Reflow-Oven Controller

Electronics design

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1 Introduction

The purpose of this document is to detail the electronics design, component selection, and calculations for a custom Reflow Oven Controller board.

This device is designed to convert a standard consumer oven into a PCB reflow soldering station. The main objective is to precisely control the oven's heating element to follow a specific temperature profile required for soldering surface-mount components. The controller manages the AC mains power to the heater, monitors the internal temperature in real-time, and provides a user interface for operation and status monitoring.

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2 System Overview

2.1 Functional Description

The Reflow Oven Controller operates as a closed-loop feedback system that regulates the temperature of a resistive heating element.

Power Control: The system controls the AC mains power (220V, 50Hz) delivered to the oven's heater. Instead of complex phase-angle control, the system utilizes a simple on/off control scheme (Zero-Crossing), which is sufficient due to the high thermal inertia of the oven.

Isolation & Safety: To ensure safety and protect the low-voltage logic, a TRIAC is used to switch the load, driven by an Opto-TRIAC to provide galvanic isolation between the microcontroller and the high-voltage mains.

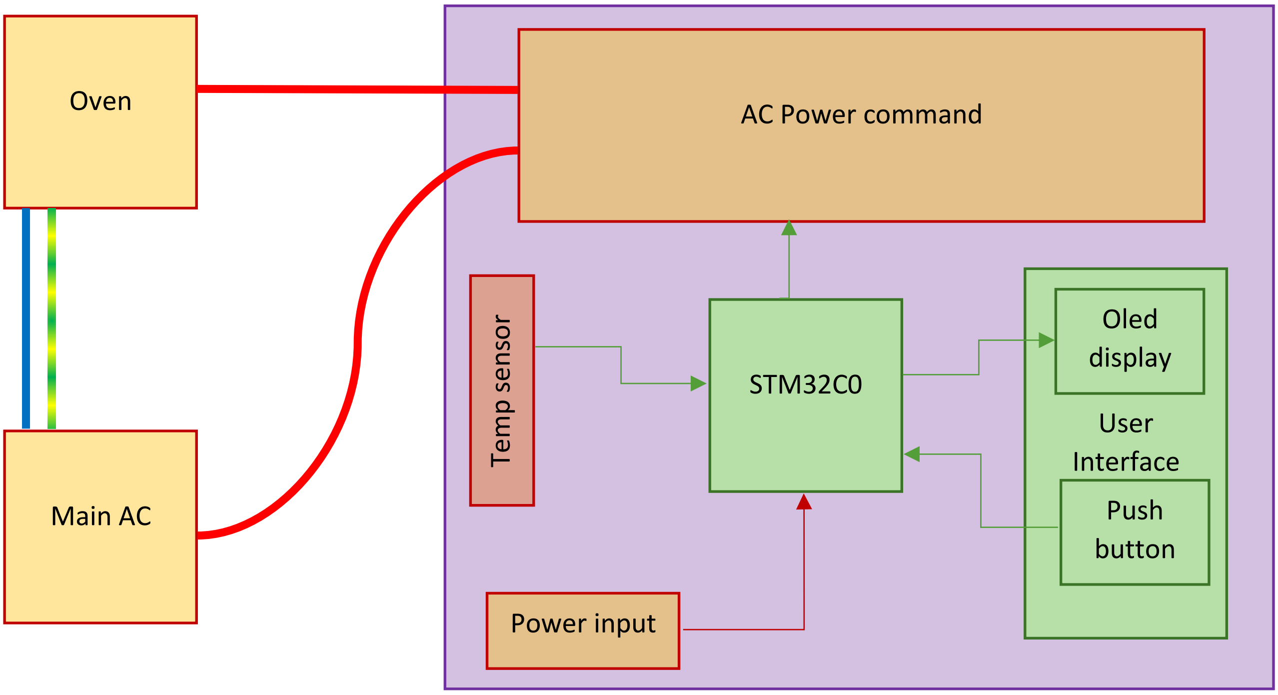
Central Processing: An STM32C0 series microcontroller acts as the brain of the system. It reads the temperature sensor, processes the control logic, drives the solid-state switch, and manages the user interface.

