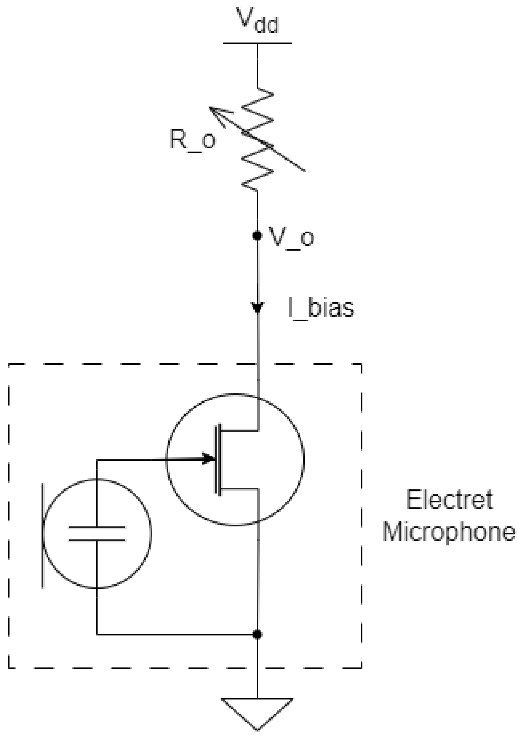
First we look at the approximate peak to peak output signal for different V_{bias} values and also calculate the bias current that needs to be compensated for that V_{bias}. Upon compensation, the signal mean should be close to V_{bias}. We can see that the amplification (peak to peak value) and bias current do not vary significantly for different V_{bias} values. So we pick V_{bias} = 2.5V for our design as mentioned earlier.

V_{pk-pk}	V_{bias}	$V'_{compensation}$	$I_{bias} = (V' - V_{bias})/R_{dc}$	Signal Mean
800mV	1.5V	6.5V	0.227mA	1.53V
800mV	2.0V	7.2V	0.236mA	1.95V
800mV	2.48V	7. 7V	0.237mA	2.50V
800mV	2.56V	7.8V	0.238mA	2.60V
800mV	3.0V	8.3V	0.241mA	3.0V

Next we have readings for the variation of the output signal peak to peak value with distance. As expected, we see drop in amplitude as distance increases. We see the amplification of signal is proportional to R_F as expected. Thus the amplifier microphone interfacing worked as expected.

Distance	V_{pk-pk}
$R_F = 260K$	
Nearest	1.8V
Near	1.5V
Speaking Distance	1.0V
Ambient Noise	0.65V
$R_F = 380K$	
Nearest	2.8V
Near	2.2V
Speaking Distance	1.3V
Ambient Noise	0.90V

4 Process Variation in Bias Current



4.1 Description of Test Setup and Method

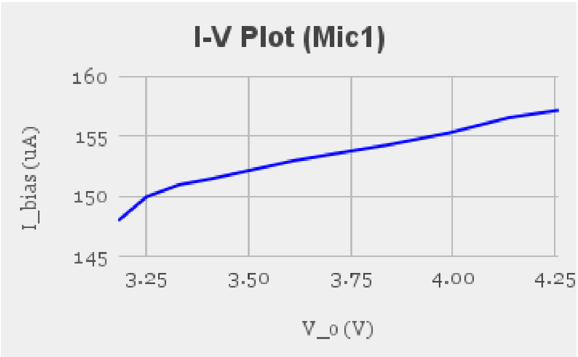
It is important that our circuit should be able to compensate the bias current for any electret microphone that the user decides to use, that is, we should be able to handle the process variation in the bias current. For this reason, we experimented with multiple electret microphones to get an idea of this process variation. The experimental setup is shown in the below circuit diagram.

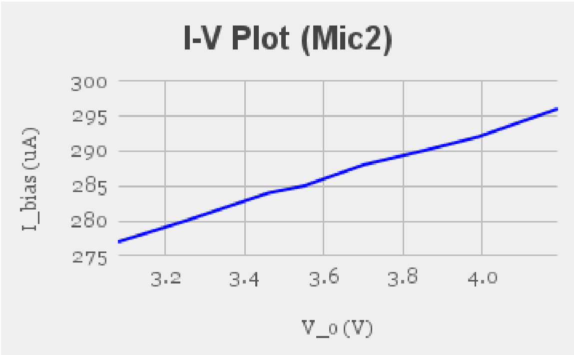
We used three different microphones for the experiment. For every microphone, the supply V_{dd} was fixed, and potentiometer value R_o was varied. The drain voltage V_o and the bias current I_{bias} were measured and recorded. Since the internal gate voltage of the electret is fixed, this gives us the I_D vs V_{DS} characteristic of the FET at fixed V_{GS}.

