# TN1598

Technical note

## Analog signal sense with isolation

## Introduction

In digital controlled power supplies, there are several voltage or current signals that need to be sensed at the analog to digital converter (ADC) peripheral of the microcontroller (MCU). The situation becomes challenging when the isolation between signal sense ground (GND) and microcontroller GND is required.

This technical note is highlighting one of the alternative solutions to sense voltage or current signal at ADC peripheral of MCU with isolation. Though there are dedicated integrated chips (IC's) available to address the above requirements, they have several limitations, such as sense signal gain, bandwidth of operational amplifier, etc. This alternate solution not only overcomes the mentioned limitations, but is also cost-effective.

**Figure 1. Daughter board developed - top view**

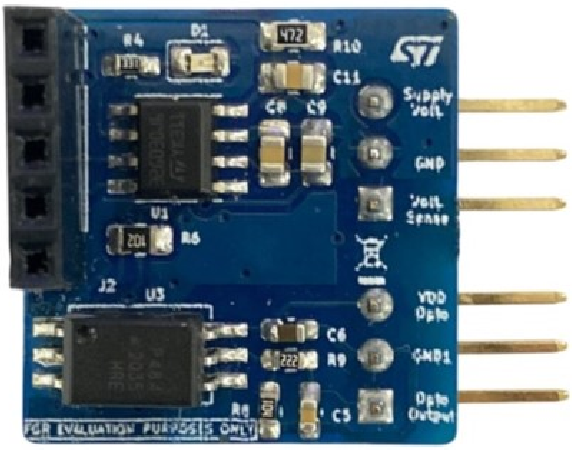
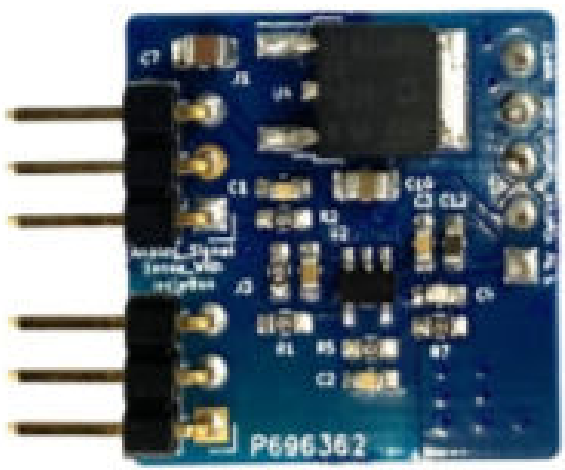
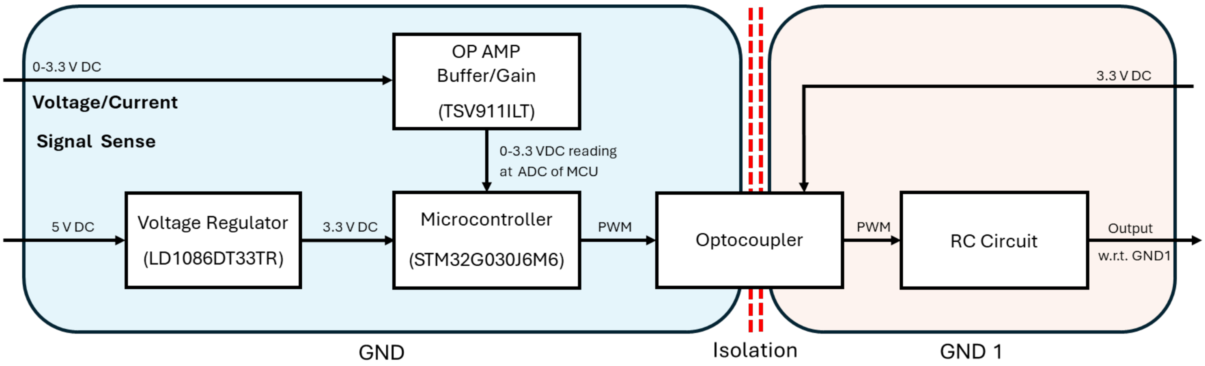



**Figure 2. Daughter board developed - bottom view**



# 1 Overview and block diagram

Figure 3. Architectural block diagram



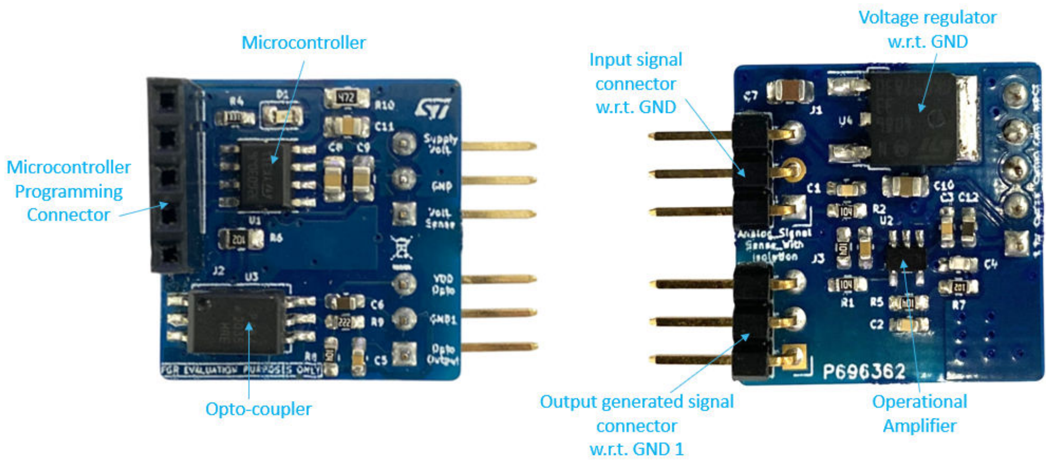

The analog signal, which is to be measured, is fed at non-inverting input of the operational amplifier, that not only provides high impedance input, but is also used for gain, if required. The signal is then sampled at the analog to digital converter (ADC) peripheral of the microcontroller. The operational amplifier and microcontroller are referred to the same ground (GND) as that of measured analog signal, as shown in Figure 3.

Depending on the ADC value, the microcontroller generates pulse width modulation (PWM), which is an input to the optocoupler. The optocoupler provides the isolation required, and the PWM generated with respect to another ground (GND 1) is passed through the RC filter. The output measurement after the RC filter w.r.t. GND 1 matches fairly accurately with the input analog signal measured w.r.t. GND.

The board pictures have been highlighted in Figure 1 and Figure 2, while the details of firmware and testing results are highlighted in subsequent sections.

## 1.1 Key components

Figure 4. Key components used on the daughter board



# 2 Electrical specifications

**Table 1. Electrical specifications of the daughter board**

| Parameters | Range |
|---|---|
| Input voltage supply - primary | 5 ~ 24 V |
| Analog sense signal voltage range | 0 ~ 3.3 V DC |
| Opto-coupler input voltage – secondary | 3.3 V DC |
| Output signal accuracy | > 98% |

The operational amplifier is configured for unity gain buffer by default, as per the Schematic diagrams. The gain of the operational amplifier can be adjusted using R1 and R5 resistances.

The value of resistance R3 must be the same as that of resistance R5.

The gain of the differential operational amplifier can be calculated with the below equation.

$$Gain = \frac{R5}{R1} \cdot \left(V_{non-inverting} - V_{inverting}\right)$$

$$Gain = \frac{R5}{R1} \cdot (V_{sense} - 0)$$

$$Gain = \frac{R5}{R1} \cdot (V_{sense})$$

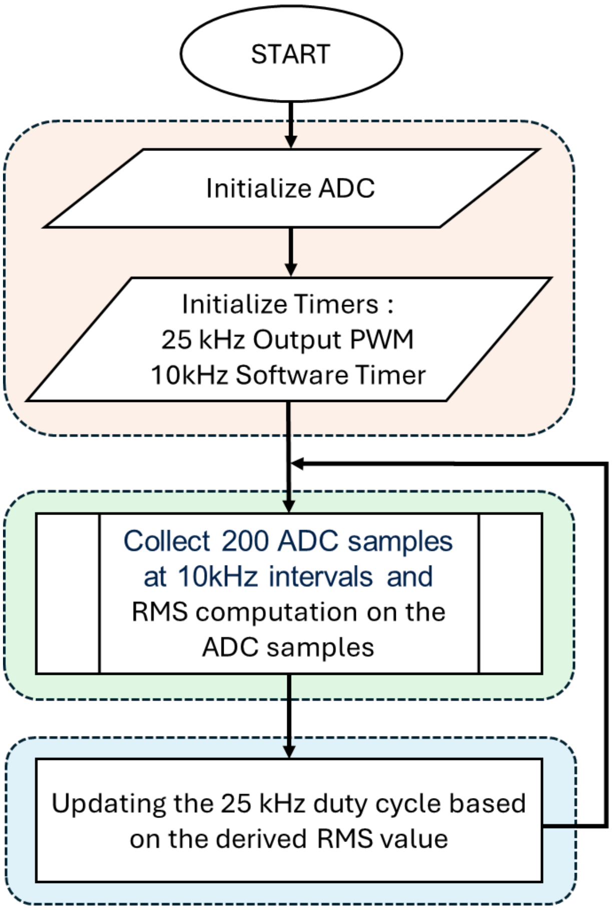
# 3 Firmware

The STM32G030 microcontroller has been configured to sample ADC signal at 10 kHz frequency. It computes 200 samples and it calculates the root mean square (RMS) value. The microcontroller also generates a 25 kHz PWM signal. The duty cycle of the PWM is governed by the calculated RMS value of the sensed signal. The firmware flowchart is highlighted in Figure 5.

The STM32G030 microcontroller is equipped with 12-bit ADC peripheral. The output PWM duty cycle is calculated with the following expression:

$$Duty\ cycle\ of\ 25\ kHz = \frac{Calculated\ RMS\ value \cdot TIMER(25kHz)_{ARR}}{2^{12}} = \frac{RMSvalue \cdot TIMER(25kHz)_{ARR}}{4096}$$

**Figure 5. Firmware flowchart**

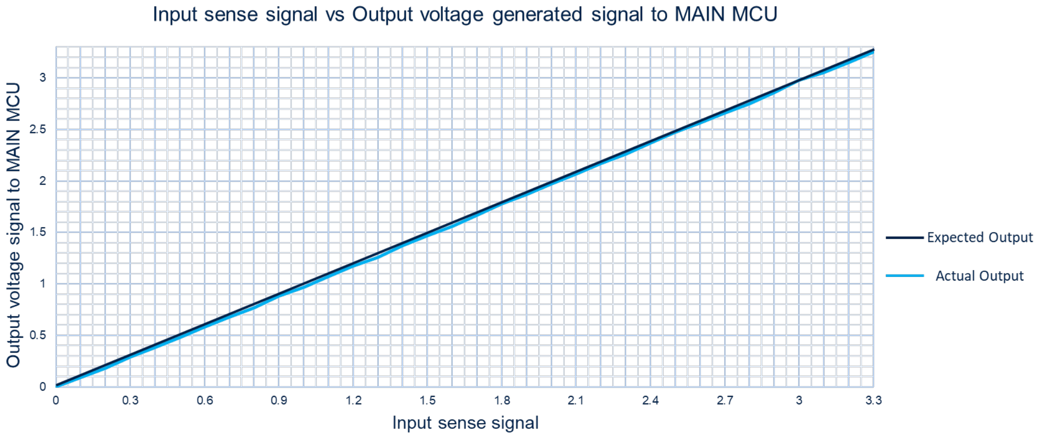


# 4 Test results and waveforms

## 4.1 Test results

A graph between input sense signal and output voltage signal has been highlighted in Figure 6. It can be oserved that the daughter board output signal is roughly the same as that of input sense signal, with an accuracy above 98%.

