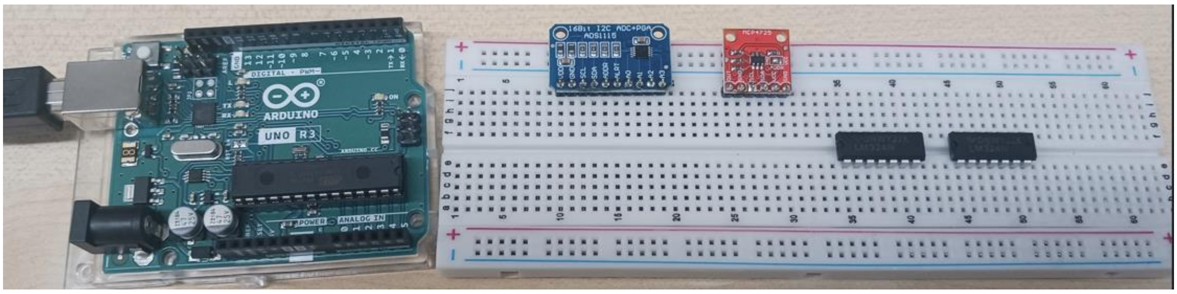
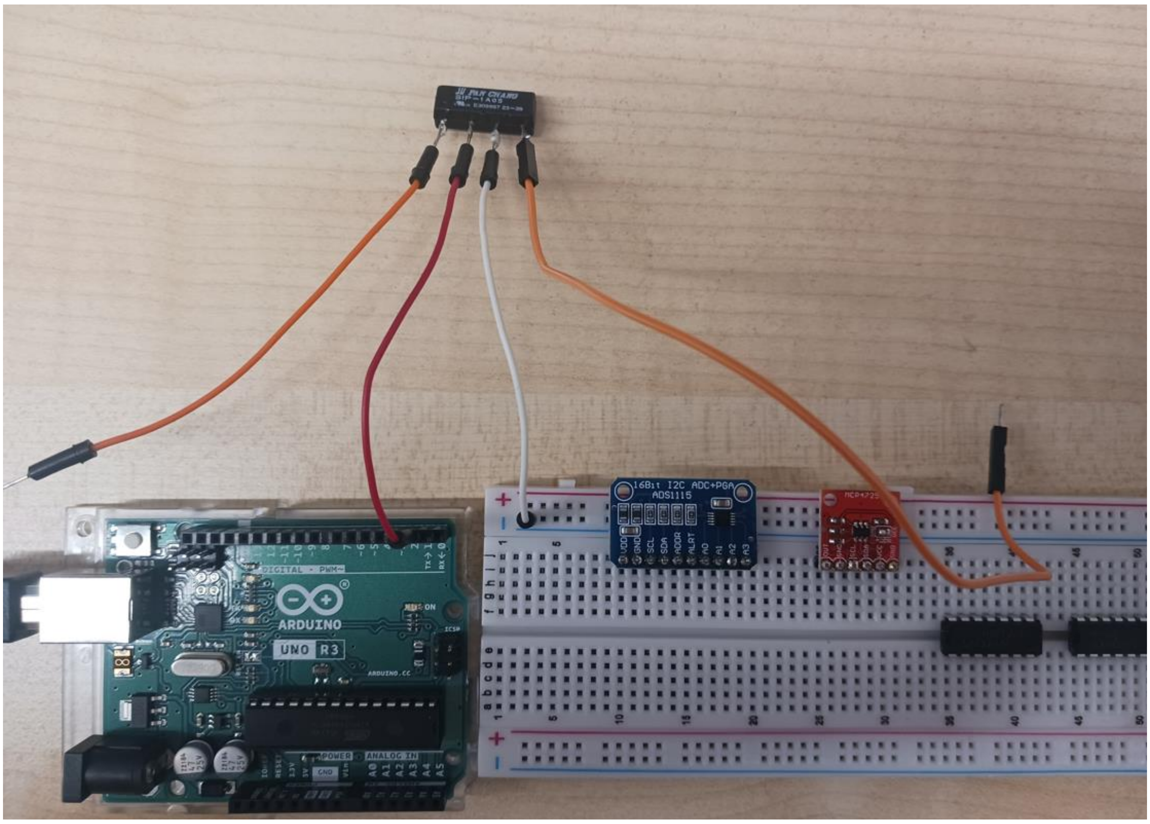
Assemble the PolArStat on a Breadboard

This guide is an addition to the supplementary information of the paper 10.1016/j.electacta.2023.143119 entitled *"PolArStat: An Arduino based potentiostat for low-power electrochemical applications"*. It is addressed to all users who want to try the PolArStat-potentiostat without the requirements of a printed circuit board. It will show a step-by-step way of assembling the PolArStat, illustrated by many images. So let´s get started.

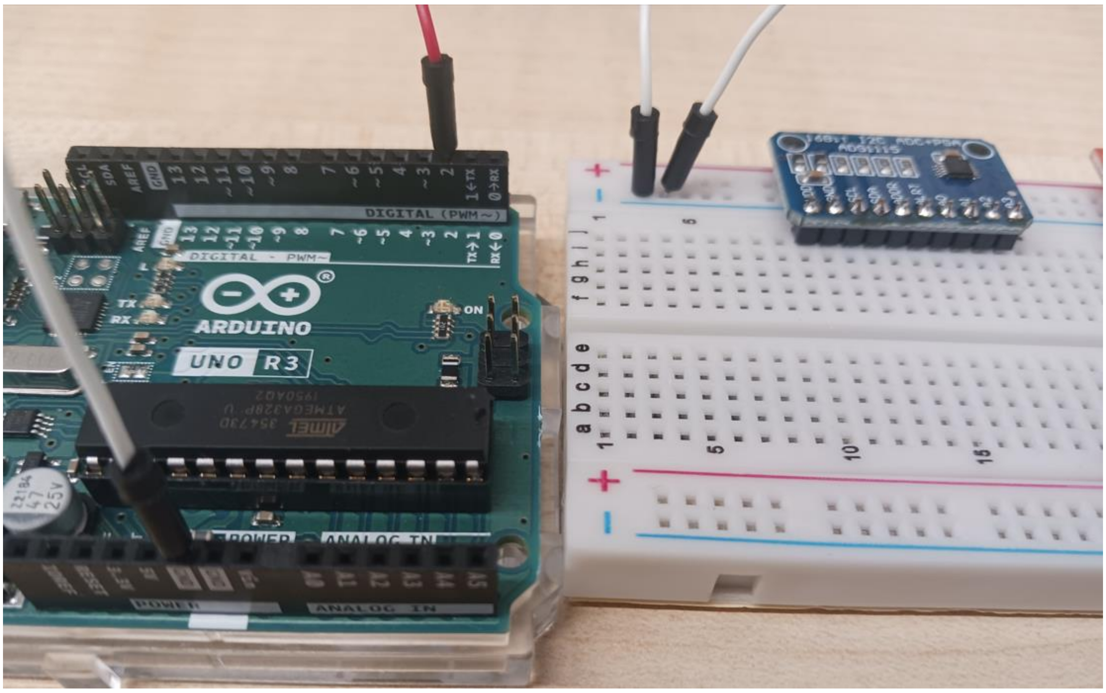
First, use your Arduini-Uno, the breakout-boards of ADS1115 and MCP4725 and your two LM324 Quad-op-amps and put them on a breadboard as shown in the next figure:



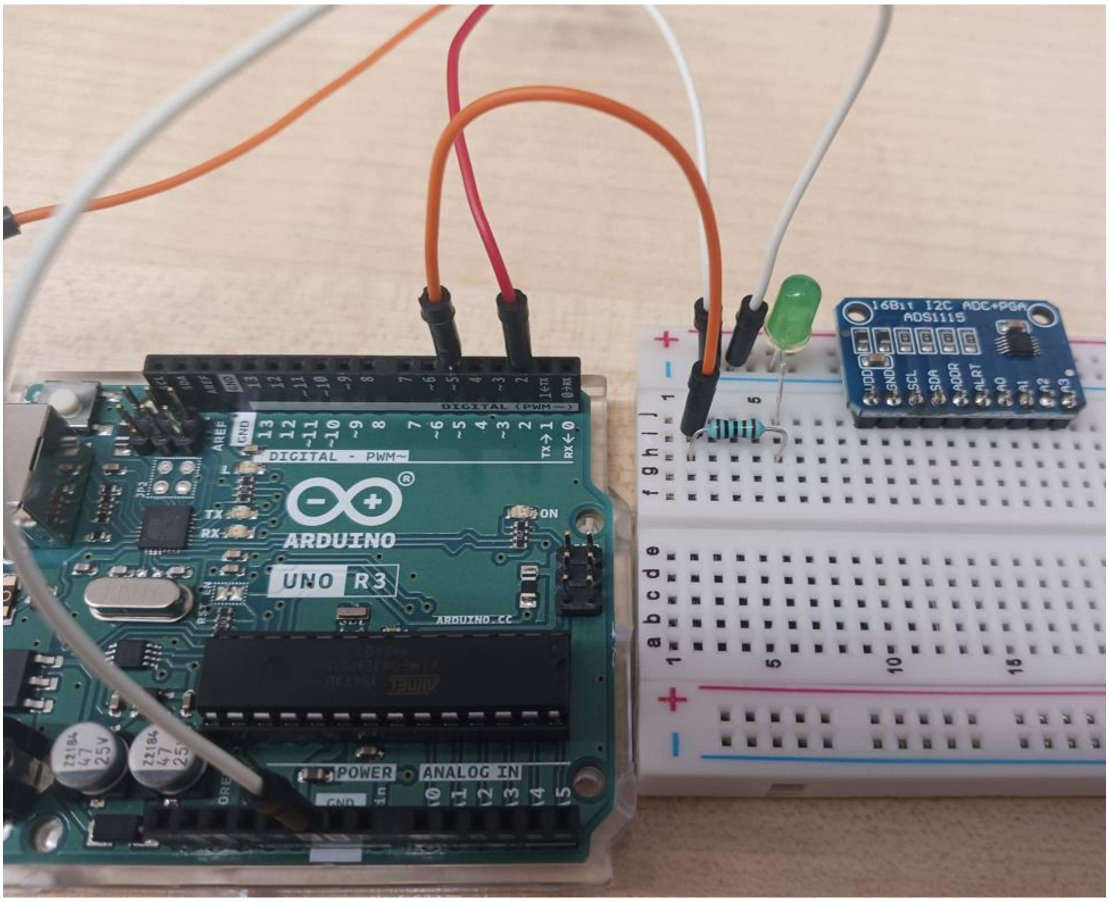
At next, connect the SIP1A05 reed-relay. The inner pins are controlling the coils of the relay. Consequently, one of these poles is connected the ground of the circuit (white wire) and one to the trigger pin (digital pin 2 of the Arduino – red wire) which outputs 5 V on demand. The two orange wires will be used/connected later, so ignore them for now.



In order to define and use the common ground of the circuit, connect the GND-pin of the Arduino Uno to the line of the breadboard, where you already made the connection of the 0 V of the reed relay.

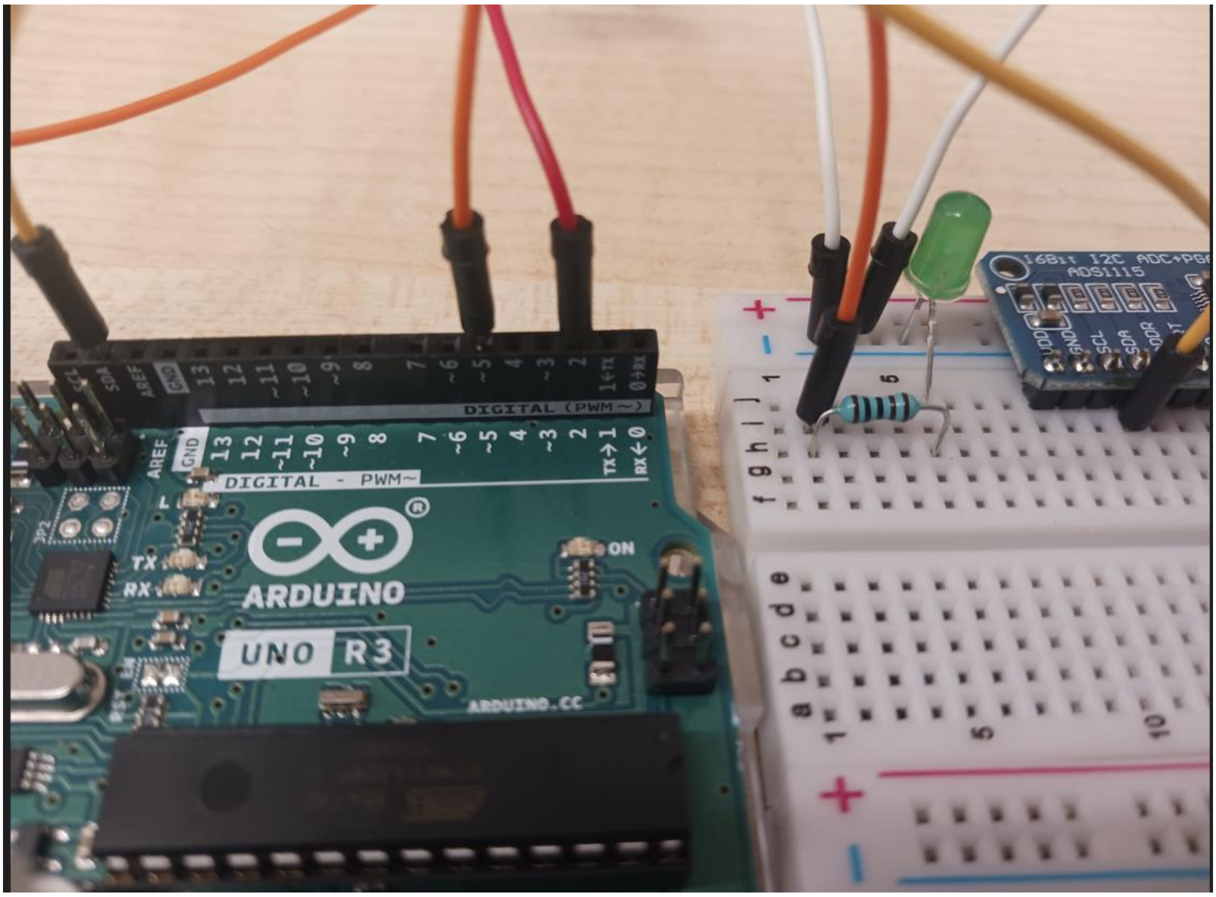


At next, the „Cell-on-LED" will be connected. This LED indicates a running measurement or calibration. It is connected in the way "Digital pin 5 → 1kOhm resistor → long leg of LED (i.e. Anode) → short Leg of LED (cathode) to GND. See the following figure as an illustration.

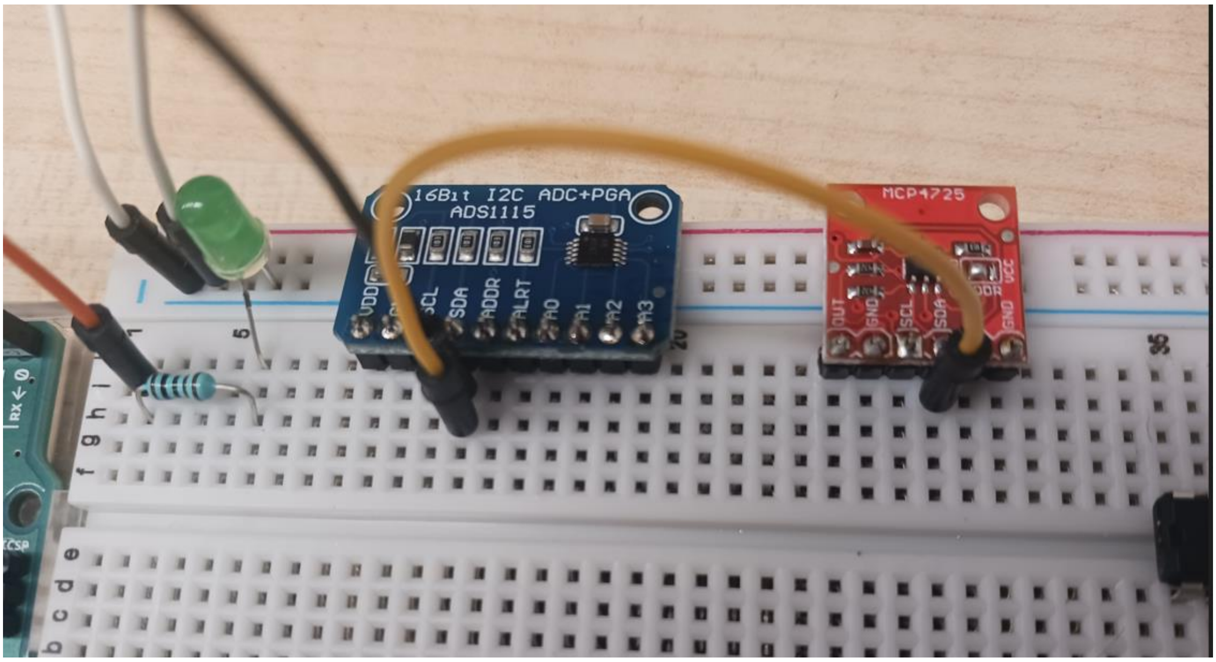


Most of the following steps are illustrated as follows. A yellow wire shows the latest connection, i.e. the connection which is done in the recent step. This particular wire is replaced by a wire of different color after the step is completed. Consequently, look for yellow wires 😊.

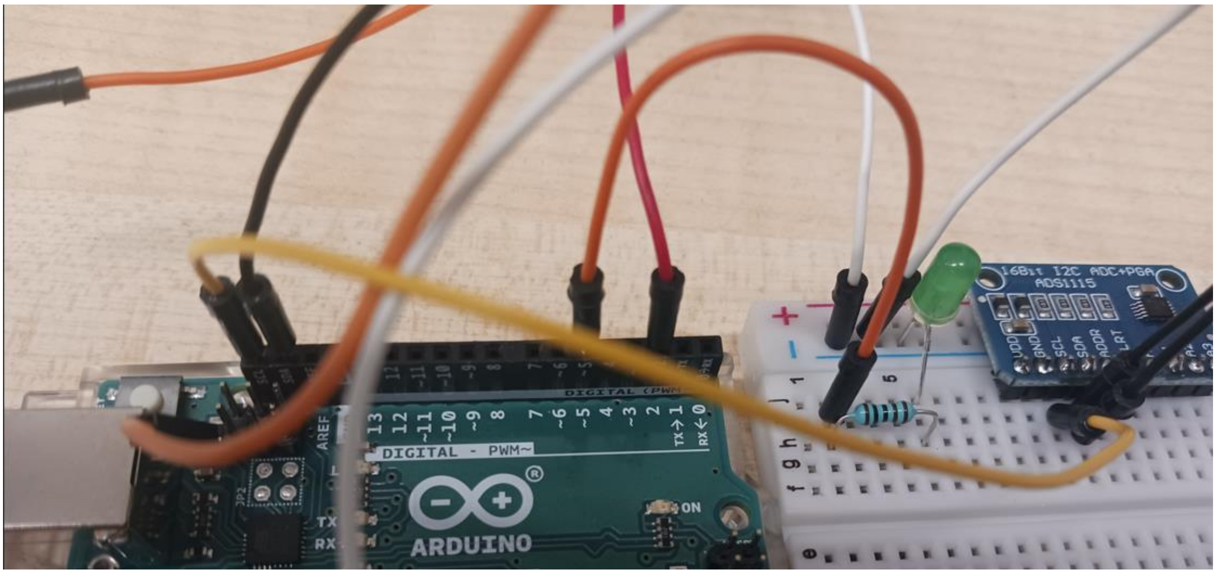
Step 1) Connect the SDA of the Arduino UNO to the SDA of the ADS1115.



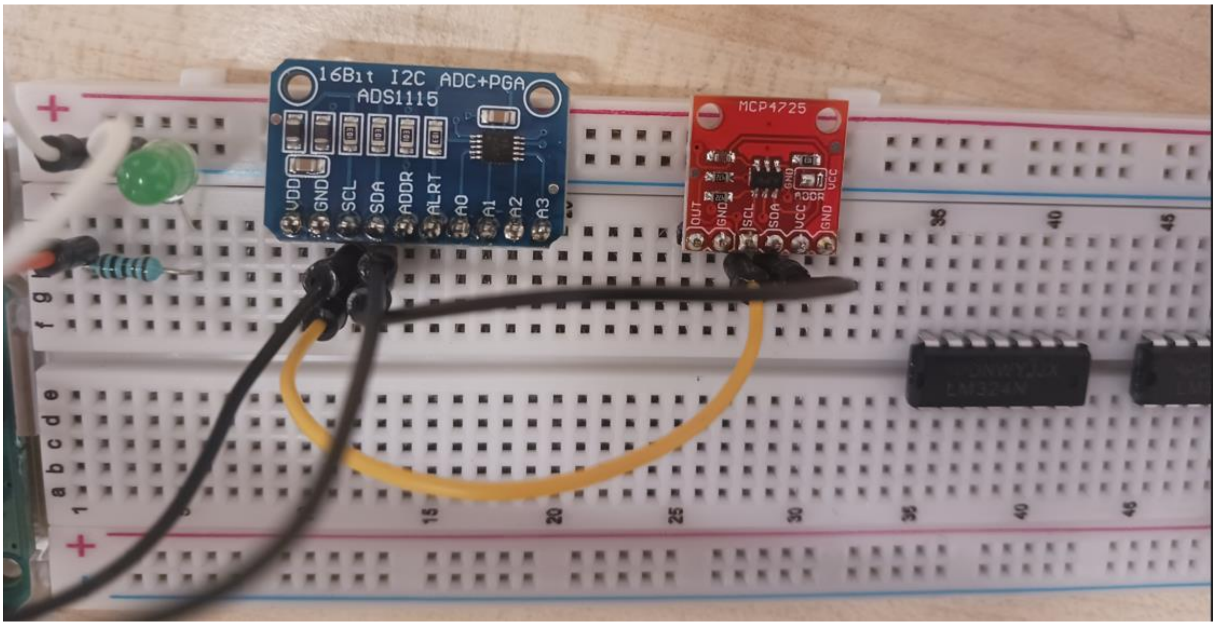
Step 2) connect SDA of ADS1115 (which is the same line as the SDA of the Arduino UNO) to SDA of the MCP4725.



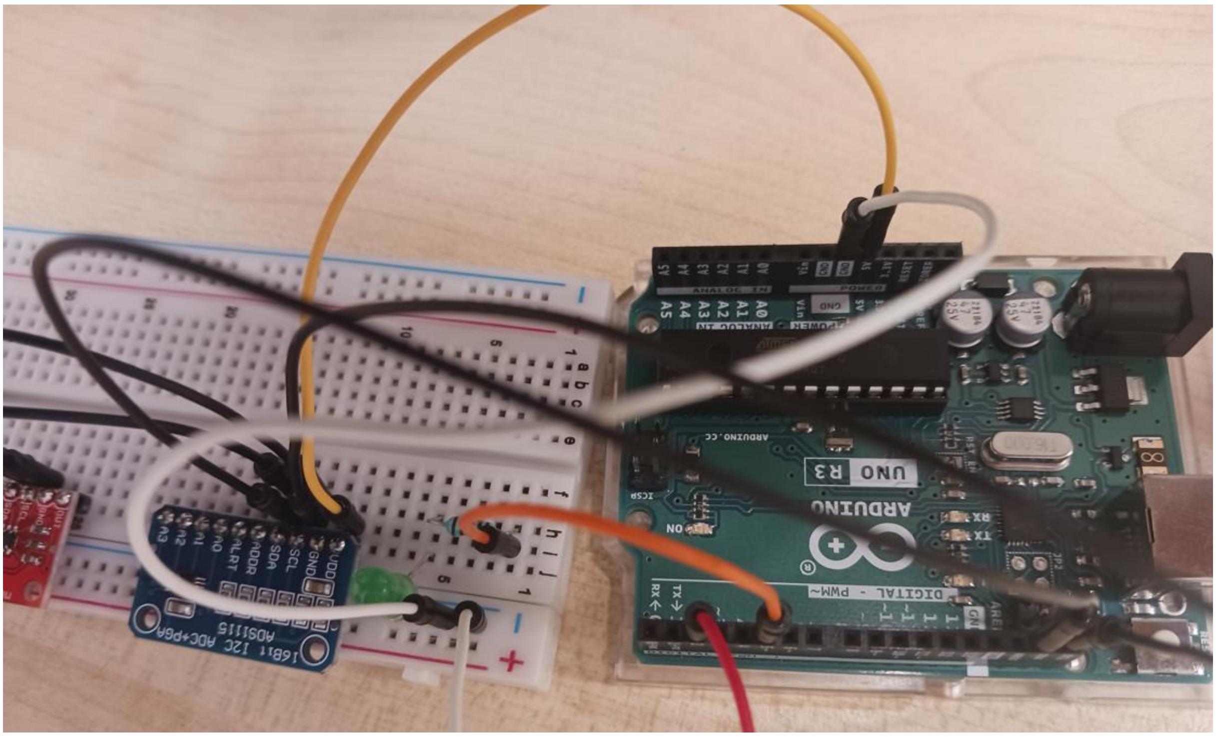
Step 3) Connect SCL of Arduino UNO to SCL of ADS1115.



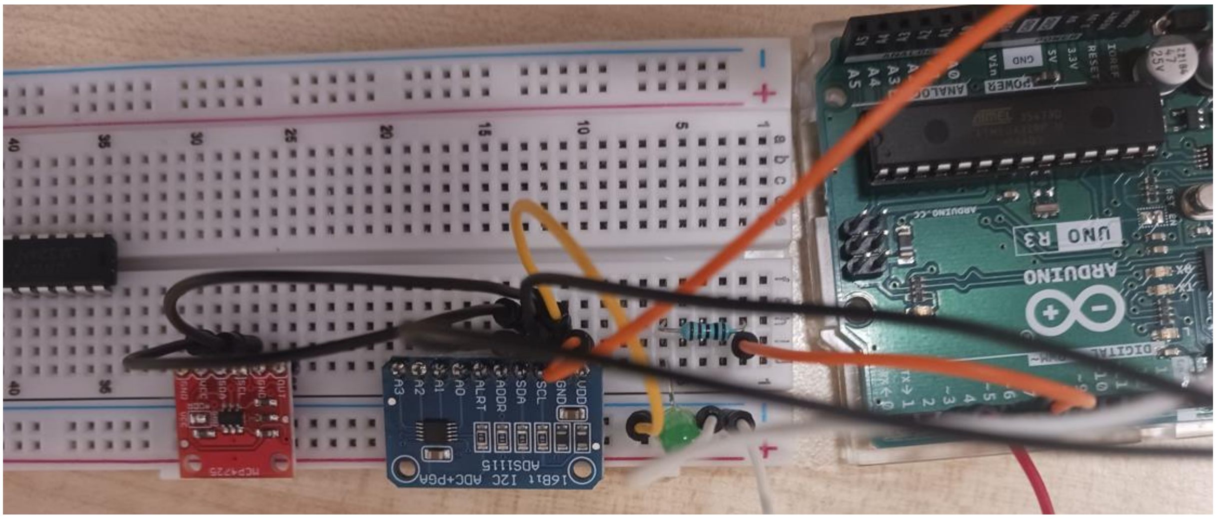
Step 4) connect SCL of ADS1115 (which is the same line as the SCL of the Arduino UNO) to SCL of the MCP4725.



