Discrete TIA Board Documentation

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Note: Zoom in to see the plots clearly

Contents

1 Introduction

This documentation provides a comprehensive overview of the design and testing of a Discrete TIA board. The board is designed to perform critical functions, such as transimpedance amplification (TIA), voltage amplification (2VB Generator), and low-pass filtering. The primary goal of this documentation is to present the board's specifications, design details, and test results, along with addressing potential issues and troubleshooting methods encountered during the development process.

2 Board Overview

2.1 Specifications

The following are the specifications of the board.

- TIA Gain of 110k.
- Low pass filter with bandwidth of 5kHz.
- 8 Independent TIA channels.
- Power Supply voltage of 5V

2.2 Design

This section goes through the design procedure followed for the development of the board.

2.2.1 TIA

Figure 1 shows the TIA. It can be easily derived the relation between input and output. which is given by the equation, if $R_F = R$,

$$V_{out} = -I_{IN}R_F$$

where R_F is the feedback resistor and C_F is the feedback capacitor. The value of R_F is chosen as $100k\Omega$ to achieve a TIA gain of 110×10^3. The value of C_F is chosen to be $10pF$ based on the datasheet of the opamp. It was later verified through simulation in Orcad Capture to ensure a stable output."

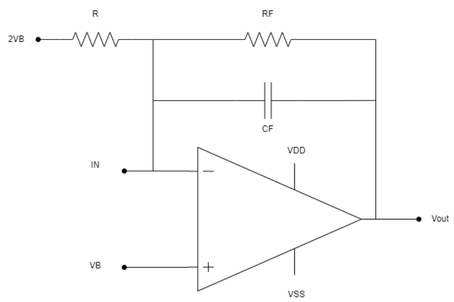


Figure 1: TIA

2.2.2 2VB Generator (Voltage Amplifier)

To eliminate the contribution of VB in the output of the TIA, we need to apply 2VB at the non-inverting terminal of the TIA. To generate this 2VB signal from VB, a simple non-inverting amplifier with a gain of 2 is used. The amplifier is depicted in figure 2. The output of the amplifier is given by the equation:

$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

To achieve a gain of 2, the values of R1 and R2 are set to be equal and chosen as $110k\Omega$.

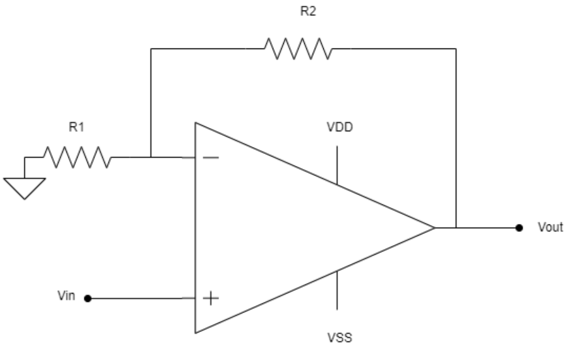


Figure 2: Non-inverting amplifier

2.2.3 Low Pass filter

The low-pass filter consists of a single resistor and capacitor, as depicted in figure 3. The cut-off frequency (fc) of the filter is determined by the equation:

$$f_c = \frac{1}{2\pi R_L C_L}$$

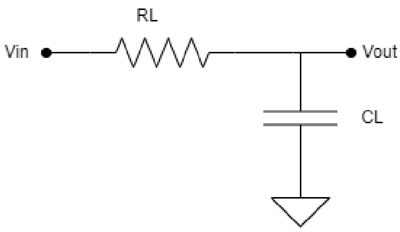


Figure 3: Low Pass Filter

To achieve a cut-off frequency of 5kHz, R_L is chosen as $100k\Omega$ and C_L is chosen as 300pF.

2.3 TIA Channel

A single TIA independent channel is as shown in figure 4.

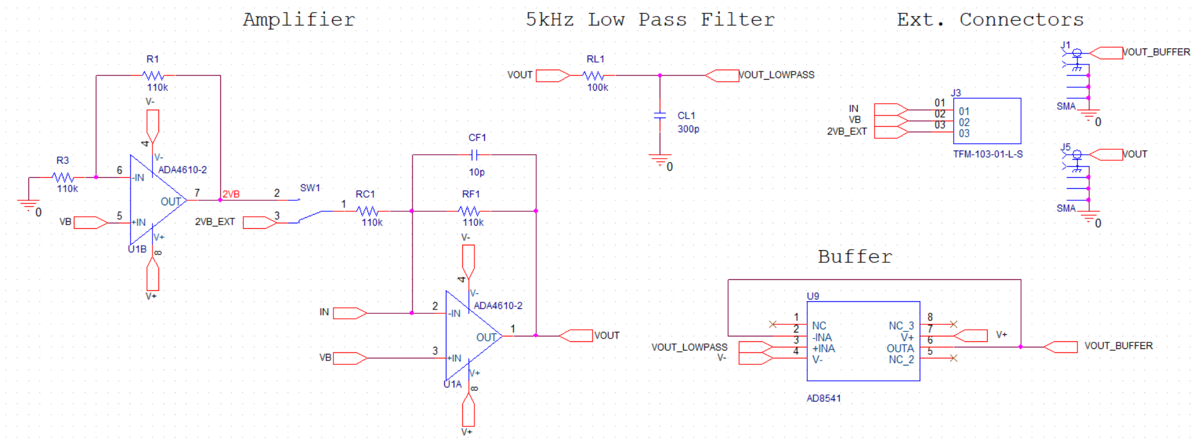


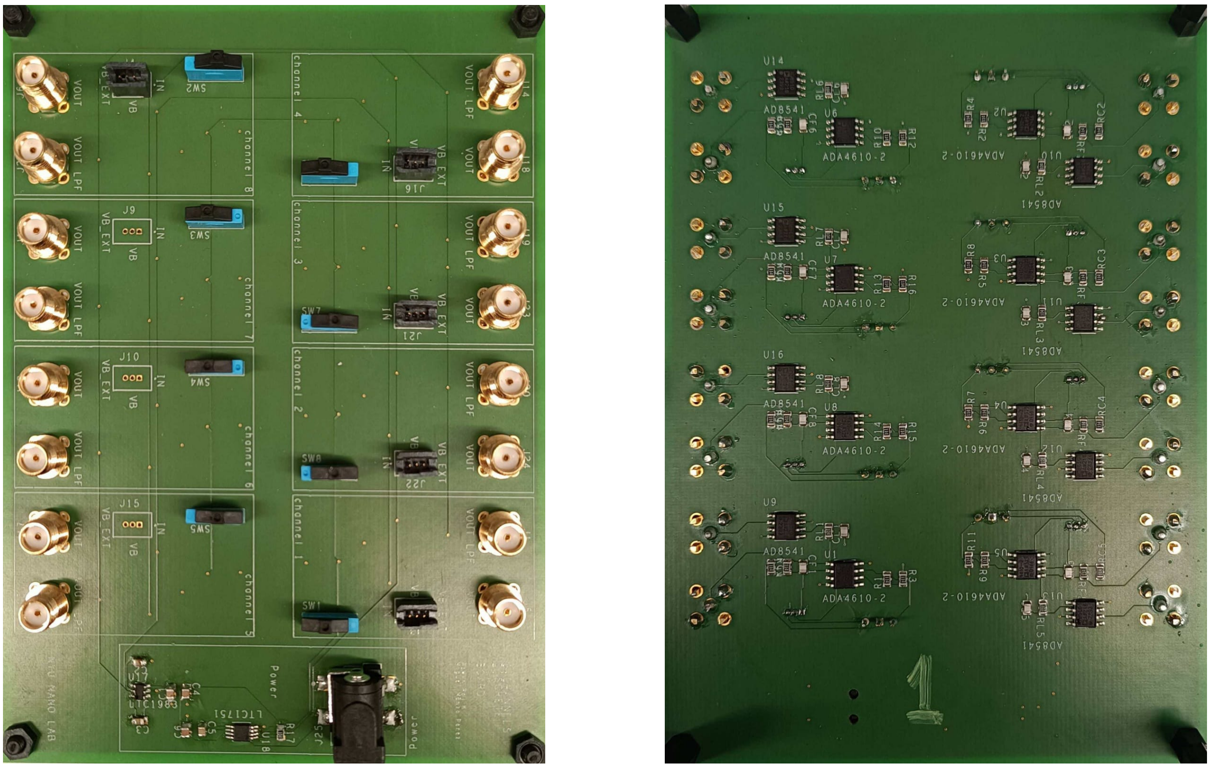
Figure 4: Single Channel

The input and outputs for a single channel are described in table 1.

Output/Input	Direction	Description
IN	Input	Input from the sensor
VB	Input	Voltage at the non-inverting terminal of the TIA
VB_EXT	Input	External 2VB voltage
VOUT	Output	Output of the TIA.
LPF	Output	Output from the Low pass filter.

Table 1: Input/Output of a single TIA Channel.

Note: To enable VB_EXT, the switch must be in a position where the dot on it is hidden.



(a) Top View (b) Bottom View

Figure 5: Discrete TIA Board

2.4 Components List

The components used are as follows,

Opamps

ADA4610-2
- TIA and 2VB voltage generation
- Unity gain crossover frequency: 9.3 MHz
- Closed-loop bandwidth: 10.6 MHz

AD8510
- Used as a buffer
- Gain bandwidth product: 8 MHz
- Slew Rate: $20V/\mu s$

Voltage Regulators

LTC1983ES6-5
- Generates -5V for the opamps
- ±4% Output Voltage Accuracy
- 100mA Output Current Capability
- 2.3V to 5.5V Operating Voltage Range

LTC1751EMS8-5
- Generates +5V for the opamps
- ±4% Output Voltage Accuracy
- 100mA Output Current Capability
- 2V to 5.5V Operating Voltage Range

Miscellaneous

PJ-002AH-SMT-TR
- Power Jack
- 5A current rating
- 24V voltage rating

TFM-103-01-L-S
- connetor for IN, VB and VB_EXT
- 3-pin connector
- Connector Type : Header
- Contact Type : Male Pin

MSS-102545-28A-D

- To swift between VB_EXT and 2VB generated by the voltage amplifier
- SPDT Switch
- 300mA Current Rating
- 24V Voltage Rating

3 Test Results

3.1 Basic Functionality Test

This test was intended to check for design, manufacturing, or assembly problems. This test is divided into three parts, testing the TIA, the voltage amplifier and the low pass filter.

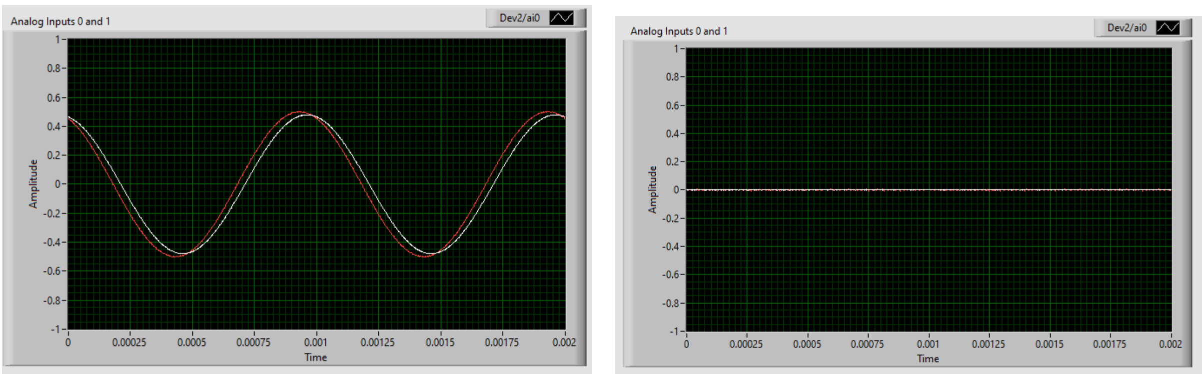
3.1.1 Testing TIA

The TIAs were used as inverting amplifiers, and a sinusoidal signal of 1V at 1 kHz was applied at the VB_EXT, IN is left unconnected and VB is grounded. The connections as summarized in the table 2

Output/Input	**Description**
IN	Floating connection
VB	Connected to ground
VB_EXT	Connected to the output port (AO0) of the NIDAC generating the sinusoid signal
VOUT	Connected to the input port (AI1)of the NIDAC
LPF	Connected to the input port (AI0)of the NIDAC

Table 2: Input output connections for each channel for testing the TIA.

The outputs at the VOUT and LPF for all the 8 channels is verified using the LabView interface. This test is done for all the channels, and the observed output is shown in figure (6). It is clear that the TIA works as expected. The phase lag in the output of the LPF output is due to the resistor and capacitor.



(a) When sw is connected to external VB

(b) When sw is connected to internal VB

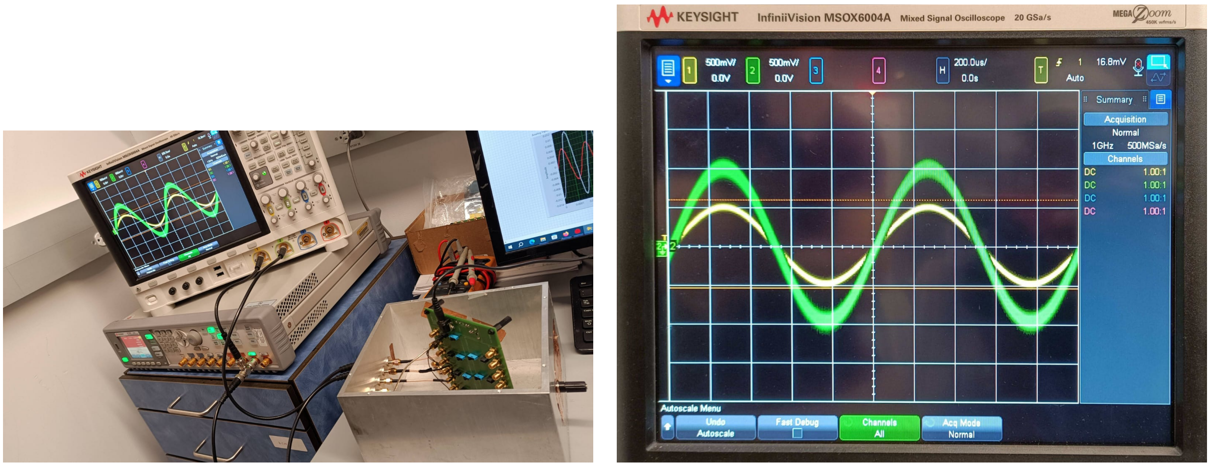
Figure 6: Channel output for sinusoidal input with frequency 1kHz. White : LPF output, Red : TIA output

3.1.2 Testing the voltage amplifier

This test is intended to check the working of the voltage amplifier. The amplifier is designed to have a non-inverting gain of 2. To verify this, a sinusoidal signal of 1kHz is supplied to the input VB, and the output is observed at pin 2 of the switch (pin facing into the center of the board).

For this testing, a signal generator (KeySight A1150A) is used to generate a sinusoid with a frequency of 1kHz and an amplitude of 0.5V. An oscilloscope is used to view the results. The switch was connected to VB_EXT to isolate the amplifier from the rest of the circuit.

Figure 7 shows the setup and the output observed on the Oscilloscope. It is observed that the amplitude of the output sinusoid is double that of the input sinusoid, indicating the functionality of the circuit.



(a) Test setup

(b) Green : output observed, Yellow : input

Figure 7: Voltage amplifier testing

3.1.3 Testing the Low Pass Filter

This test is intended to check the functionality of the Low Pass Filter. The connections are the same as those in table 2. Here, we will send an input of a sinusoid with a frequency of 6kHz to the VB_EXT.

Figure 8 shows the observed low pass filter output (white) and the TIA output (red). It is observed that when a signal of 6kHz is given as input, the low pass filter attenuates it. The amplitude is reduced, demonstrating the low pass filtering effect on high-frequency signals.

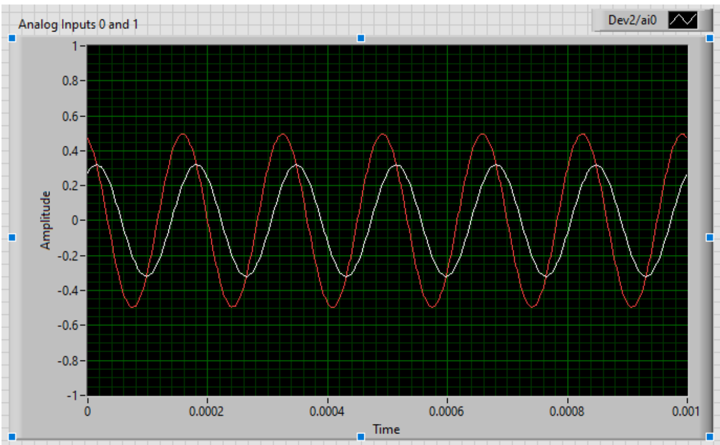


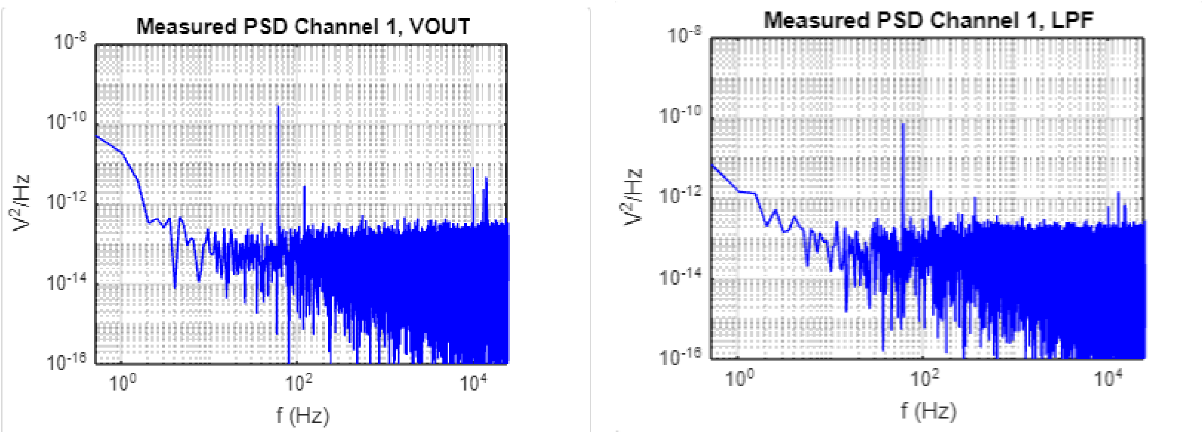
Figure 8: Low Pass Filter Test Output

3.2 Noise Test

To measure the noise, the board inputs were left open or connected to the NI DAQ outputs while generating a signal of 0 VDC (Gnd). The output voltages were acquired for approximately 2 seconds. Then, the signal observed at the output was squared, and the Fast Fourier Transform (FFT) was applied to obtain the output voltage noise Power Spectral Density (PSD). Finally, the Root Mean Square (RMS) value of the PSD was calculated by integrating over a frequency range from 0 to 5 kHz. This will give us the output referred noise. To get the input referred current noise we can divide it by the gain of the TIA (110×10^3). These steps were performed using Matlab, and the code was initially developed for another project with the same purpose. The connections are as described in Table 3.

Output/Input	Description
IN	Floating connection
VB	Connected to ground
VB_EXT	Floating connection
VOUT	Connected to the input port (AI1) of the NIDAC
LPF	Connected to the input port (AI0) of the NIDAC

Table 3: Input output connections for noise analysis



(a) VOUT

(b) LPF

Figure 9: Output Noise Power Spectral Density for Channel 1

This is performed for all the channels. Table 4 summarizes the input referred noises.

Channel	$V_{IN}(I_{RMS})$	LPF (I_{RMS})
Channel 1	2.5966×10^{-10}	1.5505×10^{-10}
Channel 2	2.8329×10^{-10}	1.8911×10^{-10}
Channel 3	2.5804×10^{-10}	2.5744×10^{-10}
Channel 4	2.5269×10^{-8}	2.5547×10^{-8}
Channel 5	2.0752×10^{-10}	2.7285×10^{-10}
Channel 6	3.9245×10^{-10}	2.7749×10^{-10}
Channel 7	2.2466×10^{-10}	1.617×10^{-10}
Channel 8	2.4244×10^{-10}	1.9204×10^{-10}

Table 4: Input Inferred Current Noise for all the channels.

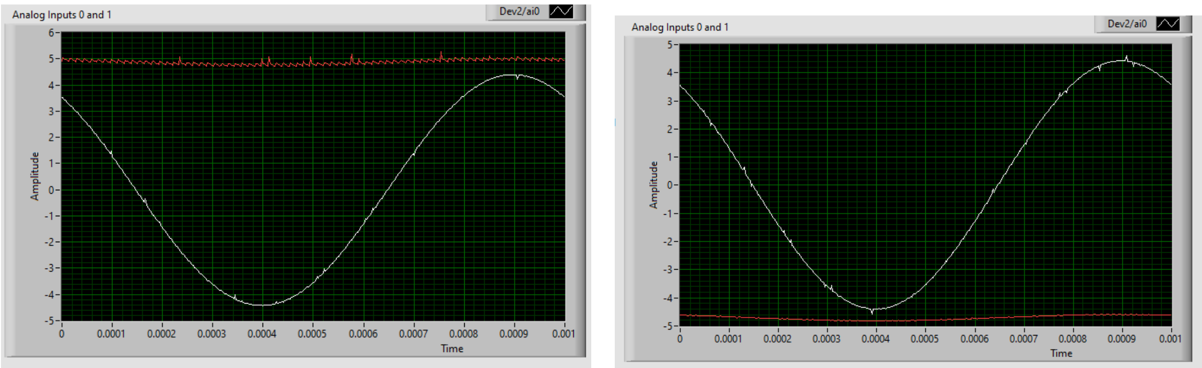
4 Trouble Shooting

4.1 High Frequency Noise from the Power Supply

The circuit's output was found to be affected by noise present in the power supply. Further analysis identified the +5V voltage regulator as the source of this noise, leading to fluctuations in the output and impacting the circuit's performance. To resolve this issue, additional filtering or decoupling may be necessary to reduce the noise and ensure stable circuit operation.

Moreover, it was discovered that the unregulated voltage from the power supply remained stable without significant noise. As a temporary solution to address the issue, the +5V regulator was removed from the board, and the channels were directly supplied with power from the power supply.

Figure 10 illustrates the output of the +5V voltage regulator (Red). The output of the -5V voltage is stable as expected without any noise. By removing the +5V voltage regulator from the circuit, the high-frequency noise it introduced was eliminated, resulting in improved circuit stability.



(a) +5V voltage regulator output (Red)

(b) -5V voltage regulator output (Red)

Figure 10: Voltage Regulator Output

For a long-term solution, it is advisable to consider additional measures, such as implementing appropriate filtering components or employing better voltage regulation methods, to effectively deal with the noise issue. Additionally, ensuring a clean and stable DC power supply is essential to prevent disturbances caused by noise or fluctuations in the power supply.

4.2 Noise Induced by the Cables

Significant noise was observed due to the contribution from the input cables used in the circuit. To mitigate this issue, a solution was implemented by shielding the input cables with ground. Figure 11 illustrates the shielding process employed to eliminate noise induced by the input cables.

The shielding technique involves surrounding the input cables with a conductive material, such as a grounded metal shield. This shield acts as a barrier to external electromagnetic interference and helps prevent noise from coupling into the cables. By connecting the shield to ground, any induced noise or electromagnetic interference is redirected away from the sensitive signal-carrying conductors, reducing the overall noise level in the circuit.

With this shielding in place, the circuit should experience reduced noise from external sources, leading to improved signal integrity and more accurate measurements or performance. However, it is essential to ensure proper grounding and shielding techniques are used to achieve optimal noise reduction benefits.

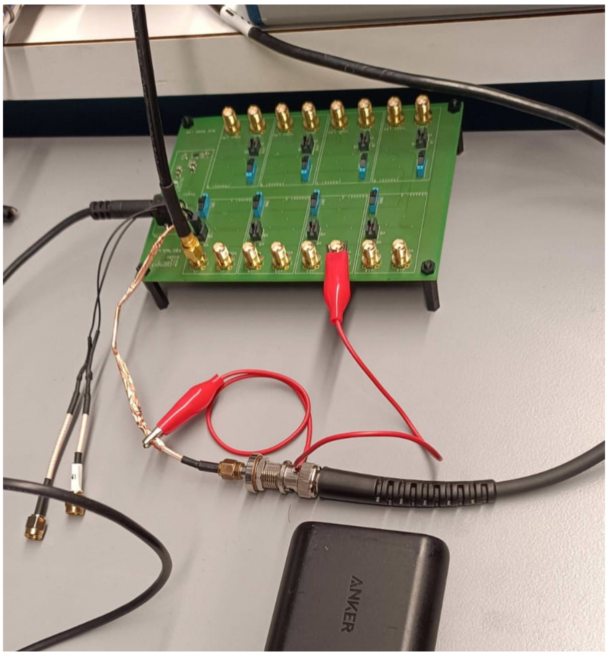


Figure 11: Cables shielded using ground to eliminate noise

4.3 Noise induced by the Power Adapter

While conducting measurements for the noise analysis, it was observed that the power adapter itself produced a low-frequency noise. This noise likely originated from the power adapter's internal components and circuitry, introducing unwanted fluctuations into the power supply.

To address this issue and achieve better noise performance, power bank was utilized. Power banks are known to provide a more stable and cleaner power output compared to some power adapters, especially when it comes to low-frequency noise.

By using the power bank as the power source, the low-frequency noise interference was reduced. As a result, the measurements obtained were more reliable and accurate, with less noise affecting the overall performance of the circuit.

Choosing an appropriate and reliable power source is crucial in noise-sensitive applications, as the quality of the power supply can directly impact the circuit's performance and measurement accuracy. The switch to a power bank in this case demonstrates the importance of considering the power supply's noise characteristics to ensure optimal functioning of the circuit and precise measurements.