**Figure 6. Input sense signal vs output signal from microcontroller**




## 4.2 Waveforms

Below are the waveforms, highlighting the change in the output signal based on different input sense signals. In order to optimize the speed, number of samples, sampling frequency, and output signal, PWM frequency can be altered in the firmware.

**Figure 7. Input sense signal (yellow) vs output signal generated (blue) - Transition from 0 to 1 V**

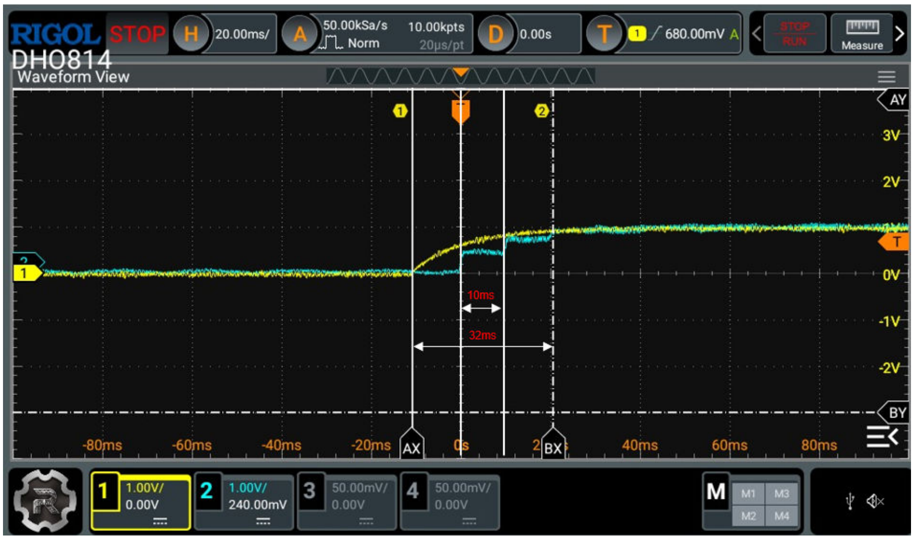


Figure 8. **Input sense signal (yellow) vs output signal generated (blue) - Transition from 0 to 2 V**

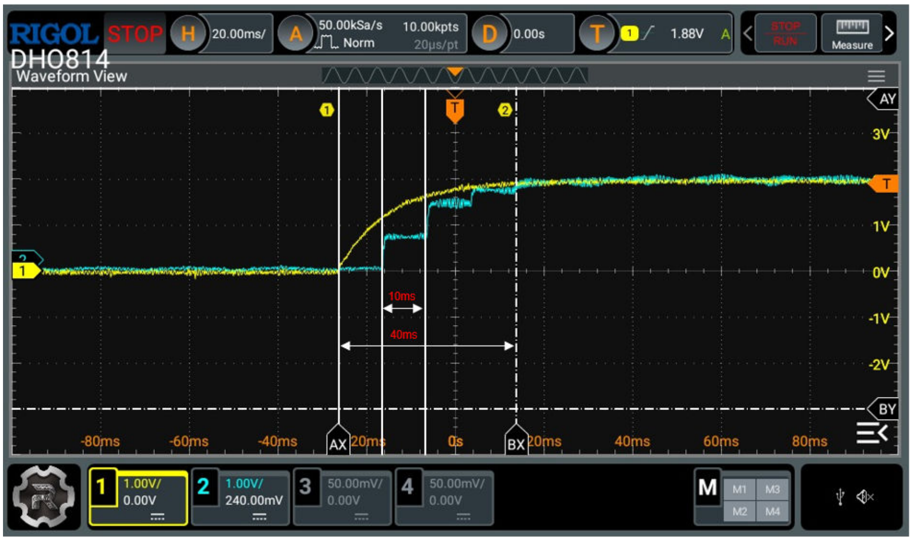



Figure 9. **Input sense signal (yellow) vs output signal generated (blue) - Transition from 0 to 3.3 V**

# 5 Use cases

Before the signal is sensed by the microcontroller, the analog signal is fed to the operational amplifier. The default resistors (R1, R3, and R5) values have been selected to have gain equal to 1.

## 5.1 Voltage signal sense

Example: 2 V analog signal sense.

The non-inverting input of operational amplifier sees the voltage level of 2 V. As this signal has decent amplitude, the default unity gain configuration of the operational amplifier can be used.

The microcontroller takes 200 samples at a 10 kHz interval and perform RMS computation. Based on the RMS computation result, the 25 kHz PWM duty cycle is calculated as highlighted in Section 3. For 2 V signal, the duty cycle is approximately 60.6%. This PWM passes through the RC (R9, C5) filter, providing stable reading at the output.

## 5.2 Current signal sense

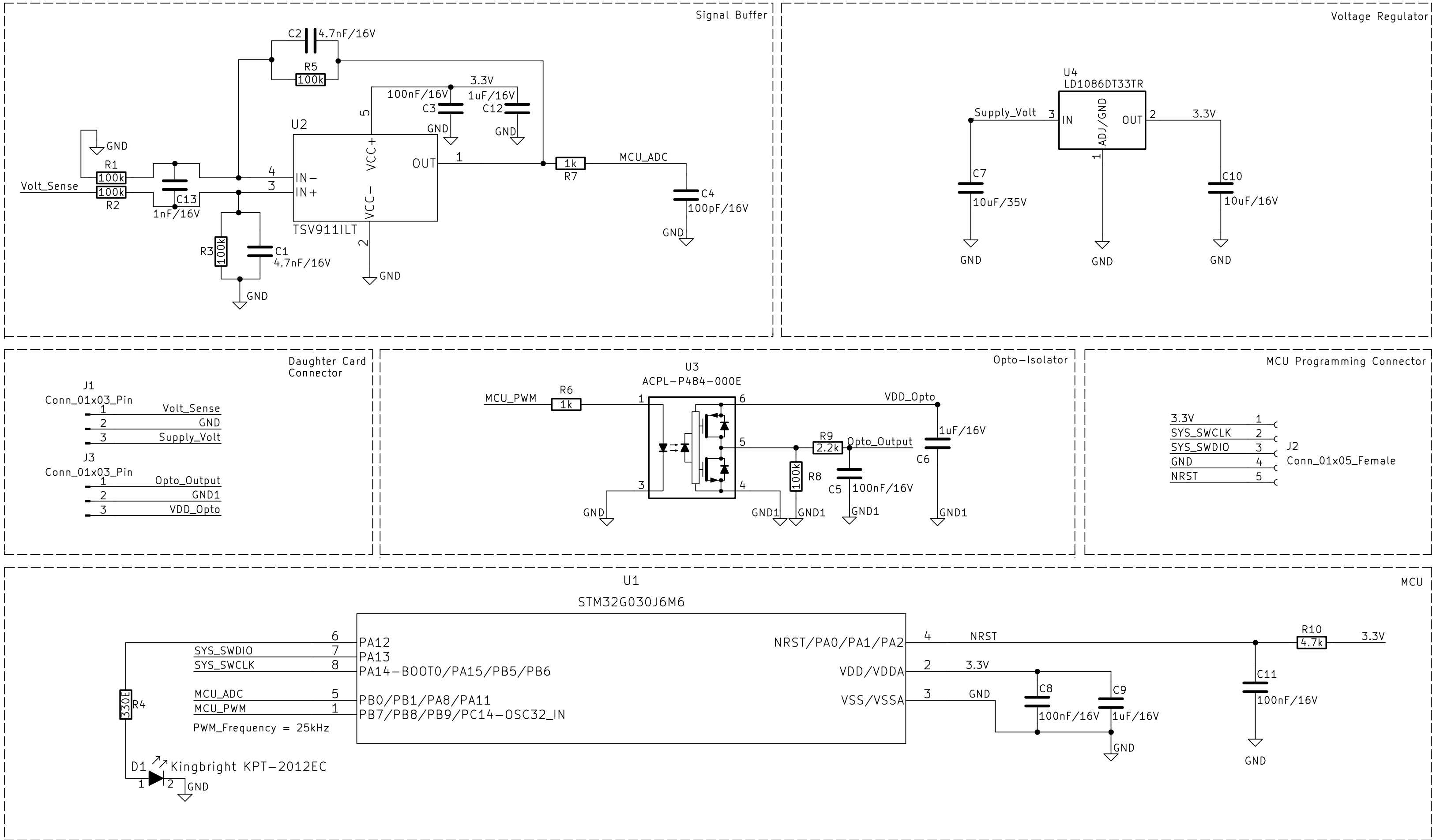
Example: 10 A through 5 MΩ shunt resistor.

The voltage across the shunt and the non-inverting input of operational amplifier see the voltage level of 50 mV (10A x 5 MΩ), which has quite a low amplitude. Using resistors (R1, R3, and R5), the gain of the operational amplifier can be increased to have a signal, which can be measured at the desired voltage level.

In this case, the gain 20 has been selected, so R3 and R5 need to be changed to 2 MΩ, while R1 should be 100 k. By applying these changes, the 50 mV (original analog signal) gives the input of microcontroller ADC peripheral of 1 V. The microcontroller takes 200 samples at a 10kHz interval and perform RMS computation. Based on the RMS computation result, the 25 kHz PWM duty cycle is calculated as highlighted in Section 3. For 1 V signal, the duty cycle is approximately 30.3%. This PWM passes through the RC (R9, C5) filter, giving stable reading at the output.

# 6 Schematic diagrams

**Figure 10.** Daughter board circuit schematic



# 7 PCB layout

Figure 11. **Board layout - top**

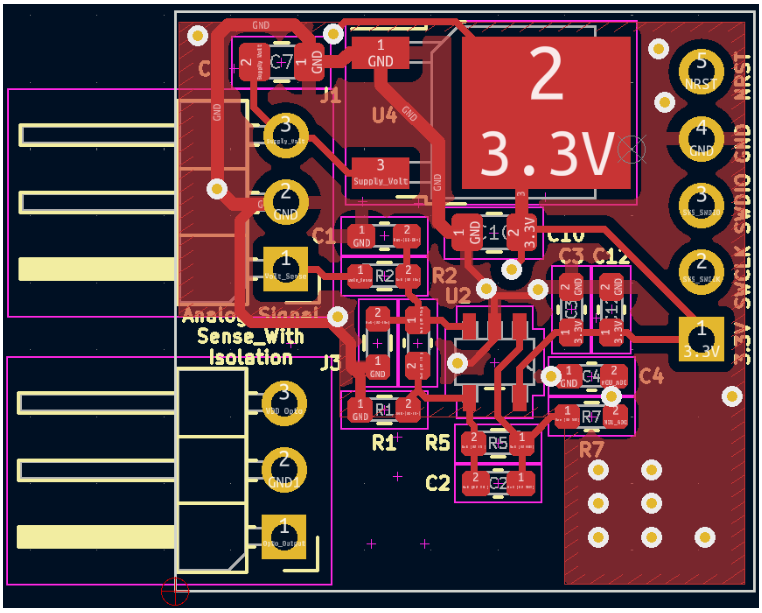
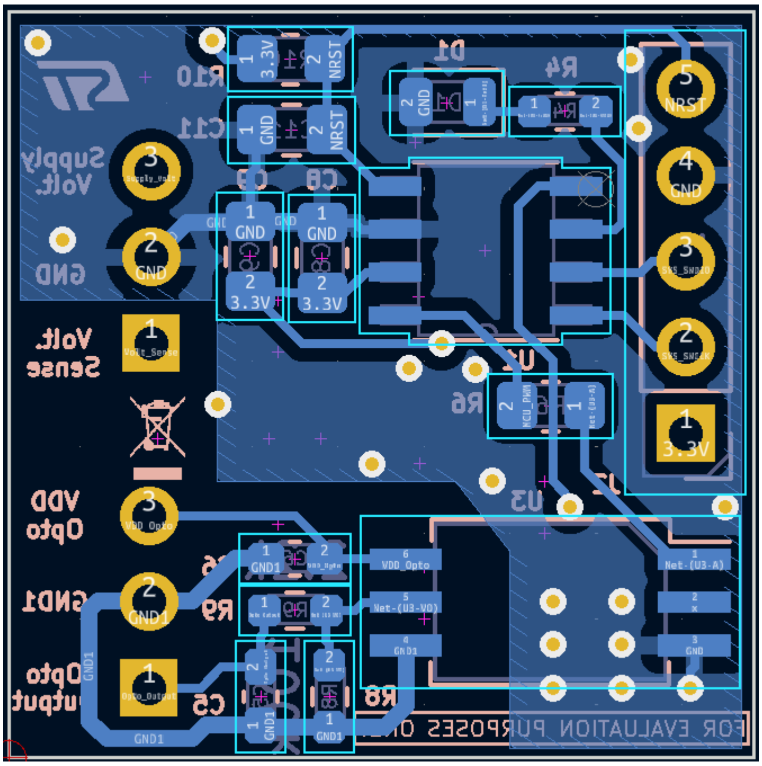



Figure 12. **Board layout - bottom**



# 8 Bill of materials

**Table 2. Daughter board bill of materials**

| Item | Q.ty | Ref. | Part/value | Description | Manufacturer | Order code |
|---|---|---|---|---|---|---|
| 1 | 2 | C1,C2 | 4.7nF | Ceramic Capacitor X7R | Wurth Elektronik | 885012206038 |
| 2 | 1 | C4 | 100pF | Ceramic Capacitor X7R | Wurth Elektronik | 885012206028 |
| 3 | 2 | C8,C11 | 100nF | Ceramic Capacitor X7R | Wurth Elektronik | 885012207045 |
| 4 | 2 | C3,C5 | 100nF | Ceramic Capacitor X7R | Wurth Elektronik | 885012206046 |
| 5 | 1 | C9 | 1uF | Ceramic Capacitor X7R | Wurth Elektronik | 885012207051 |
| 6 | 2 | C6,C12 | 1uF | Ceramic Capacitor X7R | Wurth Elektronik | 885012206052 |
| 7 | 1 | C7 | 10uF | Ceramic Capacitor X7R | TAIYO YUDEN | EMK212BB7106KG-T |
| 8 | 1 | C10 | 10uF | Ceramic Capacitor | TAIYO YUDEN | MSASG21GBB5106KTNA01 |
| 9 | 1 | C13 | 1nF | Ceramic Capacitor X7R | Wurth Elektronik | 885012206034 |
| 10 | 1 | D1 | Red Led | Red Color LED | Kingbright | APT2012EC |
| 11 | 1 | J1 | Connector 01x06_Male_Right_Angle | Connector 2.54mm Pitch | Wurth Elektronik | 61300611021 |
| 12 | 1 | J2 | Connector_01x05_Female | Connector 2.54mm Pitch | Samtec | CES-105-02-G-S |
| 13 | 5 | R1,R2,R3,R5,R8 | 100k | Thick Film Resistor | Vishay | CRCW0603100KFHEAP |
| 14 | 1 | R6 | 1k | Thick Film Resistor | Vishay | RCA08051K00FKEAHP |
| 15 | 1 | R7 | 1k | Thick Film Resistor | Vishay | CRCW06031K00FKEA |
| 16 | 1 | R4 | 330E | Thick Film Resistor | Vishay | CRCW0603330RFKEC |
| 17 | 1 | R9 | 2.2k | Thick Film Resistor | Vishay | CHP0603K2201FBT |
| 18 | 1 | R10 | 4.7k | Thick Film Resistor | Vishay | CRCW08054K70FKEC |
| 19 | 1 | U1 | STM32G030J6M6, SO-8 | Arm® Cortex®-M0+ 32-bit MCU | ST | STM32G030J6M6 |
| 20 | 1 | U2 | TSV911ILT, SOT23-5L | 8 MHz operational amplifiers | ST | TSV911ILT |
| 21 | 1 | U3 | ACPL-P484-000E | High-speed optocoupler | Broadcom | ACPL-P484-000E |
| 22 | 1 | U4 | LD1086DT33TR, DPAK | Low drop voltage regulator | ST | LD1086DT33TR |

# 9 Conclusion

The goal of this technical note is to highlight a method to sense analog signal at the ADC peripheral of the MCU with isolation, as in the case of STDES-2KW5CH48V, where primary DC BUS voltage needs to be sensed at the microcontroller referenced at secondary ground.

The components used in the Schematic diagrams can be altered as per user specific needs. For example, a voltage regulator of less quiescent current or smaller package can be used to effectively reduce PCB size.

# Appendix A Reference design warnings, restrictions and disclaimer

*Important:* *The reference design is not a complete product. It is intended exclusively for evaluation in laboratory/ development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical/mechanical components, systems and subsystems.*

**Danger:** *Exceeding the specified reference design ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings, contact an STMicroelectronics field representative prior to connecting interface electronics, including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the reference design and/or interface electronics. During normal operation, some circuit components may reach very high temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified in the reference design schematic diagrams.*

STMicroelectronics reference designs are solely intended to assist designers ("buyers") who are developing systems that incorporate STMicroelectronics semiconductor products (herein, also referred to as "components"). The buyer understands and agrees that he/she is the only responsible for independent analysis, evaluation and judgment in designing his/her own systems and products. STMicroelectronics has conducted only the measurements and tests specifically described in the published documentation for the specified reference design. STMicroelectronics may correct, enhance, improve its reference designs for future development.

STMicroelectronics reference designs are provided "as is". STMicroelectronics does not promise that reference designs are accurate or error free. STMicroelectronics makes no warranties or representations with regard to the reference designs or use of the reference designs, express, implied or statutory, and specifically disclaims all warranties, express or implied, as to the accuracy or completeness of the information contained therein.

STMicroelectronics disclaims any warranty of title and any implied warranties of merchantability, fitness for a particular purpose and non-infringement of any third-party intellectual property rights concerning STMicroelectronics reference designs or their use. STMicroelectronics shall not be liable for and shall not defend or indemnify buyers against third-party infringement claim that relates to or is based on a combination of components provided in an STMicroelectronics reference design.

In no event shall STMicroelectronics be liable for any actual, special, incidental, consequential or indirect damages, however caused, on any theory of liability and whether or not STMicroelectronics has been advised of the possibility of such damages, arising in any way out of STMicroelectronics reference designs or buyer's use of STMicroelectronics reference designs.

You further acknowledge and agree that the reference designs may not be used in or in connection with any legal or administrative proceeding in any court, arbitration, agency, commission or other tribunal or in connection with any action, cause of action, litigation, claim, allegation, demand or dispute of any kind.

## Revision history

Table 3. Document revision history

| Date | Revision | Changes |
|---|---|---|
| 07-Jul-2025 | 1 | Initial release. |

## Contents

# List of tables

# List of figures