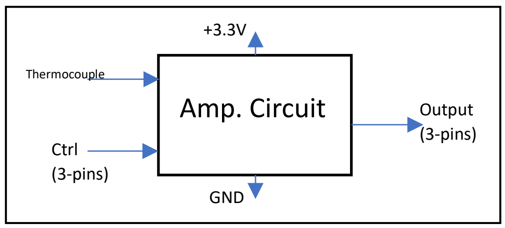
1. Prototyping:

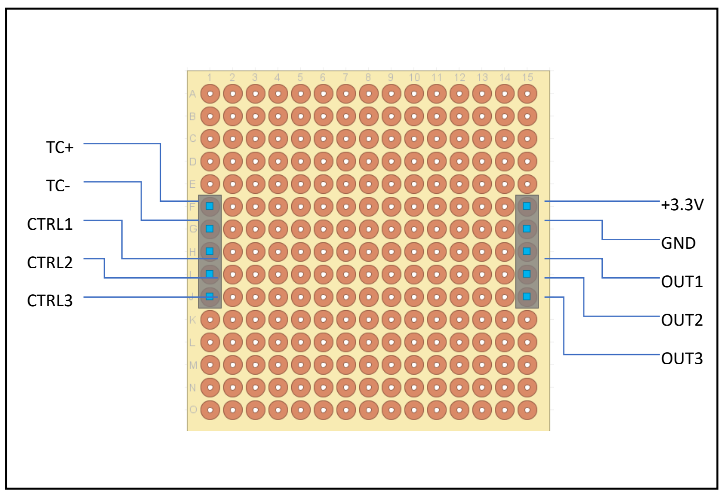
1.1. Introduction:

At prototyping phase, multiple amplifiers are to be tested and compared with each other. For each of these tests, a small PCB with pre-defined inputs and outputs is to be printed. On the main PCB, there is a pre-defined socket / header for this small amplifier test PCB. This accelerates prototyping phase and saves money.

1.2. Amplifier's pre-defined block diagram:



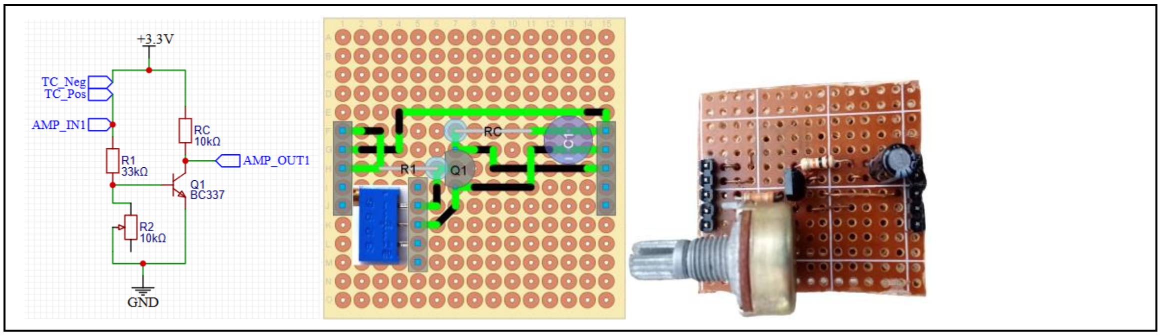
1.3. Amplifier's pre-defined input / output header position:



2. Tested amplifiers:

2.1. Single BJT transistor amplifier:

Using BC337 BJT NPN transistor, the following circuit is implemented. It gives a gain of 5 [V/V], enabling an ADC resolution of $\frac{1}{4096} * \frac{3.3}{5} \approx 161\mu V/LSB$