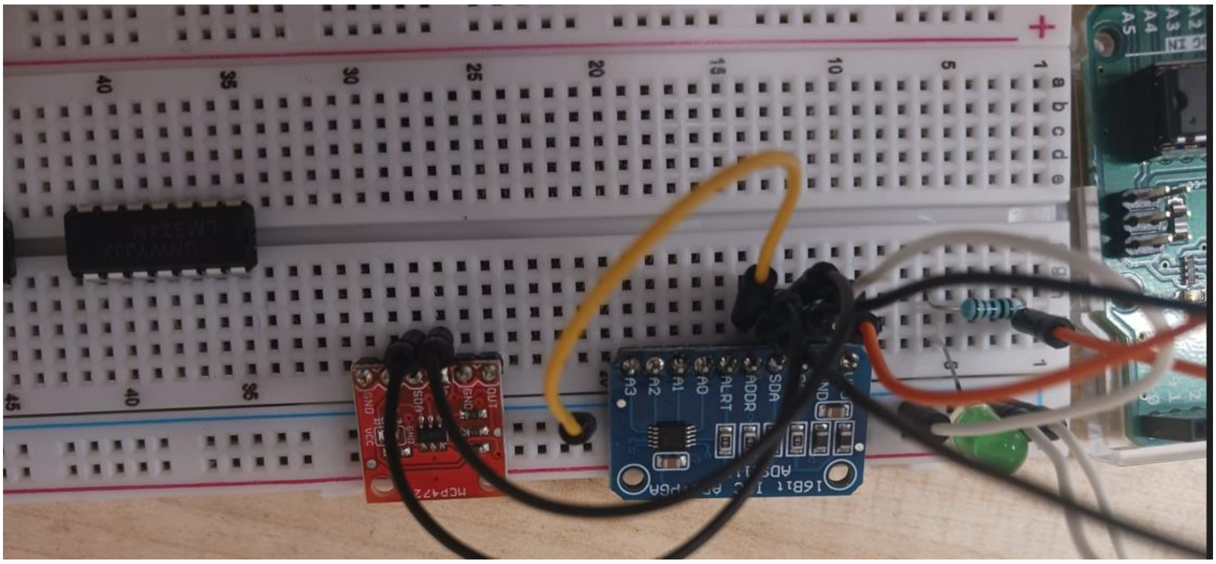
Step 5) connect the 5 V pin of the Arduino UNO to the VDD of the ADS1115. This will power the chip later on.



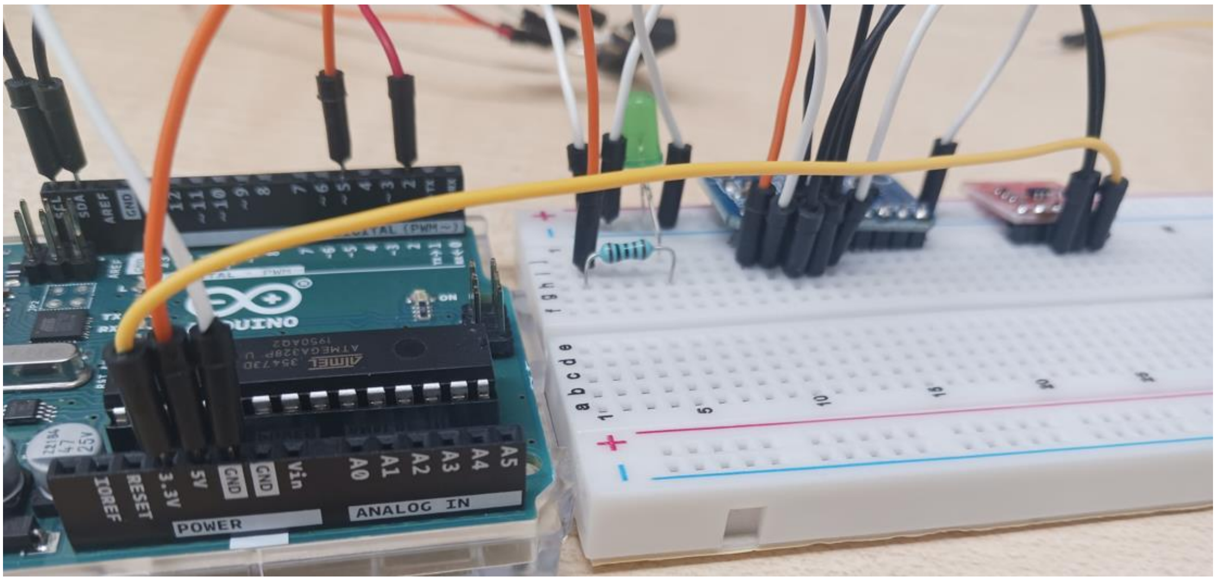
Step 6) Connect the GND of the ADS1115 to the ground of the circuit (where you have already connected the 0 V of the reed relay and the GND of the Arduini UNO).

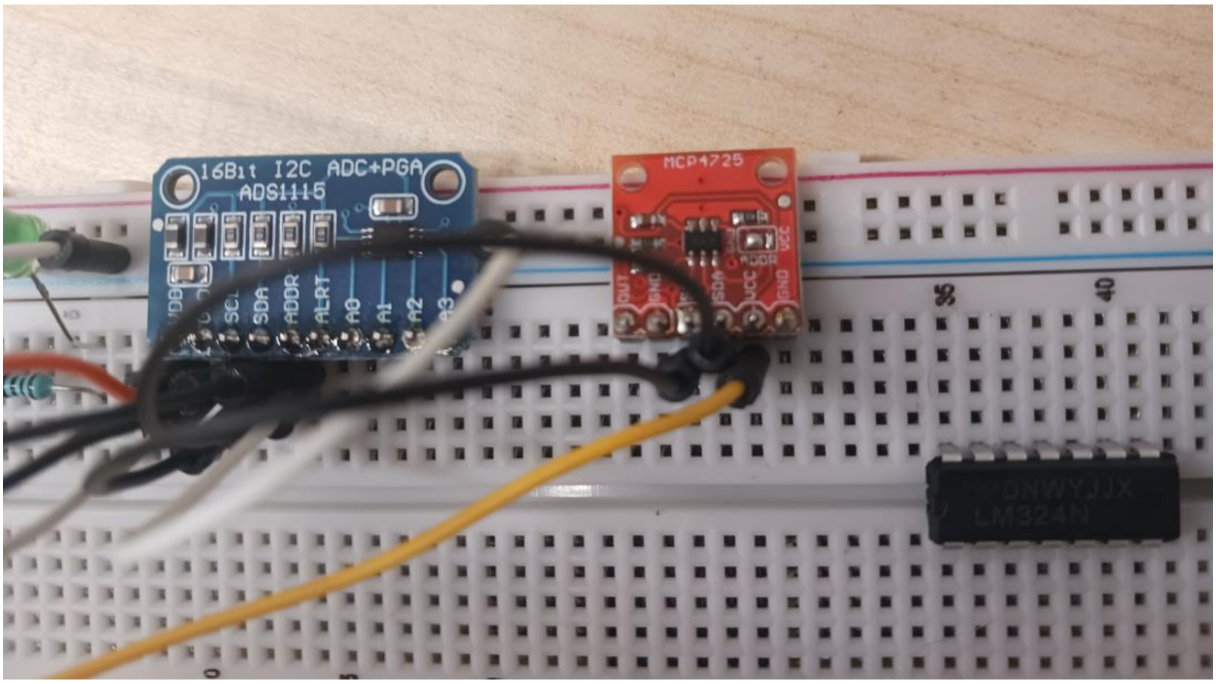


Step 7) Connect the address-pin (ADDR) of the ADS1115 to the ground of the circuit.

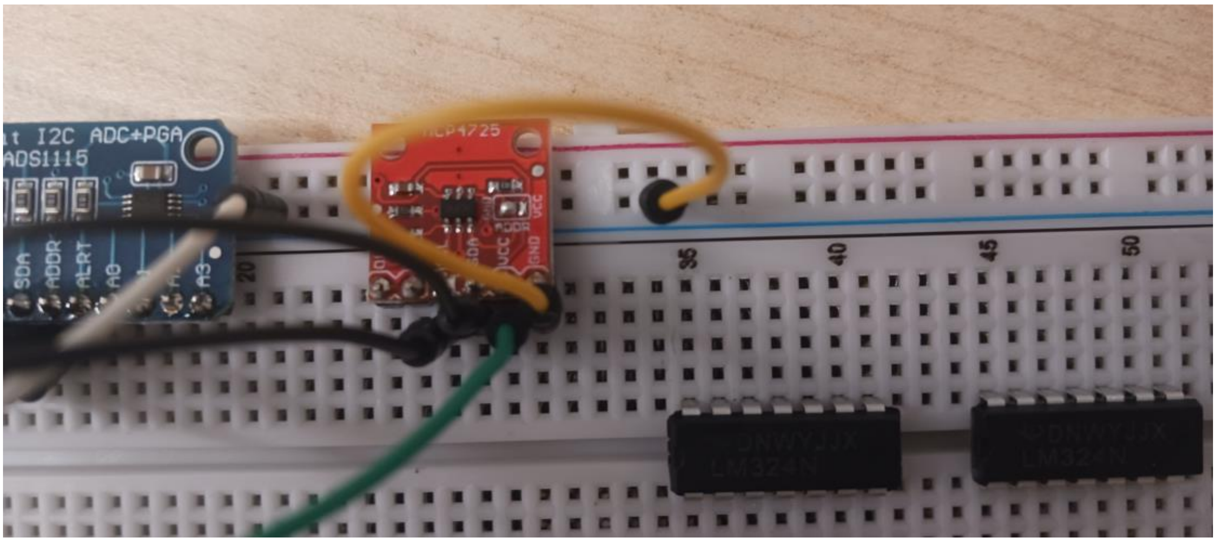


Step 8) (next TWO images) connect the 3.3 V pin of the Arduino UNO to the VCC pin of the MCP4725. This will represent the maximum voltage of the DAC-chip (i.e. the MCP4725).

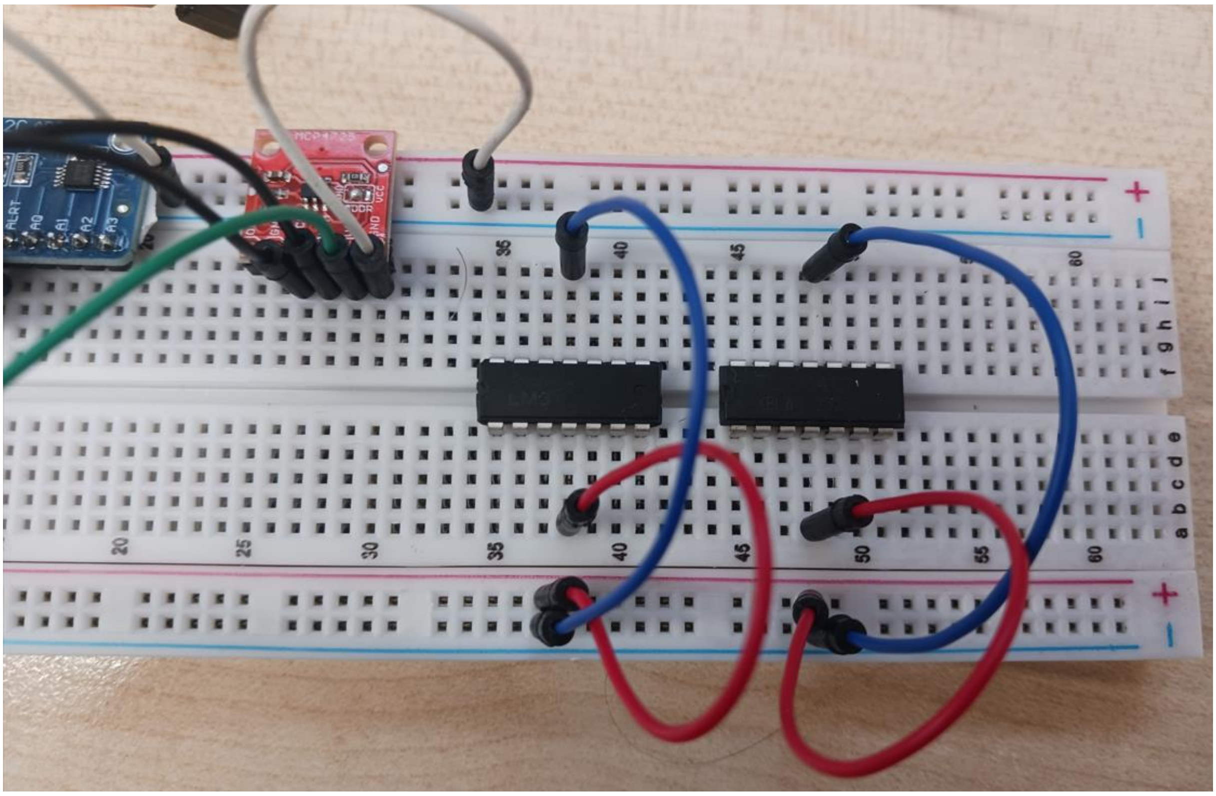




Step 9) connect the GND-pin of the MCP4725 to the ground of the circuit.

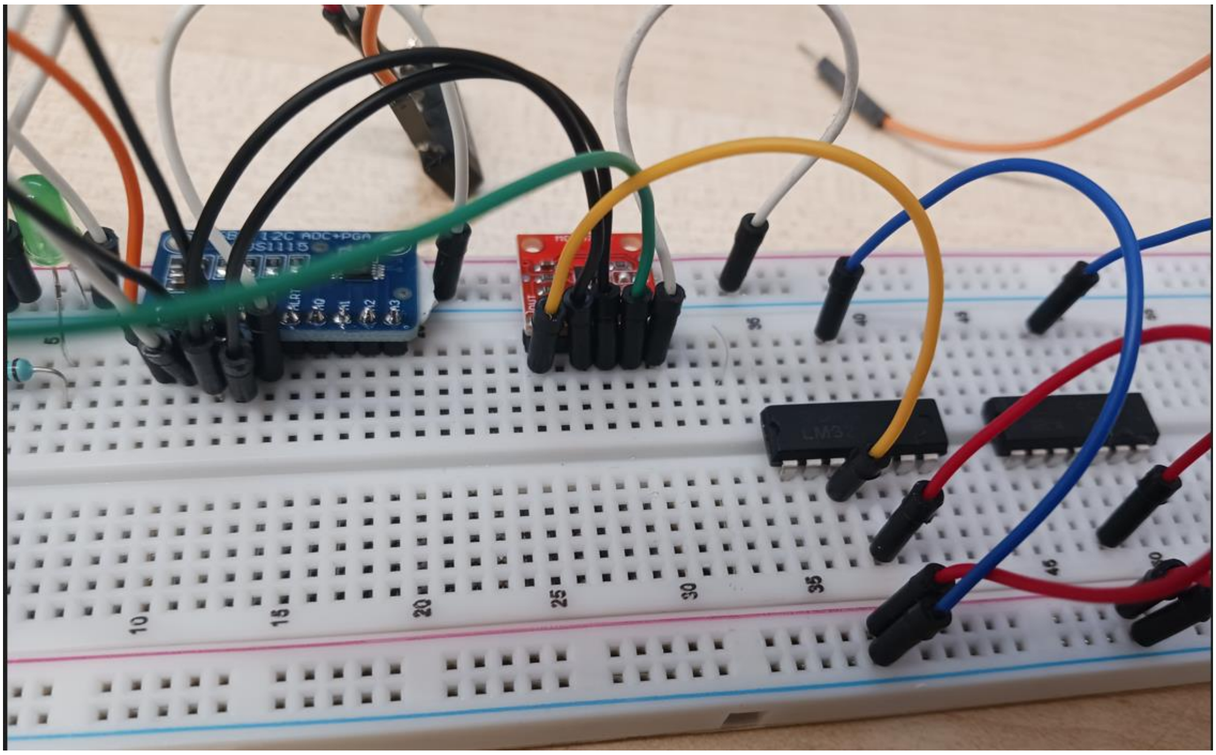


Step 10) Here we will set up the power-lines of the operational amplifiers. These require a +9 V rail (red wires) and a -9 V rail (blue wires). +9 V and -9 V are referred to the common ground. These connections will be established later. For now, connect it as shown in the following figure.

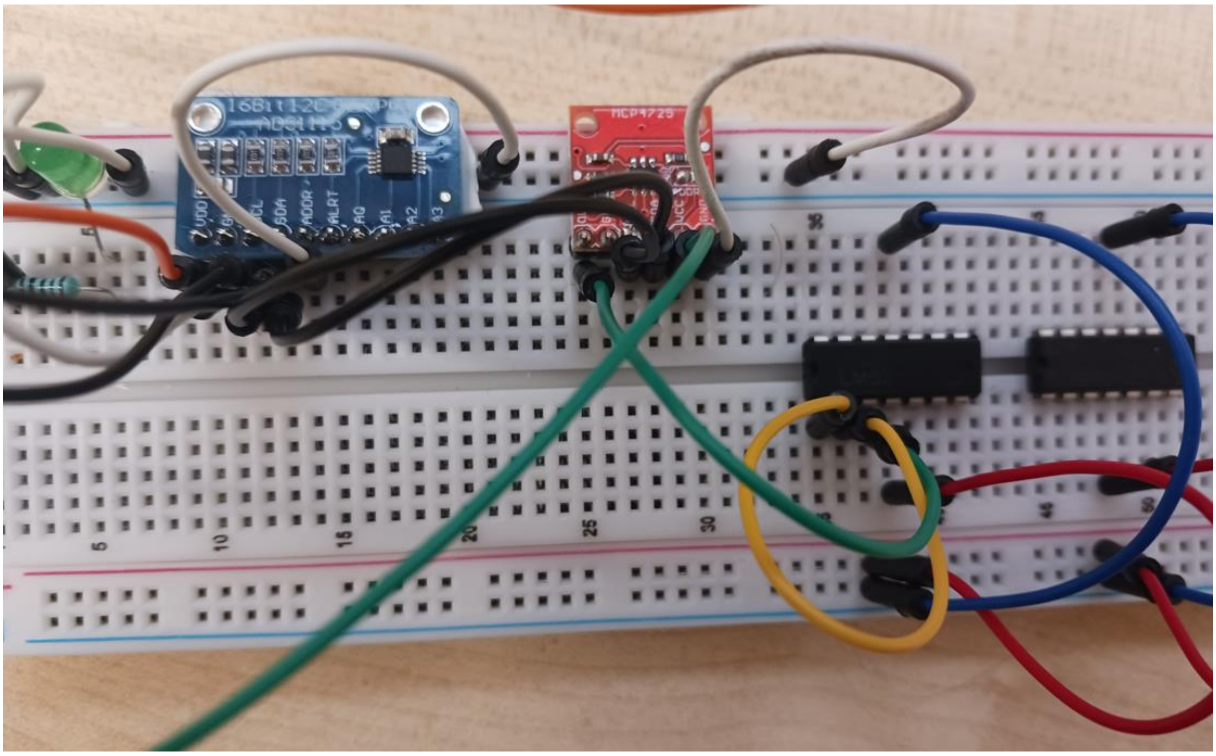


Starting from here, the individual building blocks of the circuit (as shown in the original paper) are set up.

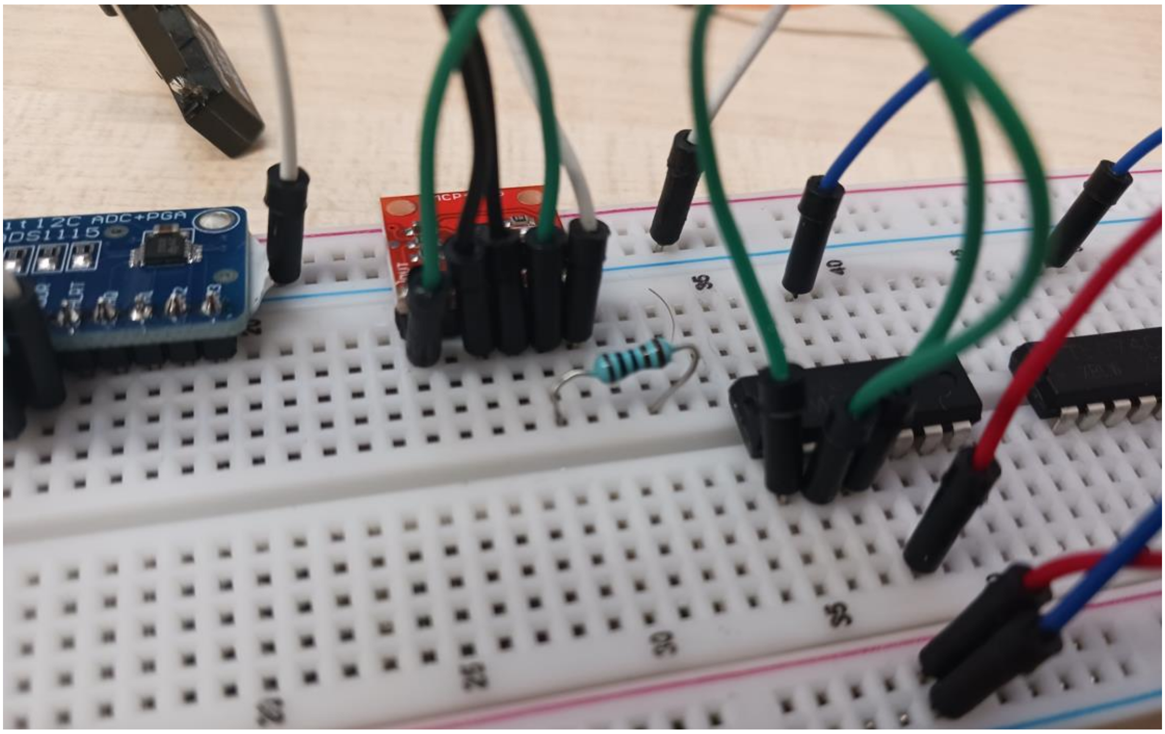
Step 11) We begin with block B) (see figure 1 of the original paper). This block will buffer the output of the MCP4725. To create it, first connect the OUT of the MCP4725 to the non-inverting input of one of the four operational amplifiers of one of the LM324 chips.



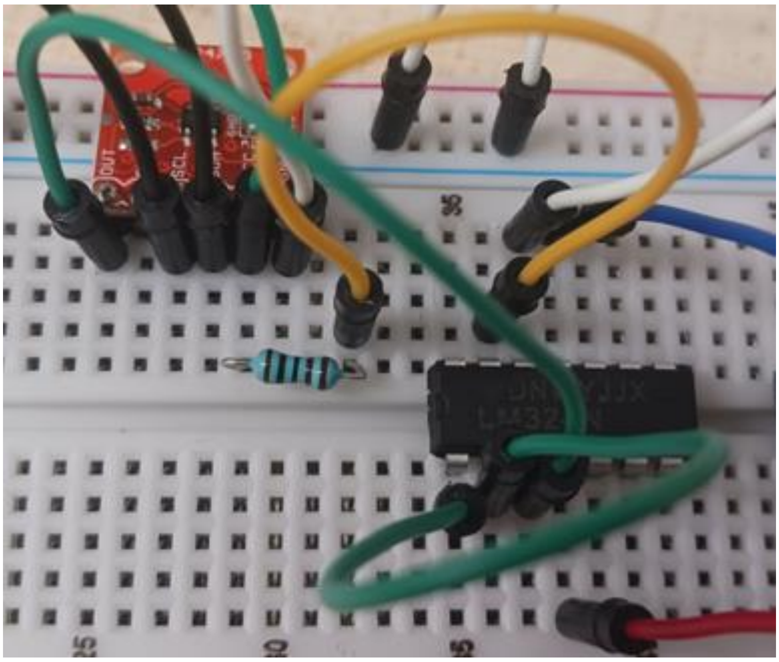
Step 12) At next, connect/tie-back the output of the amplifier chosen in step 11) with the respective non-inverting input. This completes block B.



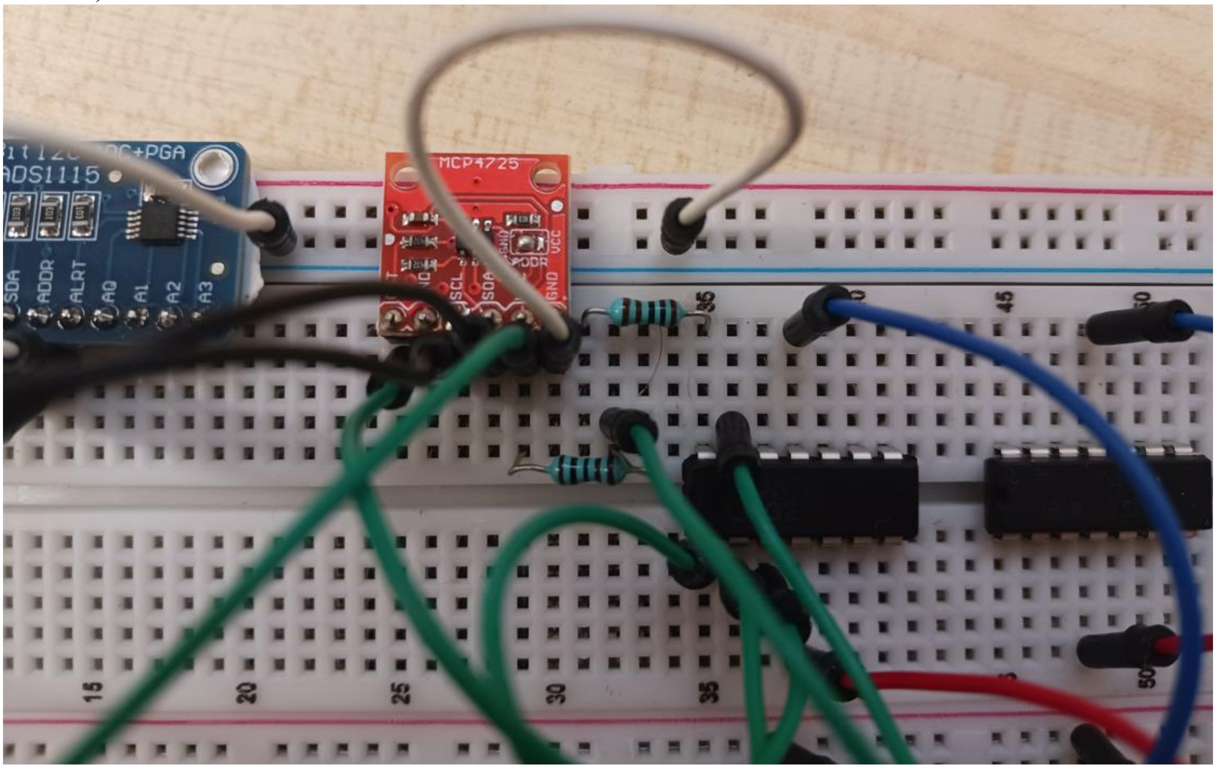
Step 13) In this step, we will start to assemble block A) of figure 1 in the original paper. This block creates the negative reference voltage of our circuit (- 3.3 V), which is the opposite of the 3.3 V pin of the Arduino Uno. For this purpose, we need to create an inverting amplifier with a unity gain. Therefore, we first connect the +3.3 V rail of the MCP4725 with the inverting input of the LM324 via R1 (see also step 14).



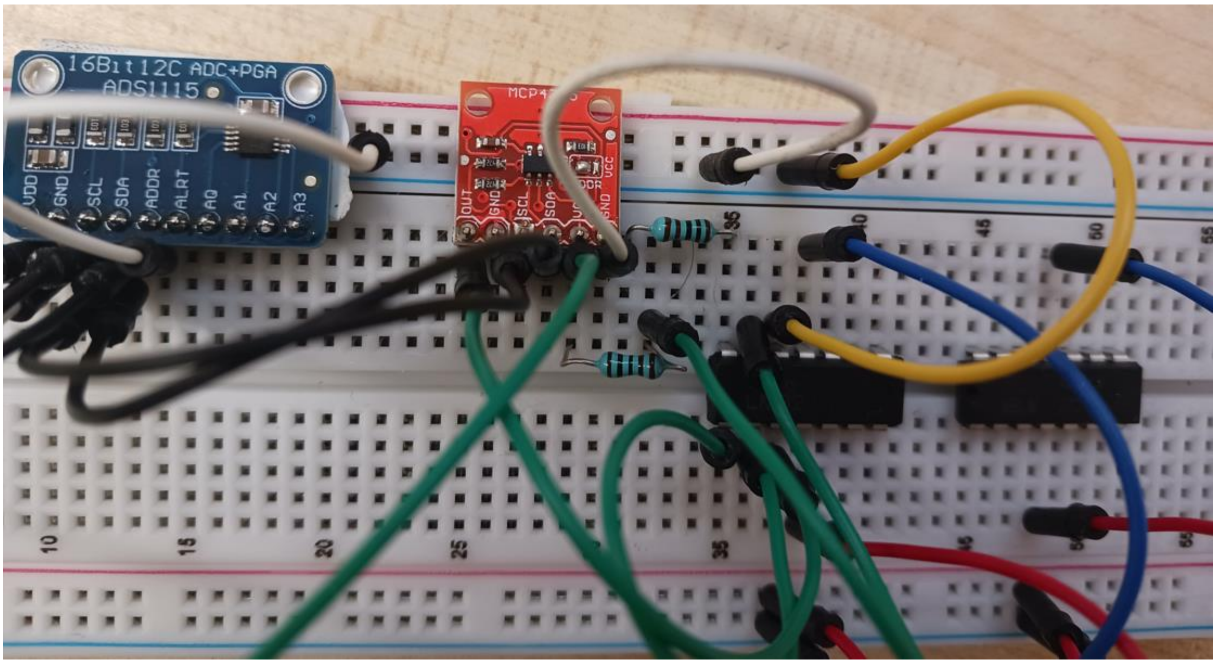
Step 14) Yellow wire connects R1 with the inverting input of the LM324.



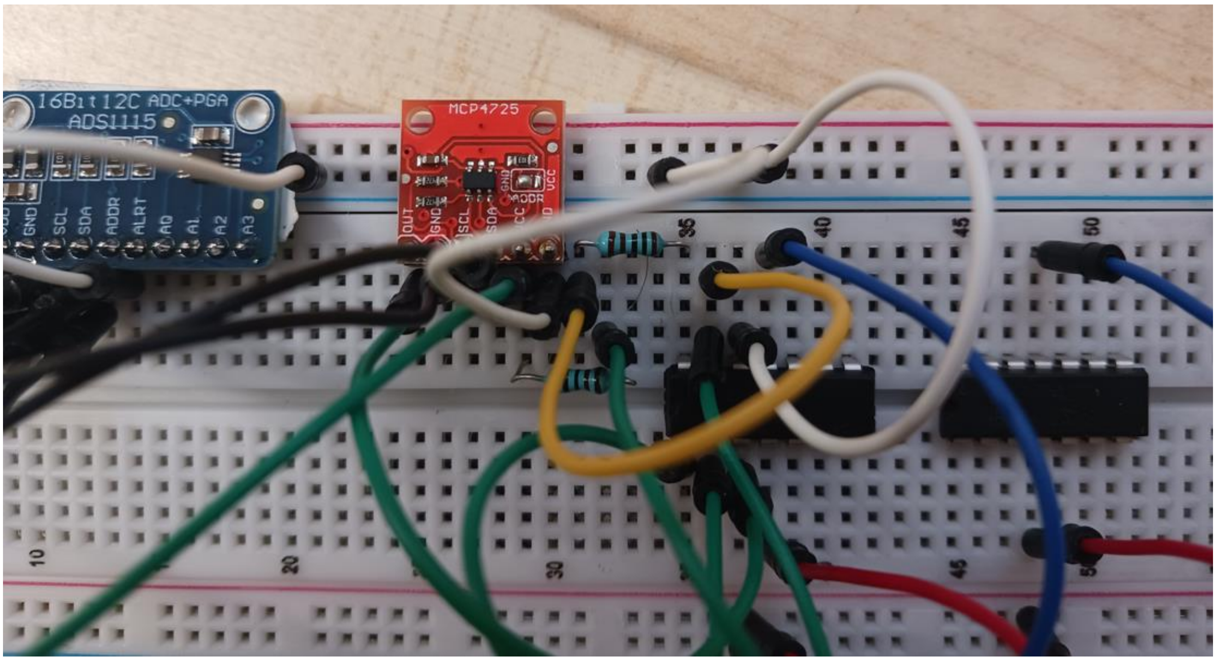
Step 15) Now, we insert the feedback resistor (R2) at the output of the operational amplifier of block A).



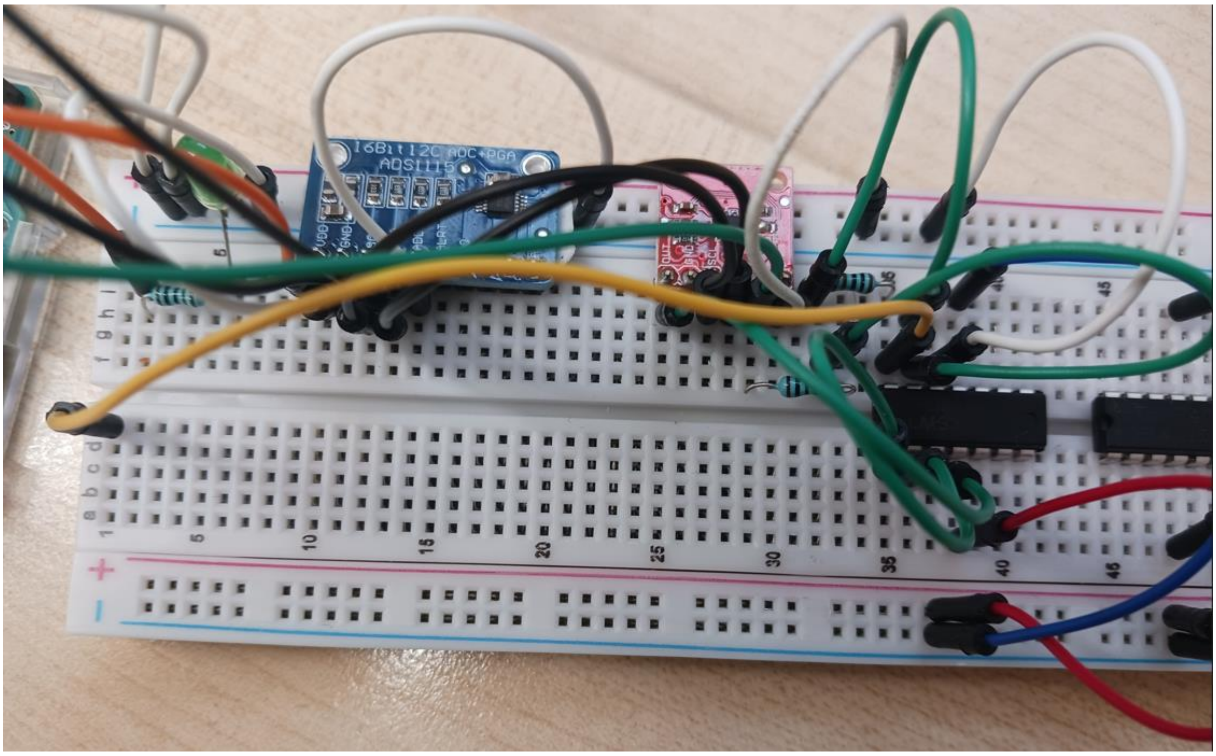
Step 16) At next, the non-inverting input of the op.amp. of block A) is connected to the ground of the circuit.



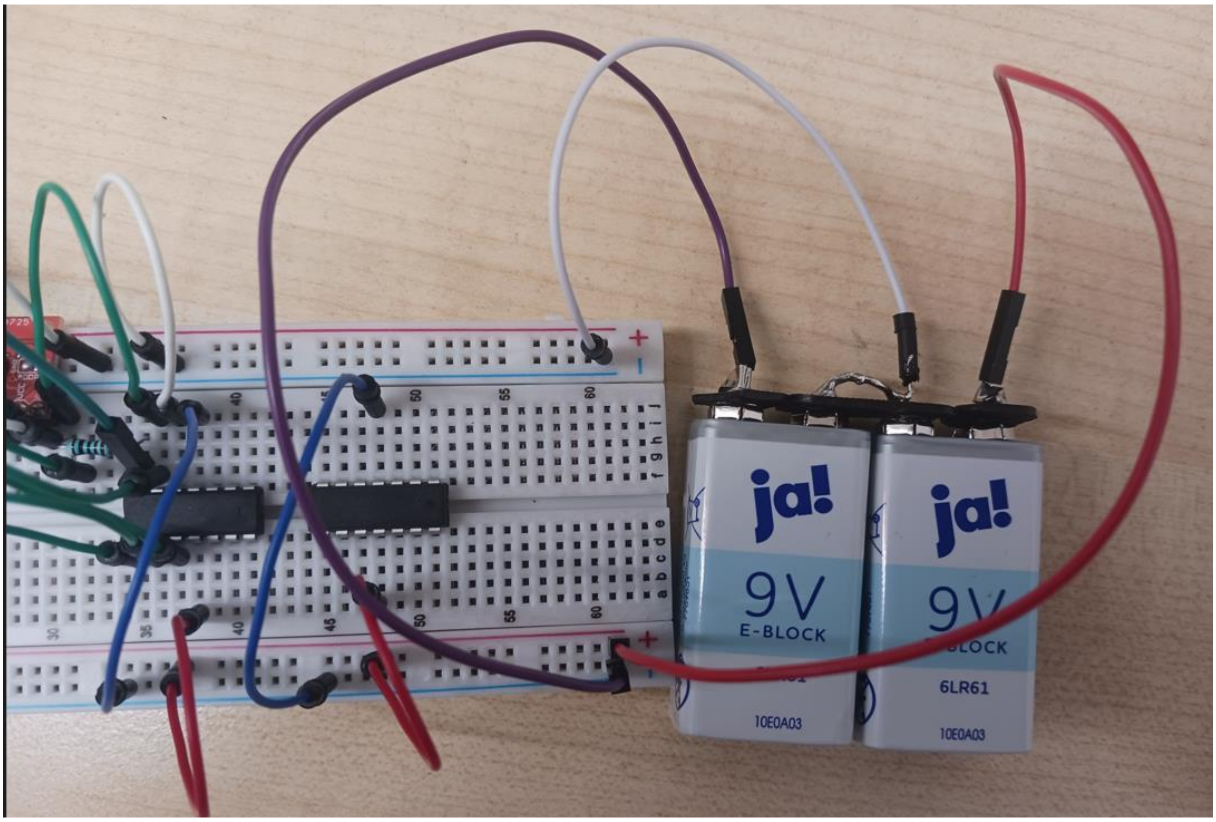
Step 17) Now, we tie back the output of the operational amplifier of block A) which has to its inverting input. This completes block A).



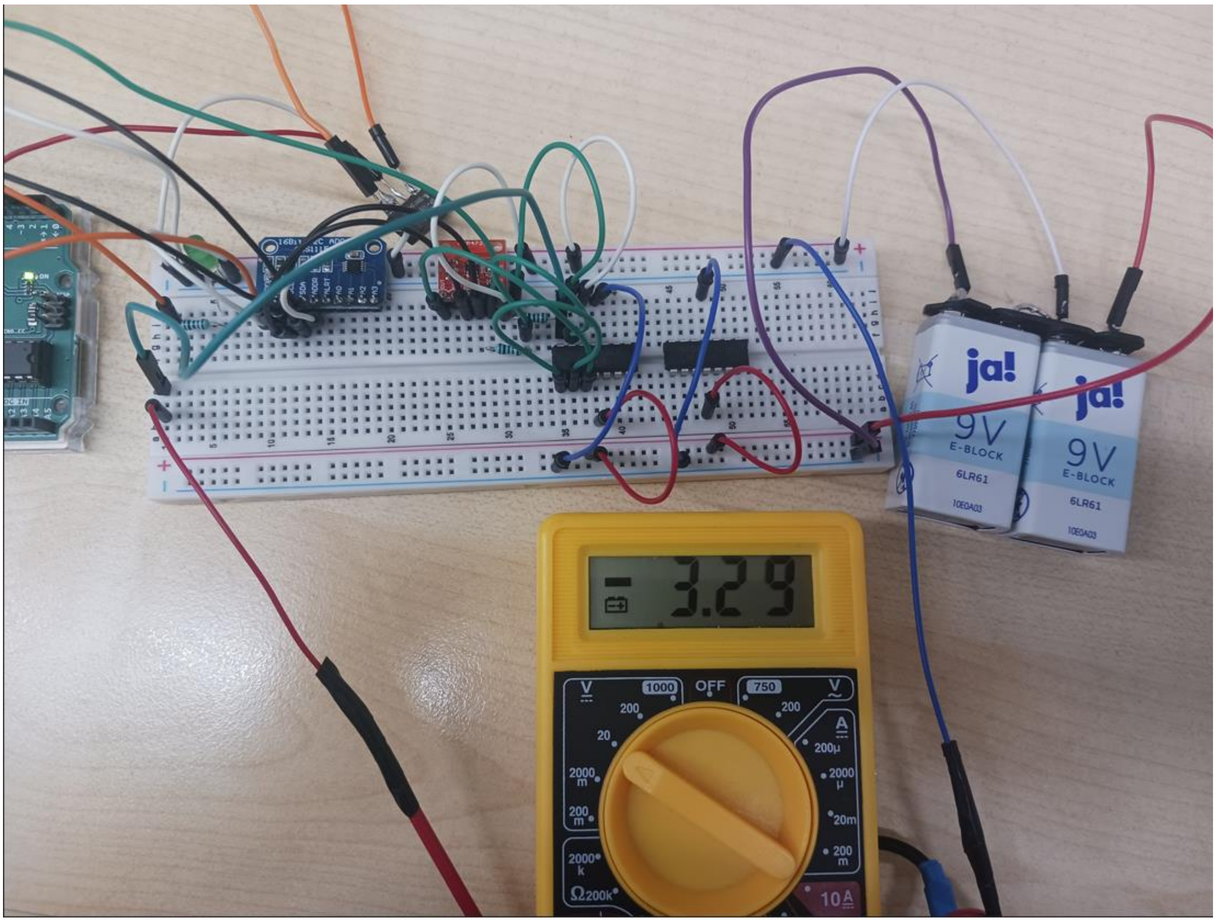
Step 18) Finally, we „grab the output signal of block A) and create a negative voltage rail, which is easily accessible later on.



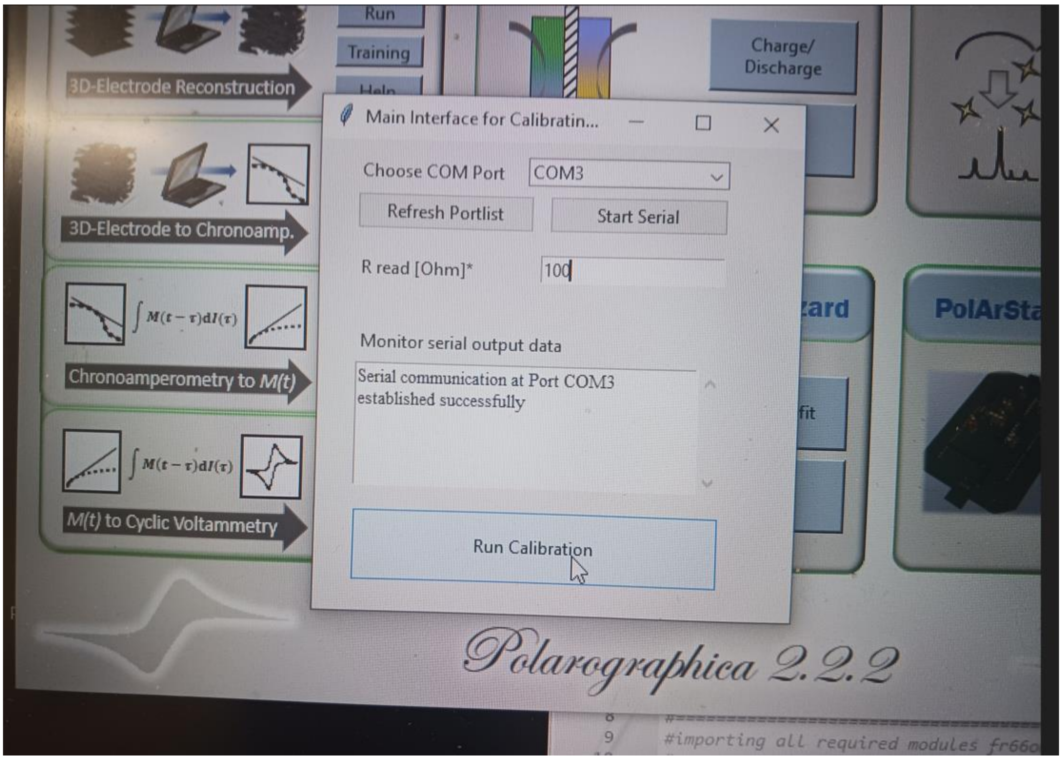
Step 19) In this step, we are powering the +9 V and the -9 V rail for the operational amplifiers. For this purpose, we create a symmetrical DC-power supply (e.g. with two 9 V batteries). Of course, any other power supply which is less or free of electrical noise and which can symmetrically give 9 V can be used. The “two 9 V battery” approach is just a facile and potentially not too expensive solution. The two 9 V batteries are connected as seen in the following figure. Essentially, we have - → (+-)→+. So across the two outer poles we have, of course, a potential difference of 18 V. However, w.r.t. the central pole (-+) we have either +9 V or -9 V. Therefore, the central pole is connected to the ground of the circuit (white wire). This defines the reference voltage of the power supply. The -9 V (blue wires) are connected to the negative power terminal of the LM324 and the +9 V to the positive power terminal of the LM324. MIND THE ORIENTATION OF THE LM324 and/or consult the datasheet. Reverse bias will destroy the LM324 very quickly and maybe also melt the breadboard…



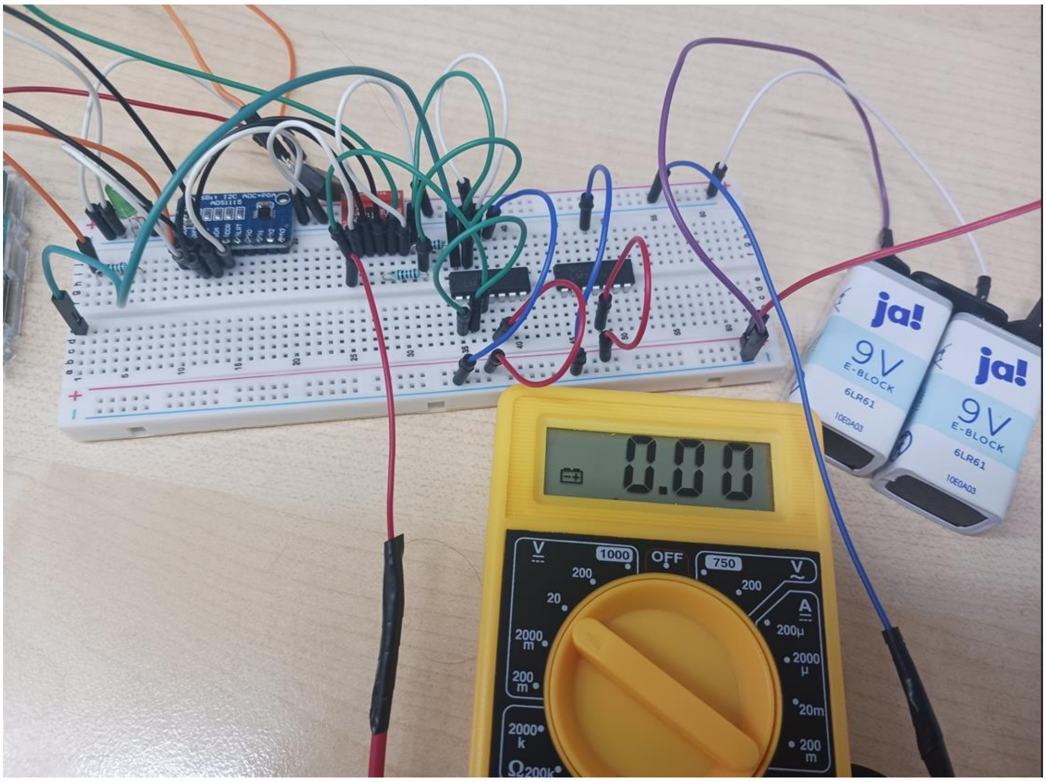
Step 20) Now, if all the power connections of the operational amplifiers are made, we can connect the Arduino Uno to a PC (or optionally, a USB-power device). To see if Block A) – the negative voltage rail – was set up properly, one can connect a multimeter/voltmeter with its negative terminal to the ground rail of the circuit and with its positive terminal to the negative voltage rail which was created in step 18. This should give – of course – negative 3.3 V (as seen in the next figure).



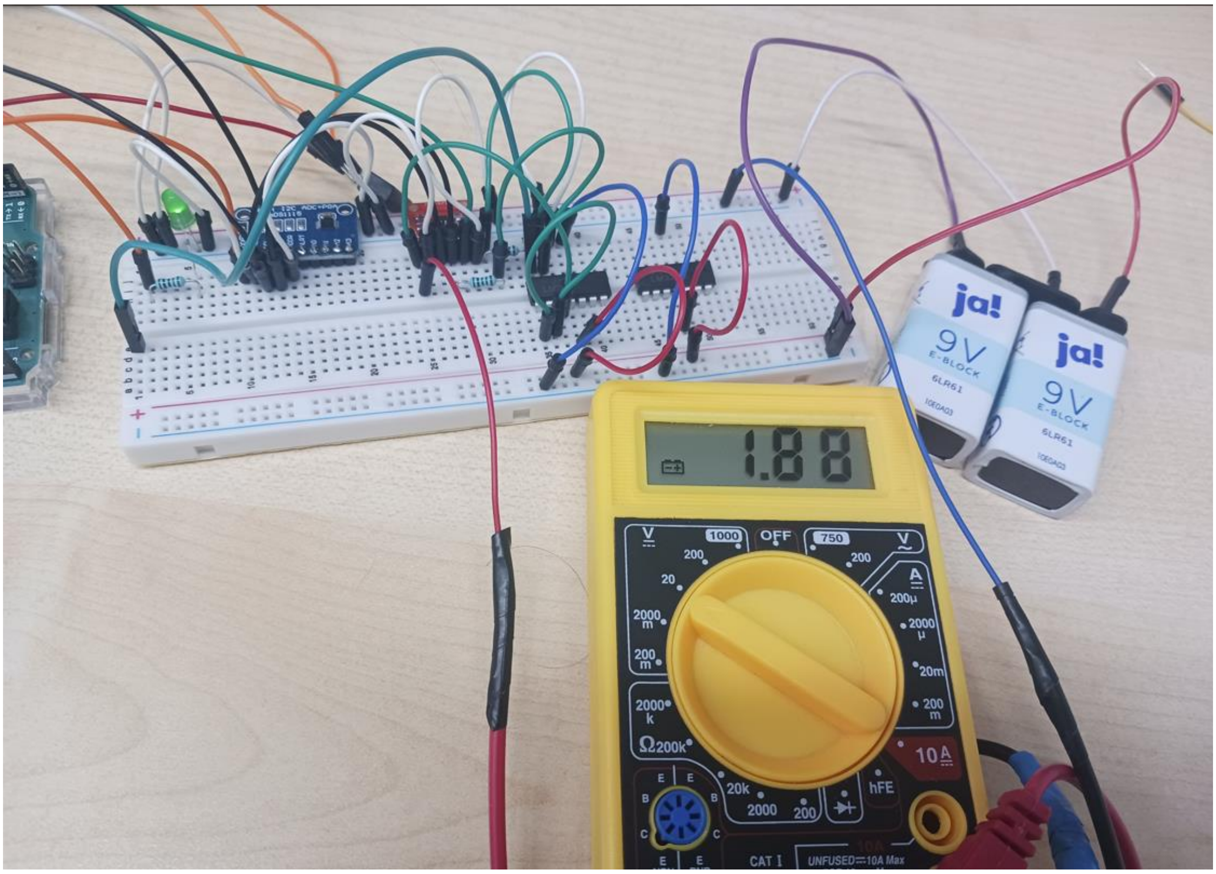
Step 21) If the Arduino does already contain the PolArStat firmware (for realizing this, see SI of the original paper), one can check the outputs of the MCP4725 now. Just initiate a “calibration” (which is inherently NOT a true calibration but just for checkup-purposes.

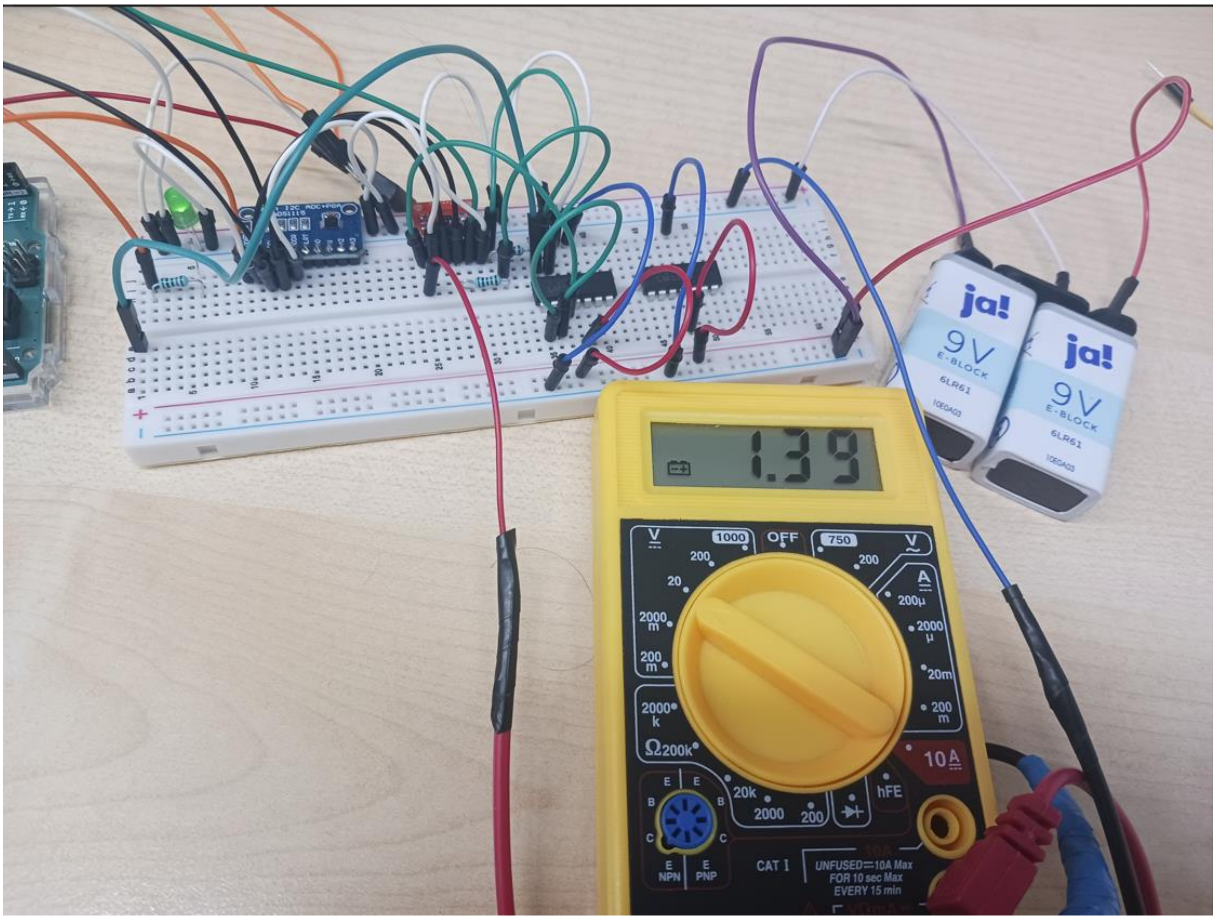


Step 22) Connect a multimeter across the ground rail and the output of the MCP4725. This should give you 0 V, if no calibration or anything else was ever started.

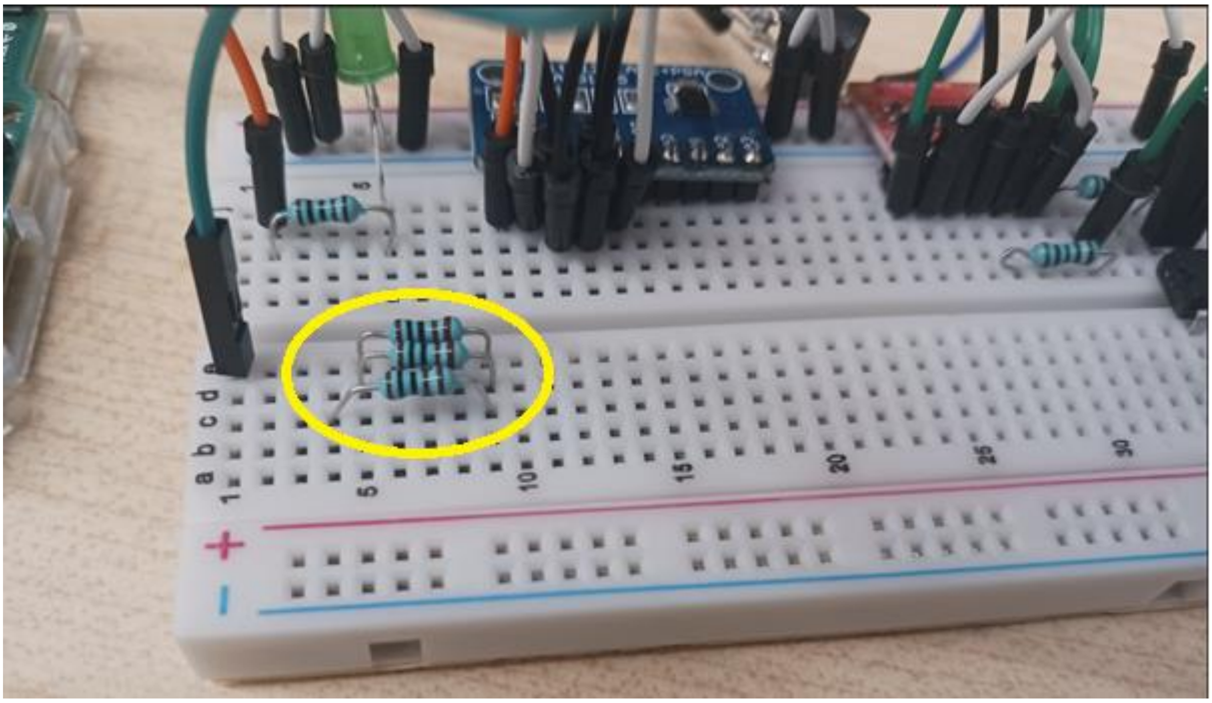


Step 23) The next two images show the output voltages of the MCP4725 during a calibration, if all connections were made properly.

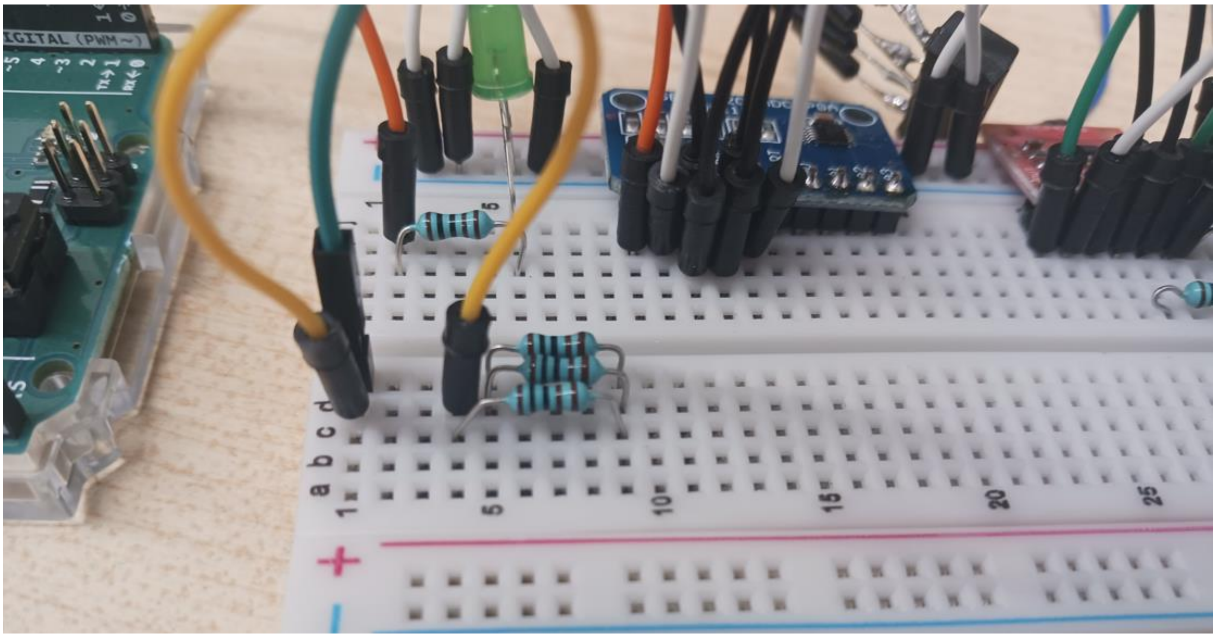




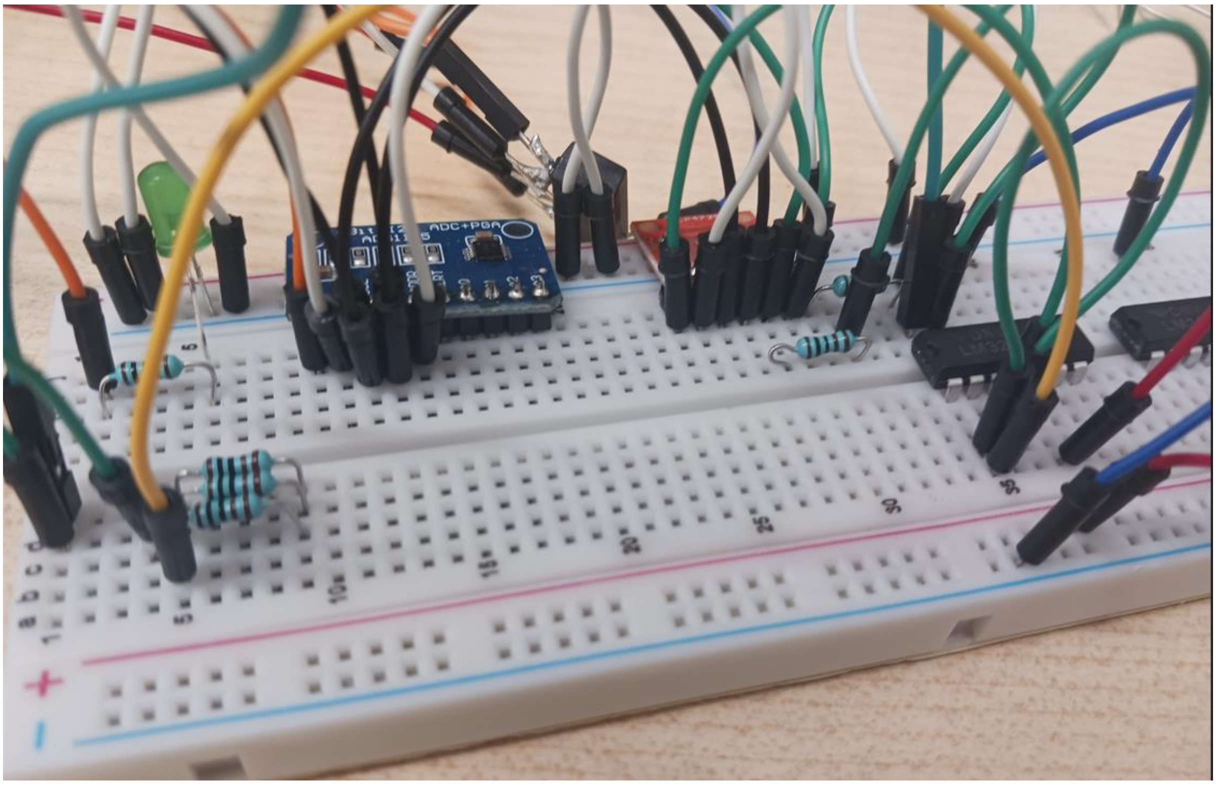
Step 24) If step 23 was successfully tested, we can continue with setting up the circuit now. At nexet, we will start with building block C) (see original paper).At first, R3, R4 and R5 are inserted.



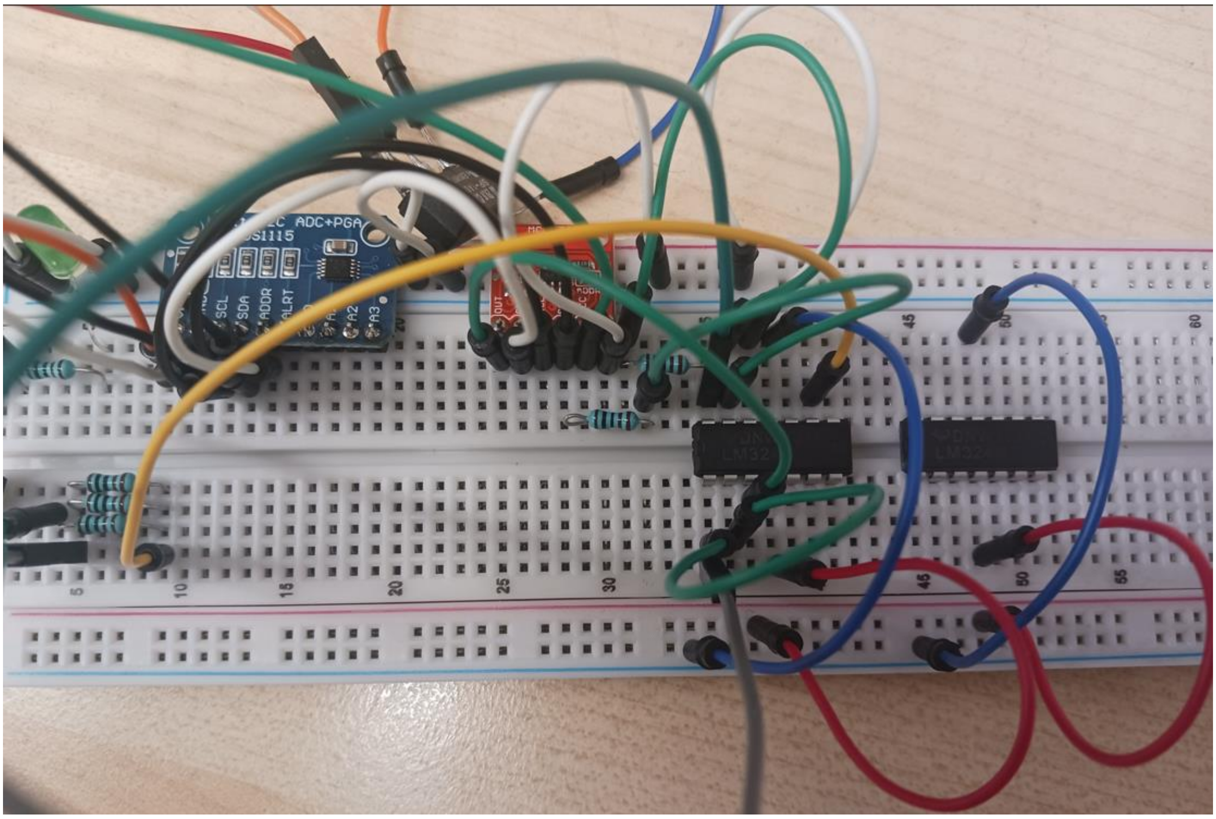
Step 25) R3 is now connected to the -3.3 V rail.



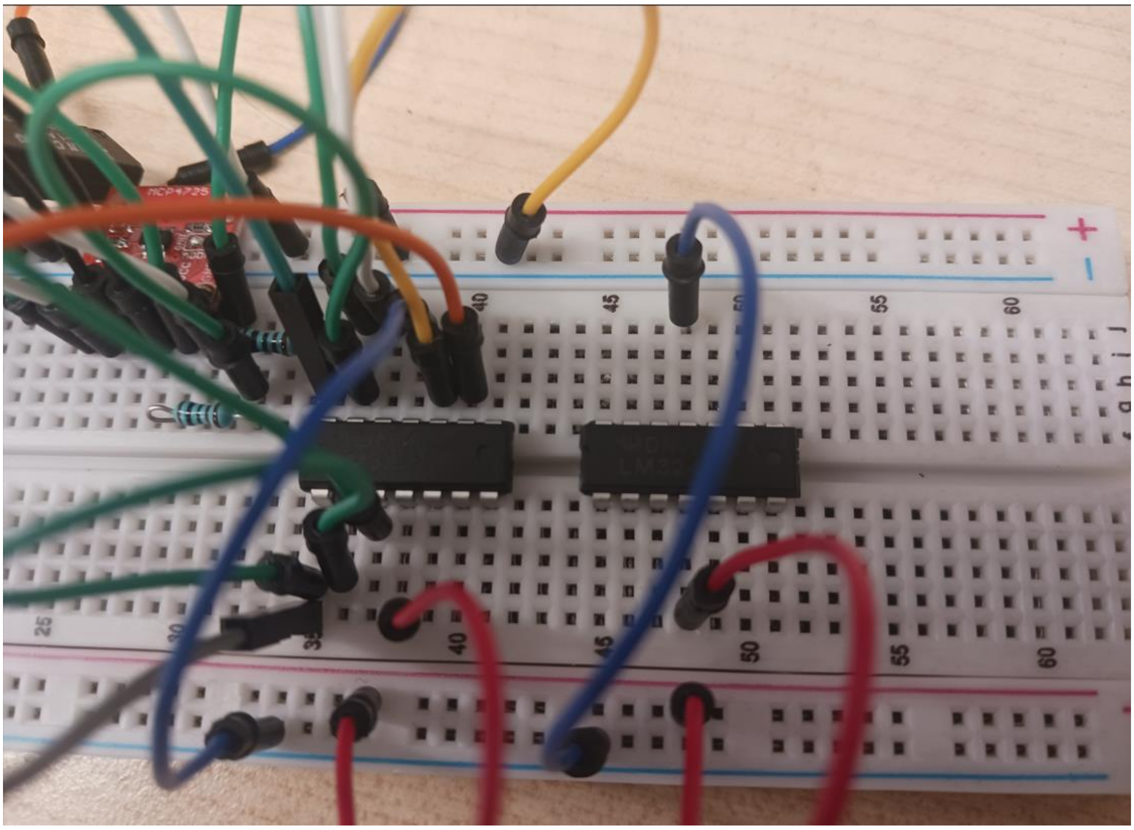
Step 26) Now, the output of block B) (i.e. the buffered output of the MCP4725) is connected to one end of the parallel connection of R4 and R5.