Sensing: Temperature monitoring is achieved using a glass-encapsulated NTC thermistor capable of withstanding high temperatures (up to 300°C) placed inside the oven.

User Interface: The operator interacts with the device through an OLED display and a set of push-buttons, allowing for profile selection and visual feedback during the reflow process.

Power Supply: The logic circuitry is powered via a USB-C connector (5V), which is regulated down to 3.3V to supply the microcontroller and peripherals.

2.2 Block Diagram



2.3 Main Design Requirements

The hardware design is driven by the following key electrical and environmental requirements:

AC Mains Compatibility: The device must operate on a 220V / 50Hz mains supply.

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Load Capacity: The power stage must handle ovens rated up to 2400 W, requiring a design reference current of approximately 12 A.

Thermal Environment: Electronic components, particularly the power stage, must be rated to operate reliably within an enclosure ambient temperature of 50°C.

Galvanic Isolation: There must be complete isolation between the AC mains and the user-accessible logic/interface section.

EMI Reduction: Switching must occur at the AC zero-crossing point to minimize electromagnetic interference (EMI) and power losses.

Low Voltage Supply: The board must be powered by a standard USB-C connection (5V) and internally regulated to 3.3V for logic operation.

Cost & Assembly: The design prioritizes low-cost components and packages suitable for hand-soldering (e.g., TSSOP-20 for the MCU, SOT-223 for the LDO).

Temperature Range: The sensing subsystem must accurately measure temperatures from ambient (~15°C) up to the reflow peak of 260°C.

3 Heater power control

The main objective is to switch the oven on and off for use as a reflow oven. A TRIAC will be used to control the mains power to the oven, and an opto-TRIAC driver will provide galvanic isolation between the microcontroller and the AC mains. Due to the thermal inertia of the oven, precise phase-angle control is not required. Simple on/off control is sufficient. To minimize unnecessary power losses and reduce EMI, a zero-crossing opto-TRIAC is used (at 50 Hz, the mains voltage crosses zero every 10 ms).

We will design the board for ovens up to 2400 W on a 220 V / 50 Hz mains supply.

The corresponding RMS current is:
- $\frac{2400\,W}{220V} \approx 10.9\,A$
- Adding a 5% margin gives 11.45 A, so we will use 12 A as the design reference current.

3.1 Triac

To select a suitable TRIAC, we use ST's ACS/TRIAC selection and simulation tool:
https://eds.st.com/acswitch/#/

The simulator is configured with the following parameters:
- Nominal input voltage: 230 V
- Output RMS current: 12 A
- Load type: Heater
- Gate control: Isolated, phototriac

The Simulator give us the following schematics:

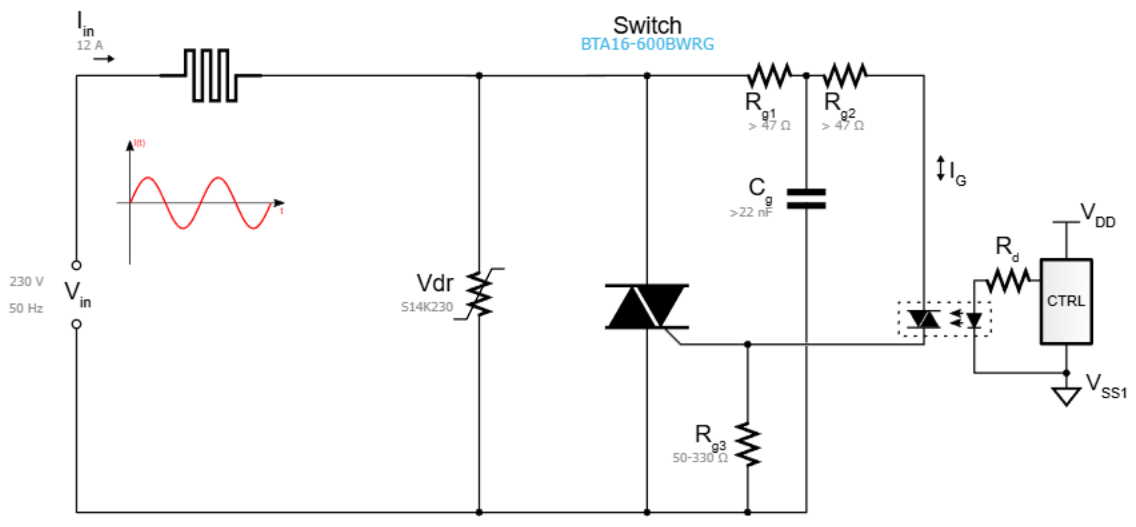


Figure 1: Heater Power Control ST Schematics

From the list of TRIACs suggested by ST, we will select the device with the lowest power dissipation. However, before making a final choice, we must refine the simulation parameters: 12 A_{RMS} is too high to handle without an adequate heatsink.

In the ST simulator, under the heatsink selection options, we choose “Case in Environment” and set the environment temperature to 50 °C (estimated internal temperature inside a closed enclosure).

With these conditions, the BTA16-600CW appears to be a good candidate:
- I_{RMS} max: 16 A
- V_{DRM}/ V_{RRM}: 600 V

From the datasheet, in Figure 2: “Maximum power dissipation versus on-state RMS current (full cycle)”, the expected power dissipation at 12 A_{RMS} is approximately 13W.

3.2 Heatsink

To dissipate these 13 W, we need a heatsink such that the total thermal resistance keeps the TRIAC junction below its maximum temperature. The required heatsink thermal resistance Rth(sa) can be calculated with:

$$P = \frac{(Tjmax - Ta)}{Rth(jc) + Rth(cs) + Rth(sa)}$$

From the datasheet and our assumptions:
-Rth(jc) = 2.1°C/W
-Tjmax = 125°C.
-Ta = 50°C (temperature inside the box)
-Rth(cs) = 0.5°C/W

$$Rth(sa) = \frac{(Tjmax - Ta)}{P} - Rth(jc) - Rth(cs) = \frac{(125-50)}{13} - 2.1 - 0.5 = 3.17°C/W$$

To safely dissipate 13 W at a 50°C ambient temperature inside the enclosure, we will need a heatsink with a thermal resistance of 3.17 °C/W or lower (the lower the value, the more effective the heatsink).

We will choose Heatsink 530002B02500G from BOYD for our design

The heatsink 530002B02500G from BOYD has a thermal resistance of 2.6 °C/W. At 14 W, it will cause a temperature rise of about 50°C (see thermal graph from datasheet) above the ambient temperature inside the box. With Ta = 50 °C, the heatsink temperature will be approximately 100°C, and the TRIAC junction will remain below its maximum 125 °C limit, ensuring safe operation.

3.3 OptoTriac

The opto-triac is driven directly by the STM32 GPIO (3.3 V maximum I/O voltage).
A zero-crossing device is required for reliable operation on 220 V rms mains.
The MOC3063, a widely used zero-crossing opto-triac, satisfies these requirements and is used in this design.

Emitter side
- Forward voltage (Vf) minimum: 0.7 V at Ift ≈ 0.1 mA
- Series resistor: 150 Ω from the 3.3 V GPIO to the LED

Power dissipation in the LED:

$$Pemitter = \frac{(3.3 - Vf\_min)^2}{150} = \frac{(3.3 - 0.7)^2}{150} \approx 48\,mW$$

Assuming an ambient temperature Ta = 50 °C and an LED thermal resistance giving a power-to-temperature factor of 0.00141 W/°C, the junction temperature is:

$$Tj_{emitter} = Ta + \frac{Pemitter}{0.00141} = 50°C + \frac{0.048}{0.00141} = 84°C$$

Detector side

The driven power triac is a BTA16CW, with a maximum gate trigger current of 25 mA.
At this current, the voltage across the opto-triac output is:
Vtm(max at 25 mA) = 1.8 V