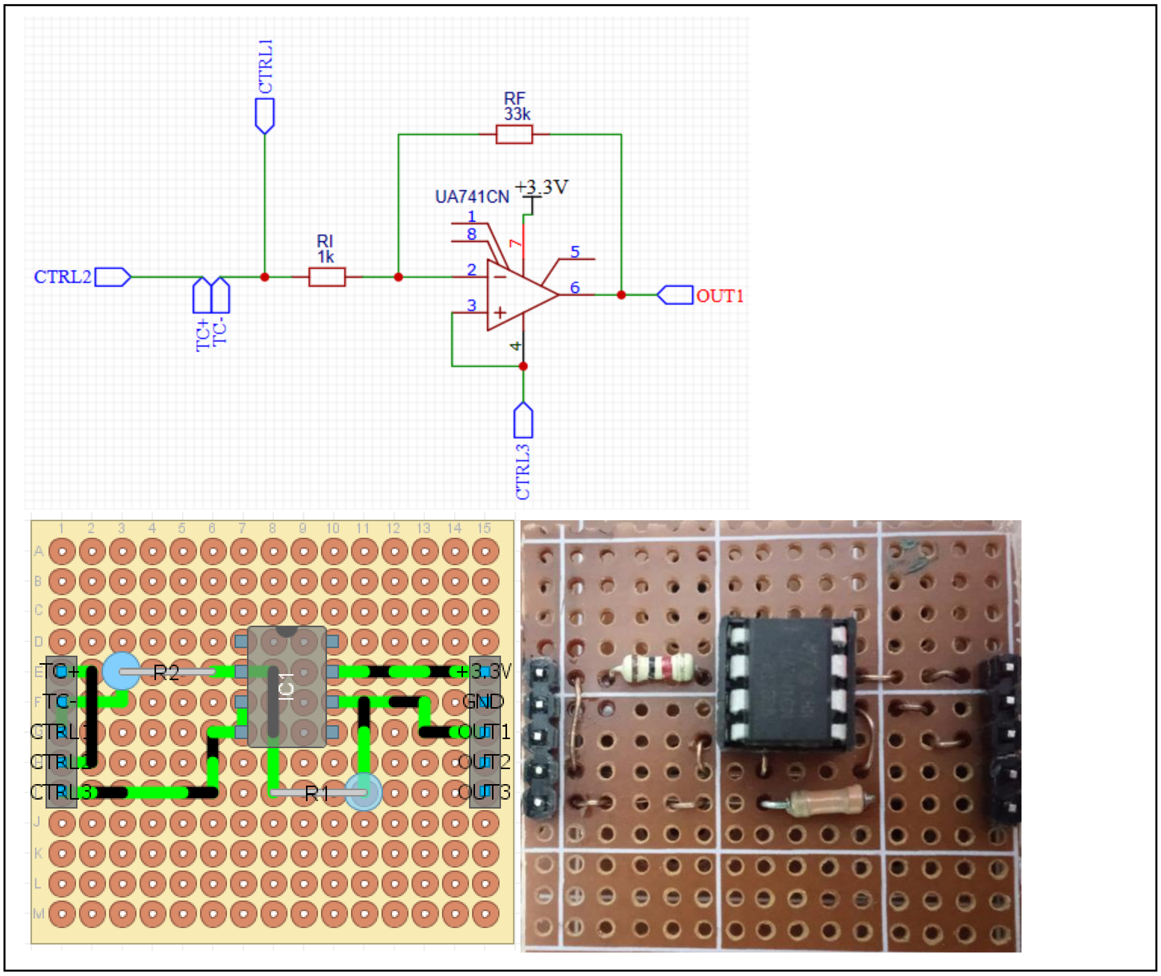


- Design notes:
  - As BJT amplifies I_B at I_C, and since $I_C = \frac{3.3 - v_o}{R_C}$, value of R_C must be low enough such that the amplified current is achievable across it. This could also be achieved by checking that $v_{CE,Fully\ On} \cong 0.2V$. Otherwise, if $v_{CE,Fully\ On} \cong few\ mV$, the operation will not be as expected.

- Disadvantages:
  - Has a low gain. To obtain higher gain transistors should be cascaded, which takes more cost when compared to the following circuit.
  - Automatic offset calibration is not stable.

2.2. Op-Amp based amplifier:

- Using UA741CN Op-Amp, the following circuit is implemented. It gives a gain of 33 [V/V], enabling an ADC resolution of $\frac{1}{4096} * \frac{3.3}{33} \approx 24.4\mu V/LSB$. It also provides stable automatic offset calibration.



- Design notes:
    - As this is – obviously – an inverting amplifier, thermocouple is connected in reverse to obtain positive output.
    - **CTRL2** signal is used to select whether thermocouple is connected to the circuit or not. This is achieved by switching **CTRL2** between 0-volts level, and open-circuit level respectively.
    - **CTRL1** signal is used to select whether circuits input voltage is a fixed 0-volts, or thermocouple voltage. This is achieved by switching **CTRL1** between 0-volts level, and open-circuit level respectively.
    - **CTRL3** is fixed at 0-volts level all time, and used as a **GND** for the op-amp circuit. This is done so that when **CTRL1** or **CTRL2** signals are low, they appear as real zeros to the op-amp. As low level voltage of the I/O module in the MCU is always a little value above zero (real circuit **GND**).
    - To calibrate offset, thermocouple is disconnected (**CTRL2** is open-circuit), and amplifier's input is set to zero (**CTRL1** is zero). Hence, output value is equal to that of the offset).

- To obtain thermocouple's voltage, thermocouple is – of course - connected (**CTRL2** is low), and amplifier's input is dedicated to TC only (**CTRL1** is open-circuit). Hence, output value is equal to:

$$A_V * v_{TC} + v_{offset}$$

By subtracting offset value (previously obtained at a periodic calibration) from output's value, thermocouple's voltage can be obtained as follows:

$$v_{TC} = \frac{v_{out} - v_{offset}}{A_V}$$

3. Temperate calculation:

As thermocouple temperature calculation depends on its voltage, and temperature of the – virtual – cold junction. Temperature of cold junction is assumed to be room temperature, which could be measured using STM32's on-chip temperature sensor.
Temperature can be calculated as follows:

$$v(T)_{|T_{ref}} = v(T)_{|0} - v(T_{ref})_{|0}$$

- In the above equation:
  - The term $v(T)_{|T_{ref}}$ is thermocouple's voltage v_{TC} (Previous section discussed how to obtain it).
  - The term $v(T_{ref})_{|0}$ could be obtained by interpolating output of the on-chip temperature sensor, in thermocouple's reference table.
  - Hence, the term $v(T)_{|0}$ can be obtained from the equation as follows:

    $$v(T)_{|0} = v(T)_{|T_{ref}} + v(T_{ref})_{|0}$$

  - Voltage $v(T)_{|0}$ is then interpolated in thermocouple's reference table to obtain value of T.

4. Noise elimination:

- Temperature noise:

  From the previous calculation, the obtained temperature is coupled with noise (Due to amplifier circuitry). These are eliminated using a SW defined LPF.

- On / Off control hysteresis:

  To avoid multiple fast relay switching which may affect both relay circuit and the load device, a hysteresis filter is defined.
  Also, relay protection SW is implemented. All it does is inserting minimum delay between switches requested by the controlling SW.

5. I/O:

- Set-point temperature is controlled using the on-board rotary encoder.

- Set-point temperature and real temperature are shown on a multiplexed 3-digit 7-segment display.

6. Porting and configuration:

- This SW is built to be portable for variety of MCU's, just replace FreeRTOS and COTS-OS/MCAL port files with these of the used target MCU.
- SW is modular and can be easily modified when using different HW setup, or when implementing additional features.

7. Prototype: