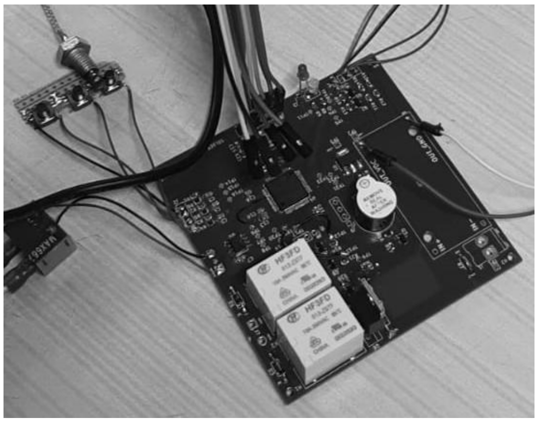
DATASHEET
THERMAL CHAMBER

Code **N0002DS001R004**

Revision 1.4

THERMAL CHAMBER



Specifications:

- Power Supply : +12 V_{DC} +/- 10%
- Power: 50 W
- Display LCD 16x2 + 2x LEDs
- Buzzer
- 3x Buttons
- UART
- Temperature range: 0 - 70 °C
- Temperature accuracy: <5 °C (*)
- Temperature stability: <1 °C (*)

(*) *Without load*

Features and Benefits:

- Extreme Low cost
- PID temperature controller

VERSION HISTORY

VERSION	NOTE	DATA
1.0	*First Release*	*14/09/2025*
1.3	*Update FW chapter*	*10/01/2026*
1.4	*Typo error*	*23/05/2026*

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1 OVERVIEW

1.1 OVERVIEW

The diagram-block of Thermal Chamber is shown in the following picture.

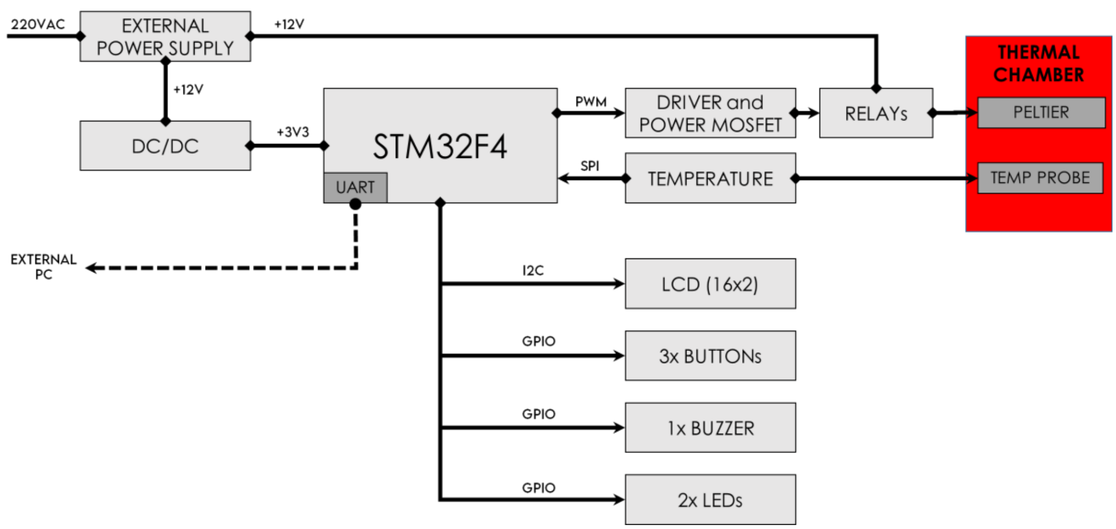

Figure 1

Power Supply

The system uses an external AC/DC power supply to generate +12V, which is used to power the internal electronics and the Peltier cell. From the +12V line, two additional voltages are derived: +5V is generated using a Buck-type DC/DC converter, and +3.3V is obtained through a linear regulator.

Microcontroller Unit (MCU)

The core of the Thermal-Chamber system is an ST STM32F413 microcontroller. The MCU acquires temperature data from the heating element via a MAX6675 thermocouple interface, connected through the SPI protocol. In addition, the MCU controls a power MOSFET using a dedicated PWM output to regulate heating.

User Interface

A 16×2 character LCD is provided for operator interaction. The display is controlled via a 2-wire I²C interface and shows both the target and actual temperature. Temperature setpoints are adjusted using three push-buttons, allowing a range from 0 °C to 70 °C.

Indicators and Alerts

Two status LEDs and one buzzer are included for visual and audible feedback. All indicators are directly driven by the MCU.

2 THERMAL CHAMBER

2.1 THERMAL CHAMBER

A mini refrigerator is utilized as the basis for the thermal chamber. Low-cost commercial units typically incorporate an internal Peltier module, which provides both heating and cooling functionality for precise temperature control.

Figure 2

3 HARDWARE

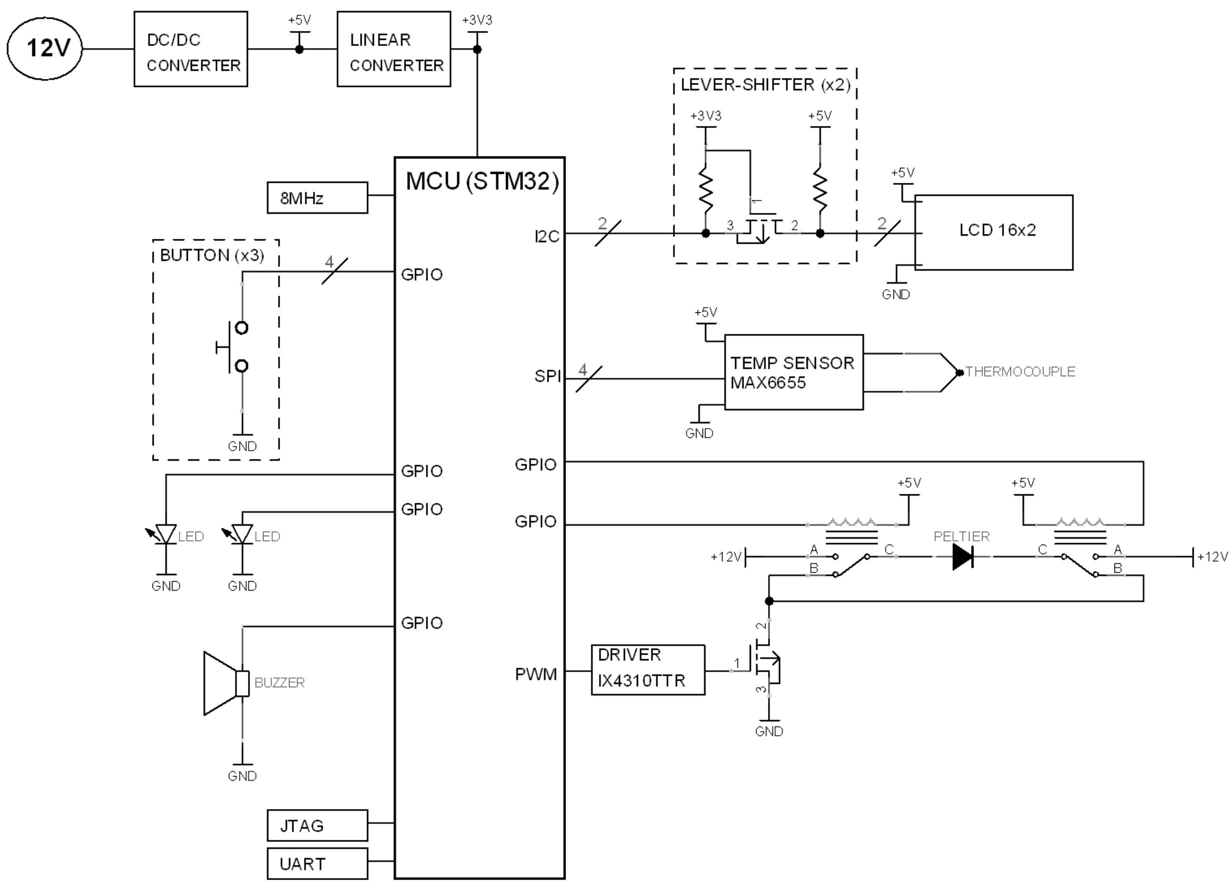

Figure 3

3.1 HW: DC/DC-BUCK and LINEAR-DC/DC

The system utilizes a small LDO step-down regulator module to supply the MCU and peripheral circuitry. The LM2596 switching regulator efficiently converts higher input voltages (+212 V nominal) to a regulated +5 V output.

LM2596-Module

- Input voltage range: 4.5 V – 40 V
- Adjustable output voltage: 1.5 V – 35 V
- Maximum output current: 3 A
- Typical efficiency: 92% (dependent on input/output voltage differential and load)
- Output ripple voltage: ~30 mV
- Switching frequency: ~150 kHz

A linear regulator is used to generate the +3.3V supply voltage.

3.2 HW: TEMPERATURE SENSOR (MAX6675)

A type-K thermocouple is integrated into the Thermal Chamber to measure temperature. The thermocouple produces a voltage proportional to the temperature difference between the hot and cold junctions. This signal is acquired by the MAX6675 thermocouple-to-digital converter, which applies cold-junction compensation and outputs the corresponding digital value via an SPI-compatible interface. The MAX6675 ensures accurate, stable, and digital temperature measurements, providing reliable monitoring for the Thermal Chamber system.

MAX6675:

- Resolution: 12-bitTemperature resolution: 0.25 °C
- Maximum measurable temperature: +1024 °C
- Thermocouple accuracy: ±8 LSB (0 °C to +700 °C)
- Interface: SPI-compatible

3.3 HW: POWER MOSFET and RELAYS

The heating and cooling of the thermal chamber are controlled using a logic-level N-channel power MOSFET, driven by a dedicated gate driver (IX4310TTR). The MCU sends a PWM signal to the gate driver, which in turn controls the MOSFET, allowing precise power modulation to the Peltier element. To switch between different thermal operating modes (heating, cooling, off), two relays are employed. The MCU controls these relays via GPIOs.

The logic is as follows:

1. Hot Mode: Relay1 = ON, Relay2 = OFF
2. Cold Mode: Relay1 = OFF, Relay2 = ON
3. Off Mode: Relay1 = OFF, Relay2 = OFF

This configuration allows full control over the direction of current through the Peltier element, enabling either heating or cooling.

3.4 HW: DISPLAY, LEDS AND BUTTONS

The system includes a 16x2 alphanumeric LCD, controlled via a level shifter to interface with the MCU (which may operate at a different logic level). The display shows real-time temperature readings and system status.

Additionally, the MCU manages:

- Three push-buttons, used for user input (e.g., mode selection, reset, etc.)
- Status LEDs, for visual feedback (e.g., system on, heating, cooling)
- A buzzer, driven via GPIO, for audio alerts or feedback signals

4 FIRMWARE

4.1 FW: FreeRTOS

By integrating FreeRTOS, the firmware is structured into multiple concurrent tasks, each responsible for a specific subsystem. This design ensures deterministic behavior, improved responsiveness, and clear separation of responsibilities.

User Interface and Feedback Tasks

- **LEDS Task**: Manages system status indicators, including blinking patterns, error codes, and operational states.
- **BUZZER Task**: Controls the buzzer for audio feedback, alarms, and user notifications.
- **BUTTONS Task**: Handles user inputs from push-buttons, including debouncing, press-type detection, and event generation.
- **LCD Task**: Manages all graphical output to the 16×2 alphanumeric LCD, including temperature readings, system status, and diagnostic messages.
- **Thermal Control Tasks:** To manage the internal temperature of the thermal chamber, the firmware includes dedicated control tasks: **TEMP Task**: Reads temperature data, applies control logic, and computes the appropriate PWM duty cycle for the power MOSFET driving the Peltier element. This ensures stable heating/cooling performance and precise thermal regulation.

Centralized Event Management via Dispatcher

All tasks communicate through a centralized **Dispatcher**, a middleware component responsible for routing messages, events, and notifications across the system.
The Dispatcher provides:

- **Decoupling between tasks**, eliminating direct dependencies
- **Predictable event flow**, improving system stability
- **Unified handling of asynchronous events**, including interrupts
- **Scalability**, allowing new modules to be added without modifying existing tasks
  - This architecture transforms the Dispatcher into the internal communication backbone of the firmware.

System Reliability Through Intelligent Watchdog Supervision

The firmware integrates an advanced **Watchdog Service**, designed to ensure system reliability in mission-critical scenarios.

Instead of refreshing the watchdog blindly, each task periodically reports its “heartbeat” to the Watchdog Service. The watchdog is refreshed **only if all registered tasks are alive and responsive**.

This mechanism provides:

- Protection against deadlocks, starvation, and task failures
- Immediate identification of the non-responsive task
- Deterministic system recovery in case of malfunction
- Increased robustness for long-running or unattended deployments

Diagnostics and Self-Test Capabilities

The firmware includes both **Power-On Self-Tests (POST)** and **runtime diagnostics**, covering:

- ADC integrity checks
- GPIO validation
- RAM pattern tests
- CPU clock verification
- Peripheral readiness checks

These diagnostics ensure that the system starts and operates in a known-good state, improving reliability and simplifying troubleshooting.

4.2 FW: PID

In the thermal chamber system, precise temperature regulation is critical to maintain stable and accurate environmental conditions. To achieve this, the firmware employs a PID (Proportional-Integral-Derivative) control algorithm within the TEMP task to modulate the power delivered to the Peltier element.

The PID controller continuously monitors the temperature measured by the MAX6675 thermocouple sensor and compares it to the desired setpoint. Based on the difference (error) between the actual temperature and the target, the PID algorithm computes a control output, which adjusts the PWM duty cycle applied to the MOSFET driver controlling the Peltier cell.

- Proportional (P) component generates a control action proportional to the current temperature error, providing immediate corrective response.
- Integral (I) component accounts for the accumulation of past errors, helping to eliminate steady-state offset and ensuring long-term accuracy.
- Derivative (D) component predicts future trends by evaluating the rate of change of the temperature error, improving system stability and reducing overshoot.

By tuning the PID parameters (Kp, Ki, Kd), the system can balance responsiveness and stability, minimizing temperature fluctuations and overshoot while achieving fast settling time.

Additionally, the SUPERVISOR-TEMP task monitors system safety by enforcing operational constraints and switching to Off Mode if temperature readings exceed safe limits, thereby protecting the hardware.

This PID-based control strategy enables the thermal chamber to maintain precise temperature control for both heating and cooling modes, ensuring reliable and repeatable environmental conditions for testing or experimental purposes..

5 MECHANICAL

5.1 MECH: BOARD

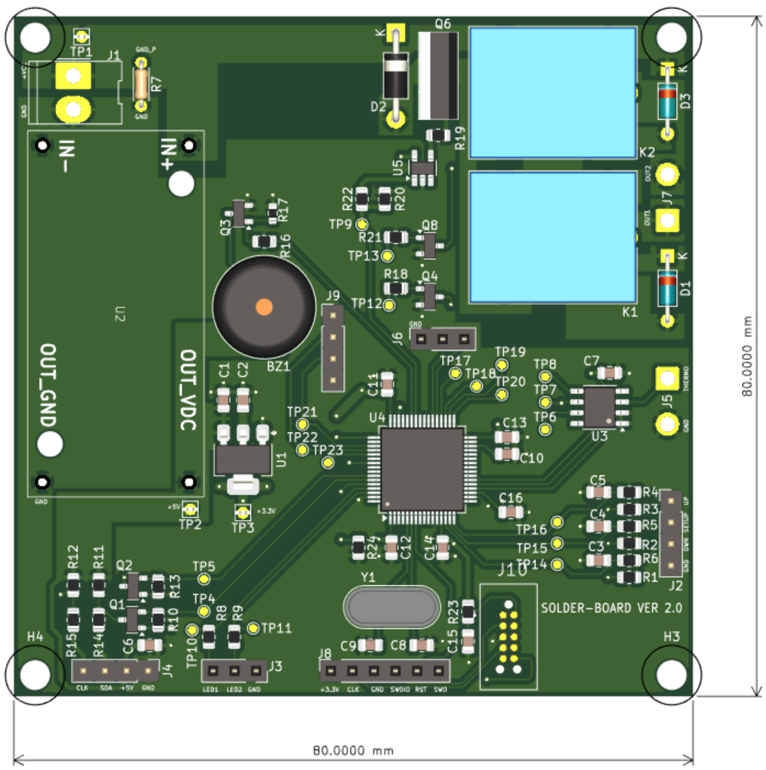

Figure 4