Power dissipation in the detector:

$$Pdetector = Vtm \times Igate = 1.8\,V \times 25\,mA \approx 45\,mW$$

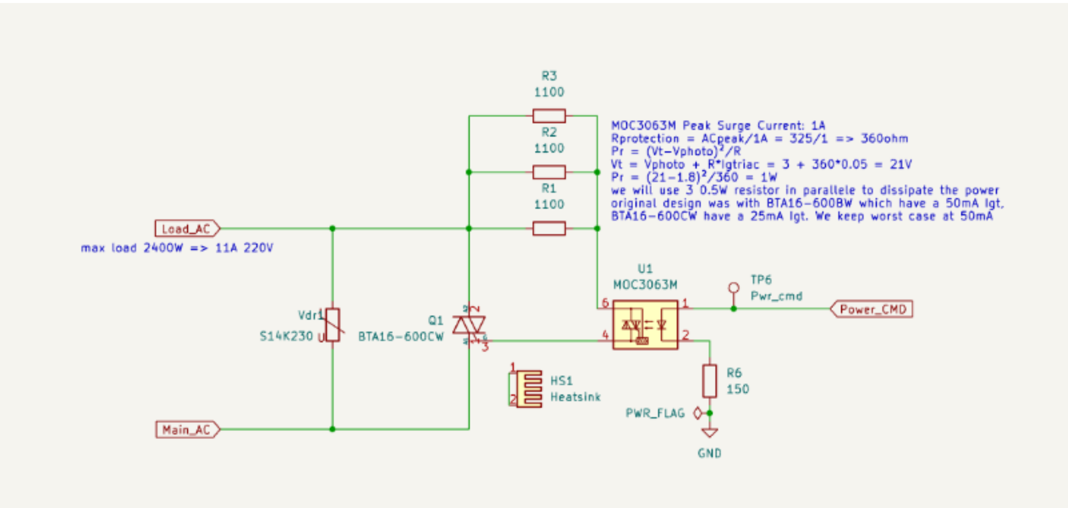
With an ambient temperature Ta = 50 °C and a power-to-temperature factor of 0.00176 W/°C for the detector section, the junction temperature is:

$$Tj_{detector} = Ta + \frac{Pdetector}{0.00176} = 50°C + \frac{0.045}{0.00176} = 76°C$$

Both the emitter and detector junction temperatures remain well within the safe operating range for the MOC3063 under the specified conditions.

3.4 Passive Components

The BTA16 is a snubberless Triac, and the load will not produce enough noise to cause issues. We can therefore simplify the design as follows.



The resistor between the triac and the optotriac is designed to protect the optotriac from current surges. The MOC3063M can withstand up to 1 A of peak current.

We calculate the minimum resistance as:

$$R = \frac{230 * \sqrt{2}}{1} = 325ohm$$

We therefore need R > 325x1,05 = 341ohm. The closest standard value in the E24 series is 360ohm

Now we calculate the maximum power dissipated in the resistor:

$$Vtriacmax = R * Igatemax + Vphotomax = 360 * 0{,}025 + 3 = 12V$$

$$Pres = \frac{(Vtriacmax - Vphotomin)^2}{R} = \frac{(12-0)^2}{360} = 0.4W$$

To be on the safe side. We will use three 1.1 kΩ, 0.5 W resistors in parallel to dissipate the power.

Recomputing for the worst-case scenario:

$$Iphotomax = \frac{230 * \sqrt{2}}{(R * 0{,}95)/3} = 0{,}934mA$$

$$Presmax = \frac{Vtriacmax^2}{(R * 0{,}95)/3} = 0.41W$$

This satisfies:

$$Iphoto < 1A$$

$$Pres/3 < 0{,}5W$$

So, three 1.1 kΩ, 0.5 W resistors in parallel are sufficient for this design.

3.5 Command resistor

The STM32 microcontroller GPIO outputs 3.3 V with a maximum current of 20 mA.

The MOC3063M LED has a maximum trigger current of 5 mA.

Based on Figure 3: LED Forward Voltage vs. Forward Current from MOC3063M datasheet

- For 5 mA Vfmax = 1.25V

- For 20 mA, Vfmin = 1.1V

Series resistor calculation:

$$Rmin = \frac{1{,}1V}{20mA} = 55ohm$$

$$Rmax = \frac{1{,}25V}{5mA} = 250ohm$$

We will use R = 150ohm, as this value is already used multiple times in our design.

With R = 150ohm, the worst-case current is:

$$If = \frac{3{,}3V * 0{,}95 - 1{,}5V}{150 * 1{,}05} = 10mA > 5mA$$

This ensures reliable triggering of the MOC3063M while staying within the STM32 GPIO current capability.