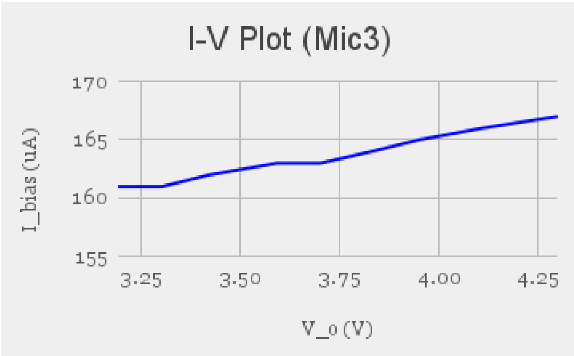
4.2 Test Results

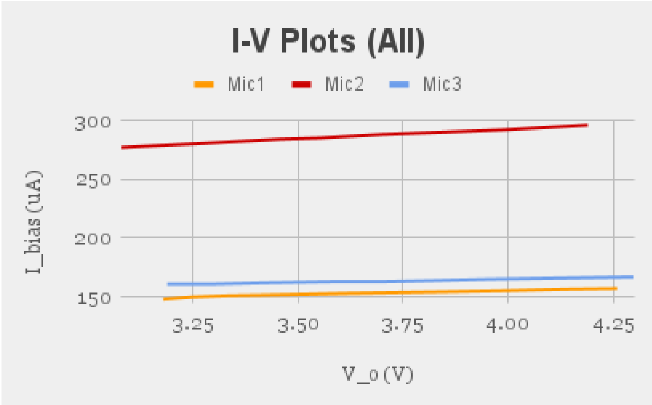
The readings and plots for the 3 microphones are as shown:

MIC 1		MIC 2		MIC 3	
V_o (V)	I_bias (uA)	V_o (V)	I_bias (uA)	V_o (V)	I_bias (uA)
3.18	148	4.19	296	4.3	167
3.25	150	3.99	292	4.11	166
3.33	151	3.85	290	3.95	165
3.41	151.5	3.7	288	3.83	164
3.61	153	3.55	285	3.7	163
3.84	154.3	3.46	284	3.59	163
3.99	155.3	3.25	280	3.42	162
4.14	156.6	3.08	277	3.3	161
4.26	157.2	-	-	3.19	161









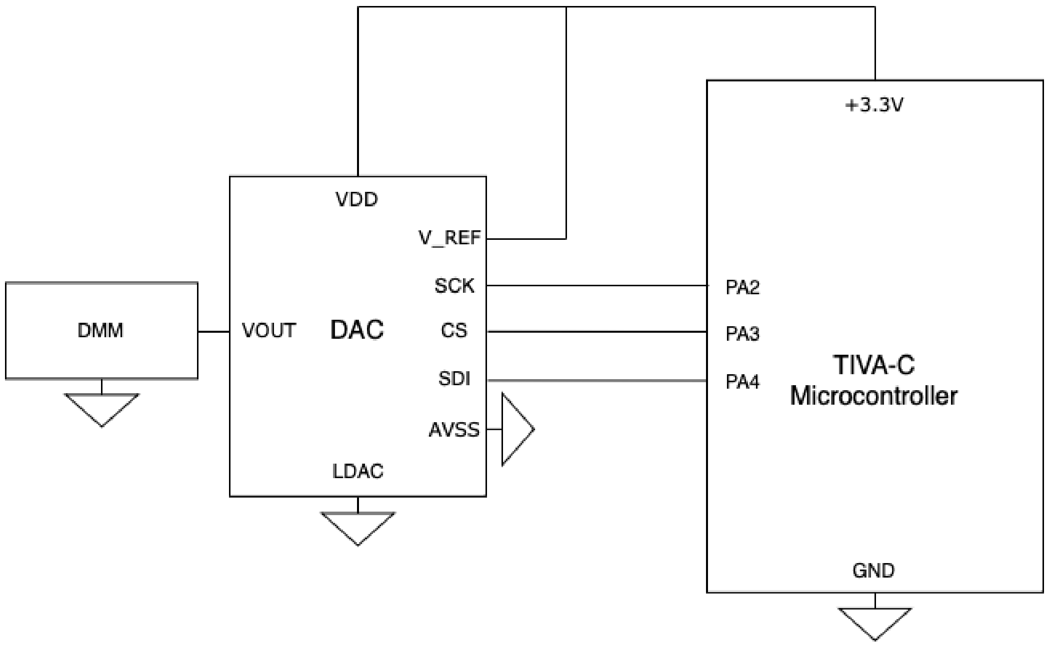
From these readings, we see a significant process variation in the bias current, and we can use this data to select a suitable range of bias currents that our circuit will be designed to compensate.

5 Key Calculations for DC Current Compensation

The above experiments allow us to choose suitable component values for the DC compensation part of the circuit. Referring to the circuit schematic, we can see two DC current compensation branches: one is a constant current $I_{dc} = \frac{V_{DD}-V_{minus}}{R_{dc}} = \frac{V_{DD}-V_{bias}}{R_{dc}}$, the second one is the DAC output passed through the voltage buffer which gives us an output current of $I_{corr} = \frac{V_{DAC}-V_{minus}}{R_{corr}} = \frac{V_{DAC}-V_{bias}}{R_{corr}}$. The total bias current is $I_{dc} + I_{corr}$ in which only I_{corr} is variable. By observing the biasing currents for various microphones we feel that a circuit capable of handling a process variation of 0 to $6mA$ would be sufficient. Thus, we set $I_{dc} \approx 0.3mA$, the mean value and let I_{corr} handle the swing of $\pm 0.3mA$. We set $R_{dc} = \frac{5V}{0.3mA} \approx 8.2k\Omega$ (closest standard resistor). Since $V_{DAC} \in (0, 5)V$ and $V_{bias} = 2.5V$ we have a swing of $\Delta_V = 5V$ ($-2.5V$ to $2.5V$). Our desired current variation handling ability is $\Delta_i = 0.6mA$ Thus, we set $R_{corr} = \frac{\Delta_V}{\Delta_i} = \frac{5V}{0.6mA} \approx 8.2k\Omega$ (the nearest standard resistor). Since our DAC is 12-bit, we have a minimum voltage resolution of $\delta_V = \frac{5V}{2^{12}} = 1.22mV$. For the chosen R_{corr} this gives a current resolution of $\delta_i = \frac{\delta_V}{R_{corr}} = \frac{1.22mV}{8.2k\Omega} = 0.148\mu A$ which is more than sufficient accuracy for our application. We say this because a typical value of feedback resistance $R_F = 380k\Omega$ will only amplify this error to $\delta_i \cdot R_F = 56.53mV$. This is the maximum DC offset we can expect at the output if our controller is giving the ideal feedback signal (this is only a first approximation). Thus we have obtained $R_{dc} = R_{corr} = 8.2k\Omega$.

6 DAC Testing

6.1 Description of Test Setup and Method



We tested the DAC MCP4921 to check if it operates as required. We interfaced it using SPI with the μC as indicated in the figure. We sent digital input to the DAC from the μC as a 12 bit value and measured the analog voltage output of the DAC using a DMM. We set the reference voltage of the DAC to $V_{ref} = 3.3$V. We expect the output to be $V_{out} = V_{ref}\frac{Input}{2^{12}}$.

6.2 Test Results

We note the analog output of the DAC for different digital inputs and compare with the expected output. As we can see, the DAC is functioning almost as expected.

Digital Input	Expected Analog Value	Experimental Analog Value
50	0.040V	0.038V
100	0.080V	0.78V
150	0.120V	0.120V
250	0.201V	0.199V
400	0.321V	0.320V
700	0.562V	0.570V
1000	0.806V	0.812V
1150	0.924V	0.920V
1650	1.329V	1.322V
2048	1.645V	1.630V
2300	1.848V	1.854V
2500	2.014V	2.020V
2900	2.330	2.320
3400	2.740V	2.738V
3800	3.061V	3.058V
4000	3.214V	3.211V
4095	3.290V	3.290V

7 Percentage Testing Numbers

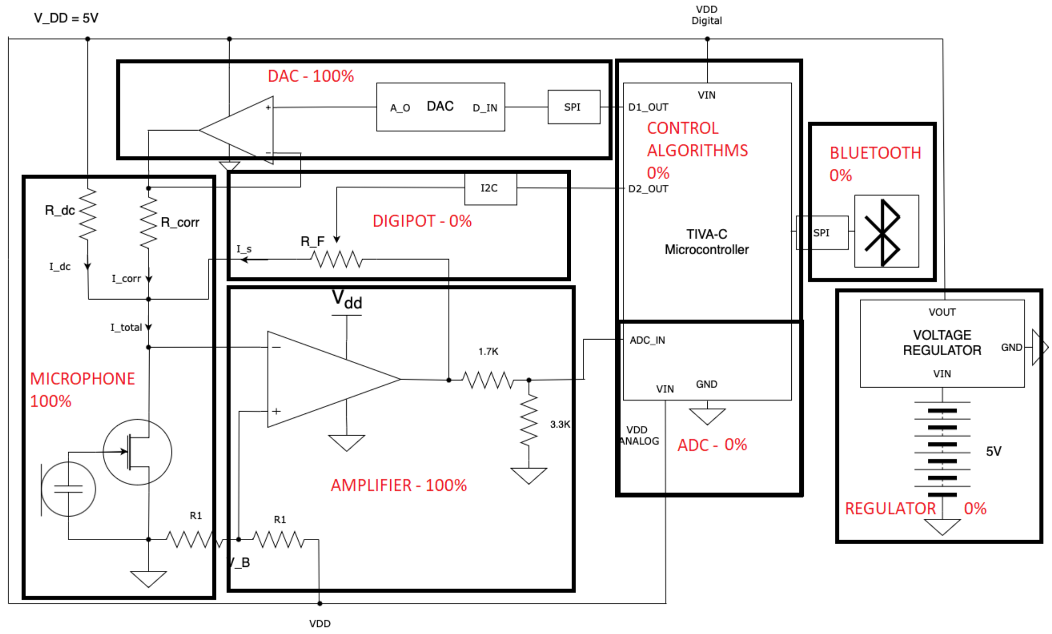


Figure 1: Percentage testing of different blocks

8 Next Steps

8.1 The tasks remaning to realize the project in its entirety are as follows:

- Bluetooth Module Interfacing: Configuring the HC-05 Bluetooth module to communicate with a microcontroller using UART Interface to transmit data to an external device.
- Digital Potentiometer Interfacing: Configuring the TPL0102-EP Digital Potentiometer with I2C Interfacing to allow digital control of the resistance values using the control algorithm to provide Automatic Gain Control by programming the microcontroller to send commands to the Digital Potentiometer.
- Control Algorithm: Developing an algorithm to control the system by defining how the components will work together and implementing the necessary calculations and feedback loops.
- Printing the PCB: Sending the design files to a fabrication house to have the board printed.
- PCB testing and verification: Testing the functionality of the PCB by using a multimeter and oscilloscope to check for proper voltage and signal levels, and inspecting the board for defects or errors.
- Testing PCB with external devices: Testing the entire system by integrating the PCB with the Microphone, DAC, Digital Potentiometer, and the Bluetooth Module and verifying that all components work together as expected.
- Designing the packaging: Designing the enclosure and mechanical components of the system to protect it from environmental factors and make it user-friendly.
- Assembling components together in final packaging: Assembling all the components of the system inside the final packaging, including wiring and soldering, and performing final testing and verification of the system's functionality.

8.2 Work Distribution

The work distribution among the Team members is as follows:

- Bluetooth Module Interfacing: Keshav and Waqar
- Digital Potentiometer Interfacing: Waqar and Pranava
- Control Algorithm: Keshav and Waqar
- PCB testing and verification: Pranava and Waqar
- Designing the packaging: Pranava and Keshav
- Testing PCB with external devices: Keshav and Waqar
- Assembling components together in final packaging: Waqar and Pranava
- Final Testing and Verification: All members

8.3 The detailed day-wise timeline is as follows:

- March 28 (Tuesday): Revise the schematic and layout for the PCB and send the design files to the fabrication house to have the board printed.
- March 29 (Wednesday): Research Bluetooth module interfacing and Digital Dotentiometer interfacing.
- March 31 (Friday): Design the external packaging and implement the Bluetooth module and Digital Potentiometer Interface.
- April 1 (Saturday): Write the control algorithm and test it using the μC and all external components.
- April 2 (Sunday): Receive the PCB from the fabrication house. Test the functionality of the PCB using a multimeter and oscilloscope to check for proper voltage and signal levels.
- April 4 (Tuesday): Test the system by integrating the PCB with the microphone, DAC, Digital Potentiometer, and Bluetooth module.
- April 5 (Wednesday): Continue testing the system and verifying that all components work together as expected.
- April 7 (Friday): Assemble all the components of the system inside the final packaging, including wiring and soldering. Perform final testing and verification of the system's functionality. Finalize the packaging design for project submission.

9 Demo Video

https://drive.google.com/drive/folders/1lqrEt7tiYxozfnio8Oz2OaFihWA2Pki2?usp=sharing

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