4 Microcontroller

4.1 Microcontroller selection

The microcontroller is responsible for managing the user interface, temperature measurement, and control of the oven power stage. The following constraints and requirements drove the selection:

Electrical and System Constraints

Supply voltage:
- The board is powered from a USB-C connector.
- A linear regulator (LDO) is used to stabilize the input voltage.
- The microcontroller must operate from a regulated supply below 5 V (nominally 3.3 V).

Required peripherals and I/Os:
- 6 digital inputs for the user interface:
- 1 I²C interface for the OLED display
- 1 analog input for temperature measurement
- 1 digital output for power control

In summary, the microcontroller must provide at least:
- VCC < 5 V
- 6 GPIO inputs
- 1 GPIO output
- 1 I²C bus
- 1 ADC channel

Package and Assembly Constraints

Since the board is intended to be assembled without a reflow oven in the first iterations, ease of hand-soldering is a key criterion:

Preferred package: TSSOP, which offers:
- Sufficient pin pitch for manual soldering
- Good balance between pin count and PCB area

Minimum pin count: at least 10 pins are required (6 inputs + 1 output + I²C + analog input + supply/ground), so TSSOP-8 is not suitable.

Given these constraints, TSSOP-20 devices are a good fit: they are widely available, easy to solder by hand, and provide sufficient I/O and peripherals.

Technology and Cost Considerations

Several MCU families were considered:

Arduino-style MCUs (e.g., ATmega328P):
- Operate at 5 V and are well known.
- However, they are relatively expensive for this application.

ESP32 / Wi-Fi-capable MCUs:
- Provide significantly more performance and peripherals than needed.
- Higher power consumption and unnecessary complexity for this design.

STM32 family (32-bit ARM Cortex-M):

- Low cost, especially in the low-end series.
- Good availability of small packages such as TSSOP-20.
- Familiar toolchain and ecosystem from previous projects.

Given prior experience with STM32 and their cost/performance ratio, an STM32 device was chosen.

Candidate Microcontrollers

Two pin-compatible STM32 devices were identified as suitable candidates:

- STM32C011F6P6
- STM32C031F6P6

Common features relevant to this design:

- Supply voltage compatible with the regulated USB-derived rail (< 5 V).
- TSSOP-20 package, suitable for hand soldering.
- Sufficient GPIOs to handle:
  - 6 push-button inputs
  - 1 digital output for MOC3063M control
  - I^2C interface for the OLED display
  - 1 ADC channel for the thermistor

The main difference between the two devices is available RAM:

- STM32C011F6P6: 6 KB RAM
- STM32C031F6P6: 12 KB RAM

The OLED display has a resolution of 128 × 64 pixels, corresponding to 8192 bits (1024 bytes) for a full framebuffer. Depending on the graphics library and implementation, a significant portion of RAM may be needed to store display buffers, fonts, and temporary data structures.

Because the firmware will be developed after the hardware design, the exact RAM requirement is not fully defined at this stage. To keep flexibility the PCB will be designed to accept either STM32C011F6P6 or STM32C031F6P6 (same pinout/package).

During firmware development, memory usage will be evaluated:

- If 6 KB RAM is sufficient, the STM32C011 can be used, minimizing cost.
- If additional memory is required (e.g., for more complex UI or buffering), the STM32C031 will be assembled instead.

Final Choice

The design supports both STM32C011F6P6 and STM32C031F6P6 in TSSOP-20 package. The STM32C0 series meets all functional, electrical, and packaging constraints while remaining low cost and easy to assemble by hand. The final MCU variant (C011 vs. C031) will be selected based on actual RAM requirements determined during firmware development.

4.2 STM32C0 implementation

The microcontroller used is from the STM32C0 series in a TSSOP-20 package. Pin usage follows the recommendations from the STM32C0 datasheet and is tailored to the application’s I/O, analog, and communication requirements.

Reserved and Special-Function Pins

PF2 – NRST:
- Used as the global reset input for the MCU.
- A 10 kΩ pull-up resistor to VCC is added to prevent unintended resets due to noise.
- A momentary push-button connects NRST to GND to allow manual reset.
- A 100 nF capacitor is connected between NRST and GND, as recommended in the datasheet, to improve noise immunity.

PA14 – BOOT0:
- Used to select the boot mode (normal user flash vs. system bootloader).
- The default state is normal user flash boot:
  - A 10 kΩ pull-down resistor to GND ensures BOOT0 is low during normal operation.
  - A momentary push-button connects BOOT0 to VCC when pressed, allowing the MCU to enter the bootloader if required.
- A 100 nF capacitor is placed between BOOT0 and GND as recommended, to avoid spurious boot mode changes due to noise.

PA14 / PA15 – SWD Interface:
- PA14: SWCLK
- PA15: SWDIO
- These pins are routed to a standard ST-LINK SWD connector for programming and debugging.
- No other functions are assigned to these pins to ensure reliable SWD communication.

PC14 / PC15 – Oscillator Pins:
- Dedicated to an external low-speed or high-speed crystal/oscillator.
- For this design, no external oscillator is used. The internal oscillator of the STM32C0 is sufficient for the required timing accuracy.
- PC14 and PC15 are therefore left unconnected.

Functional Pin Mapping

The remaining pins are assigned as follows:

I²C interface (OLED display)
- PB6: I2C SCL
- PB7: I2C SDA

User push buttons (digital inputs)
- PA2: “Return” button
- PA3: “Valid” button
- PA4 – PA7: 4 directional buttons (cross pattern)

Temperature measurement (analog input)
- PA0: ADC input for the NTC thermistor.

Oven power control (digital output)
- PA8: Digital output driving the control input of the MOC3063M optotriac driver.

Status LEDs (digital outputs)
- PA9/PA10: LED output

This pin mapping was defined in STM32CubeIDE, ensuring all required peripherals (I²C, ADC, GPIO) are properly configured and that there are spare I/Os for debugging or future extensions.

Power Supply Decoupling

The MCU is powered from the regulated VCC rail derived from the USB-C input via an LDO. According to the STM32C0 datasheet, local decoupling capacitors (100nF and 4.7uF) are required between VCC and GND (at the MCU pins):

5 Temperature sensor

5.1 Component selection

To monitor the temperature inside the oven, we considered two options:

Thermocouple
Thermocouples offer a very wide measurement range (approximately −200°C to 1000°C) and good accuracy, but they require dedicated front-end electronics (amplifier, cold-junction compensation, ADC), which increases both cost and design complexity.

Thermistor
Standard NTC thermistors are typically rated up to about 150°C, but glass-encapsulated thermistors can operate up to roughly 300°C. They are inexpensive and can be read with a simple resistor divider connected to the microcontroller's ADC input.

Given the target reflow profile (from ambient ≈15°C up to 260°C), and in order to minimize cost and complexity, we selected a glass NTC thermistor, reference NRBG105F3950B1F, specified from −40°C to 300°C.

Resistor Divider Design
The thermistor is used in a voltage divider to generate a temperature-dependent voltage for the STM32 ADC:
Supply voltage: 3.3 V
One fixed resistor R
The NTC thermistor NRBG105F3950B1F

We want to choose R so that the ADC sees the widest possible voltage variation over the most relevant temperature range, which in our case is 60°C to 260°C (the useful reflow control region).

$$Vt = 3.3V * \frac{R}{Rth1 + R}$$

From the datasheet:
at 60°C Rth1 =24.75kohm
at 260°C Rth1 = 145ohm
we want |Vt60°C – Vt260°C| as high as possible

$$Max|Vt60 - Vt260| = Max\left|3.3 * \frac{R}{Rth60 + R} - 3.3 * \frac{R}{Rth260 + R}\right|$$

$$Max\left|\frac{R(Rth260 + R) - R(Rth60 + R)}{(Rth60 + R)(Rth260 + R)}\right| = Max\left|\frac{-R * Rth60}{R^2 + (Rth60 + Rth260)R + Rth60 * Rth260}\right|$$

We look after the derivate in zero.

$$\frac{-(Rth60 - Rth260) * (R^2 + (Rth60 + Rth260)R + Rth60 * Rth260) + R24605(2R + (Rth60 + Rth260))}{(R^2 + (Rth60 + Rth260)R + Rth60 * Rth260)^2}$$

$$(Rth60 - Rth260)R^2 - (Rth60 - Rth260) * Rth60 * Rth260 = 0$$

$$R^2 = \frac{(Rth60 - Rth260) * Rth60 * Rth260}{(Rth60 - Rth260)} = Rth60 * Rth260$$

$$R = \sqrt{Rth60 * Rth260} = \sqrt{3588750} = 1894ohm$$

From the optimization, the ideal bridge resistor value is approximately 1.894 kΩ. We will use a standard 1.80 kΩ, 0.1% resistor, which is the closest commonly available value.

At 60°C $V_t = 0.22V$

At 260°C $V_t = 3.05V$

This provides a large voltage swing at the STM32 ADC input.

6 User interface

The user interface includes:

- 6 push-buttons:
  - 4 directional buttons (Up, Down, Left, Right)
  - 1 “Valid” button
  - 1 “Return” button
- 1 OLED display (I^2C, 3.3 V)
- 2 status LEDs (Red and Green)

Buttons:

- Each button is connected between an STM32 GPIO and GND.
- Internal pull-up resistors of the STM32 are used.
- Logic: button released = logic high, button pressed = logic low.
- No external pull-up resistors are required.

OLED Display:

- Powered by 3.3 V from the on-board LDO.
- Connected to the STM32 via I^2C (SCL, SDA).
- I^2C pull-ups are configured inside the STM32.

Status LEDs:

- 2 LEDs (Red, Green), each in series with a 150 Ω resistor.
- Driven directly from STM32 GPIOs (no transistor needed).
- Current per LED is limited to about 10 mA, within STM32 GPIO limits (80 mA total).

7 Power regulator

This design uses a USB-C connector as the main power input. To operate USB-C in a simple "default power" sink mode (5 V supply), each CC pin must be pulled down to ground. We therefore connect a 5.1 kΩ (1%) resistor from:
- CC1 to GND
- CC2 to GND

The system logic operates at 3.3 V. Since the maximum current consumption is below 300 mA, a linear regulator (LDO) provides a simpler and adequate solution compared to a switching regulator (SMPS).

We selected the L1117S33 3.3 V LDO, commonly used on STM32 evaluation boards. Key characteristics:
- Input voltage: up to 15 V
- Fixed output: 3.3 V
- Typical dropout voltage: ~1 V
- Maximum output current: up to 800 mA

We use the SOT-223 package because it is relatively easy to solder, it has a compact footprint and it can dissipate the required power with an appropriate copper thermal pad.

For the worst-case calculation, we assume:
- Input voltage (including tolerance): 5 V × 1.05 = 5.25 V
- Output voltage (including tolerance): 3.235 V (worst-case lower bound)
- Maximum load current: 300 mA

The power dissipated by the LDO is:

$$\mathrm{P} = (5\mathrm{V} * 1.05 - 3.235\mathrm{V}) * 0.3\mathrm{A} = 0.6\mathrm{W}$$

Given the junction-to-ambient thermal resistance Rtja of 110 °C/W for the SOT-223 package:

$$\mathrm{Tmax} = \mathrm{Ta} + \mathrm{Rtja} * \mathrm{P} = 50 + 110 * 0.6 = 116°\mathrm{C}$$

With an ambient temperature of 50 °C, the junction temperature is estimated at about 116 °C, which remains below the maximum junction temperature Tjmax 125°C.

According to application note AN044_EN (Figure 11), a SOT-223 package mounted on a PCB with a 100 mm² thermal pad can dissipate up to approximately 0.7 W. Our PCB layout includes a copper thermal pad larger than 100 mm², to maximize heat dissipation and provide additional safety margin.

The L1117 datasheet recommends:
- A 10 µF capacitor between the input pin and GND
- A 10 µF capacitor between the output pin and GND

These capacitors are placed as close as possible to the LDO pins to ensure stability and reduce noise on the 3.3 V rail.

A power indicator LED is connected between the 3.3 V output and GND through a 150 Ω series resistor. This LED provides a visual indication that the board is correctly powered and that the 3.3 V rail is present.