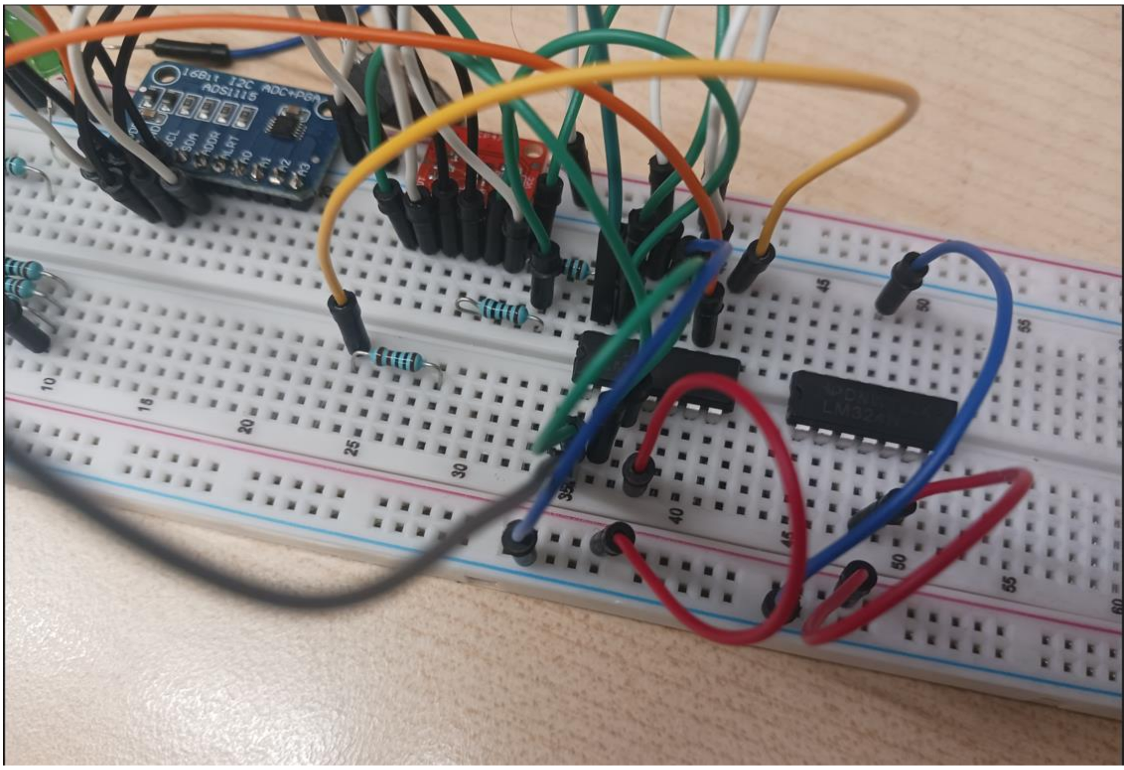
Step 27) Here, the joint end of R3, R4 and R5 is fed into one of the inverting inputs of the LM324



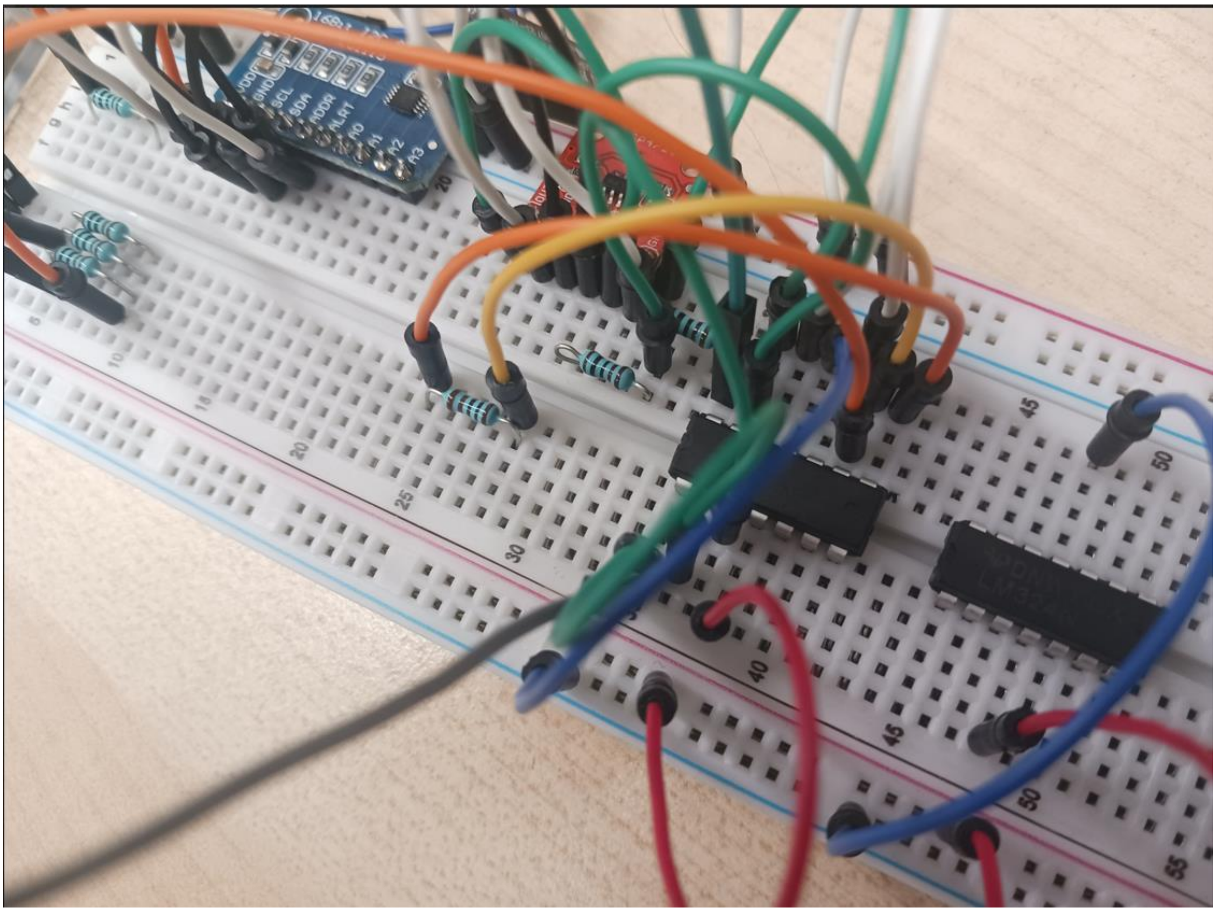
Step 28) To configure the op. amp. of step 27 as an inverting op. amp., its non-inverting input is connected to the circuit´ ground.



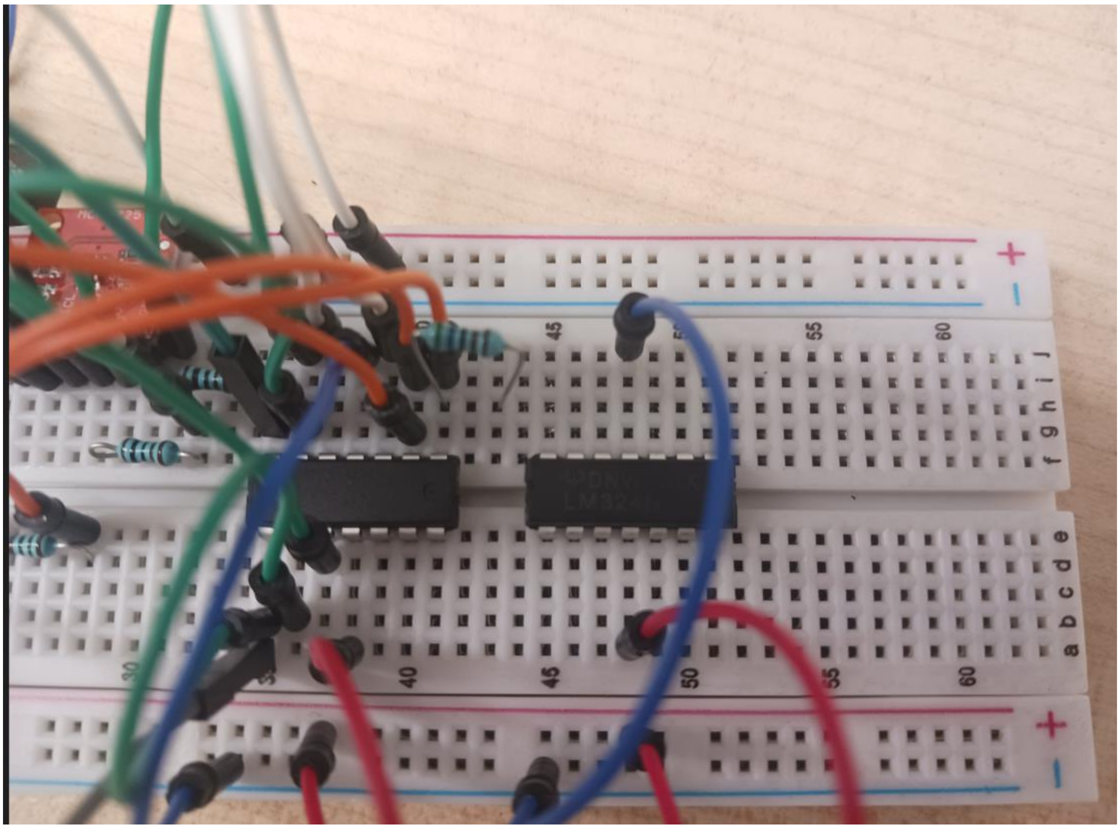
Step 29) Now, the feedback-loop via R6 (see original paper) is created. For this purpose, the output of the op. amp. is “pulled out” and connected to a 1 kOhm resistor.



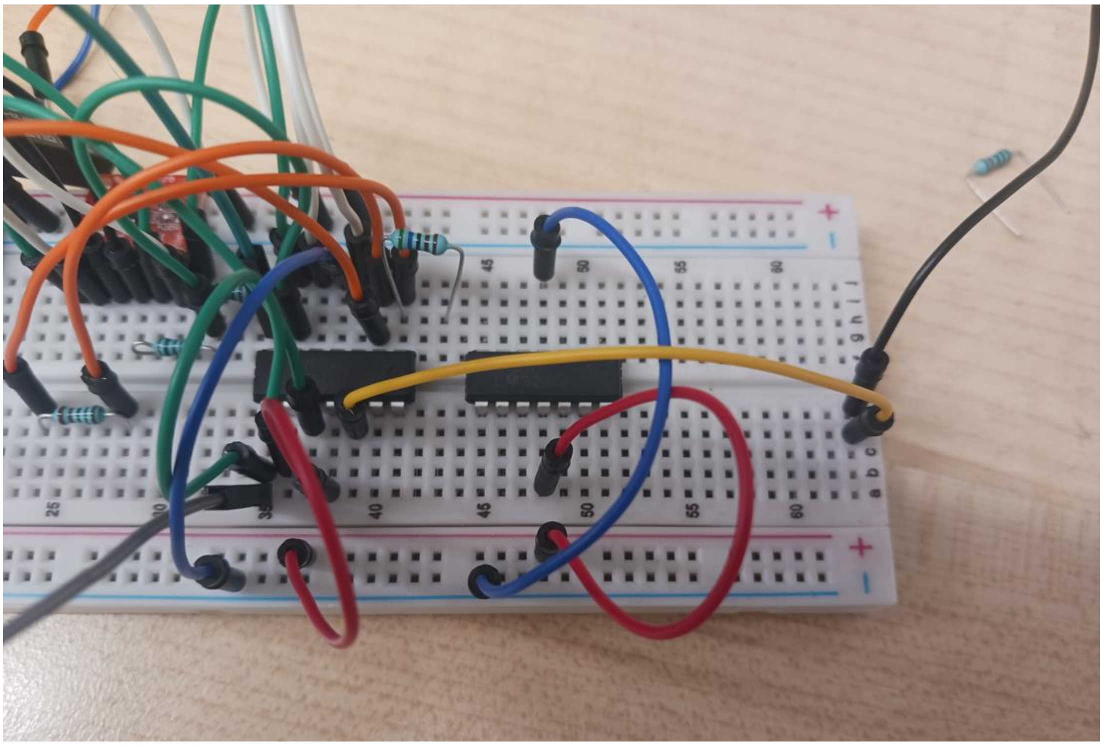
Step 30) Now, the feedback-loop via R6 is closed, by connecting the remaining end of the 1 kOhm resistor of step 27 with the inverting input of the op. amp. of block C). This step completes block C).



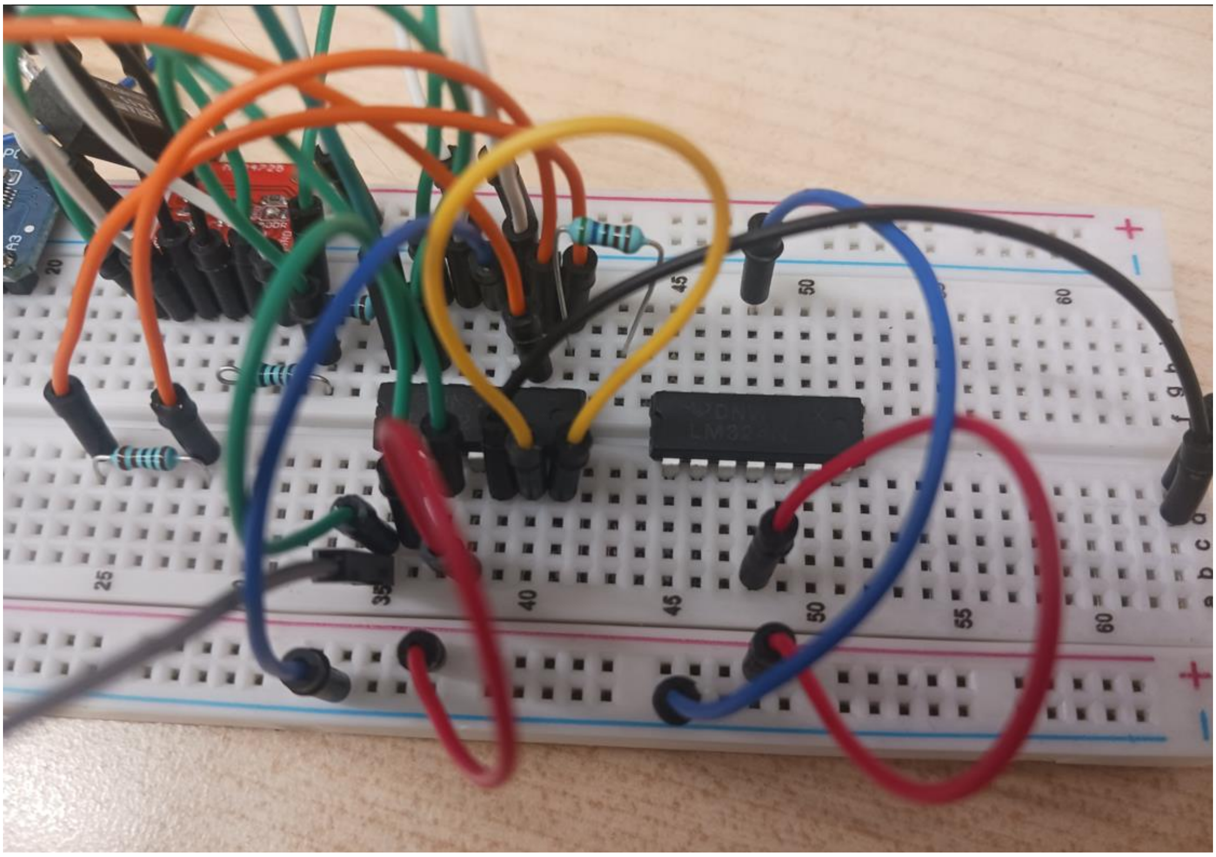
Step 31) At next, R8 (see original paper figure 1) is inserted. One of its´ terminals is connected to the output of block C), the other end is left open for the moment.



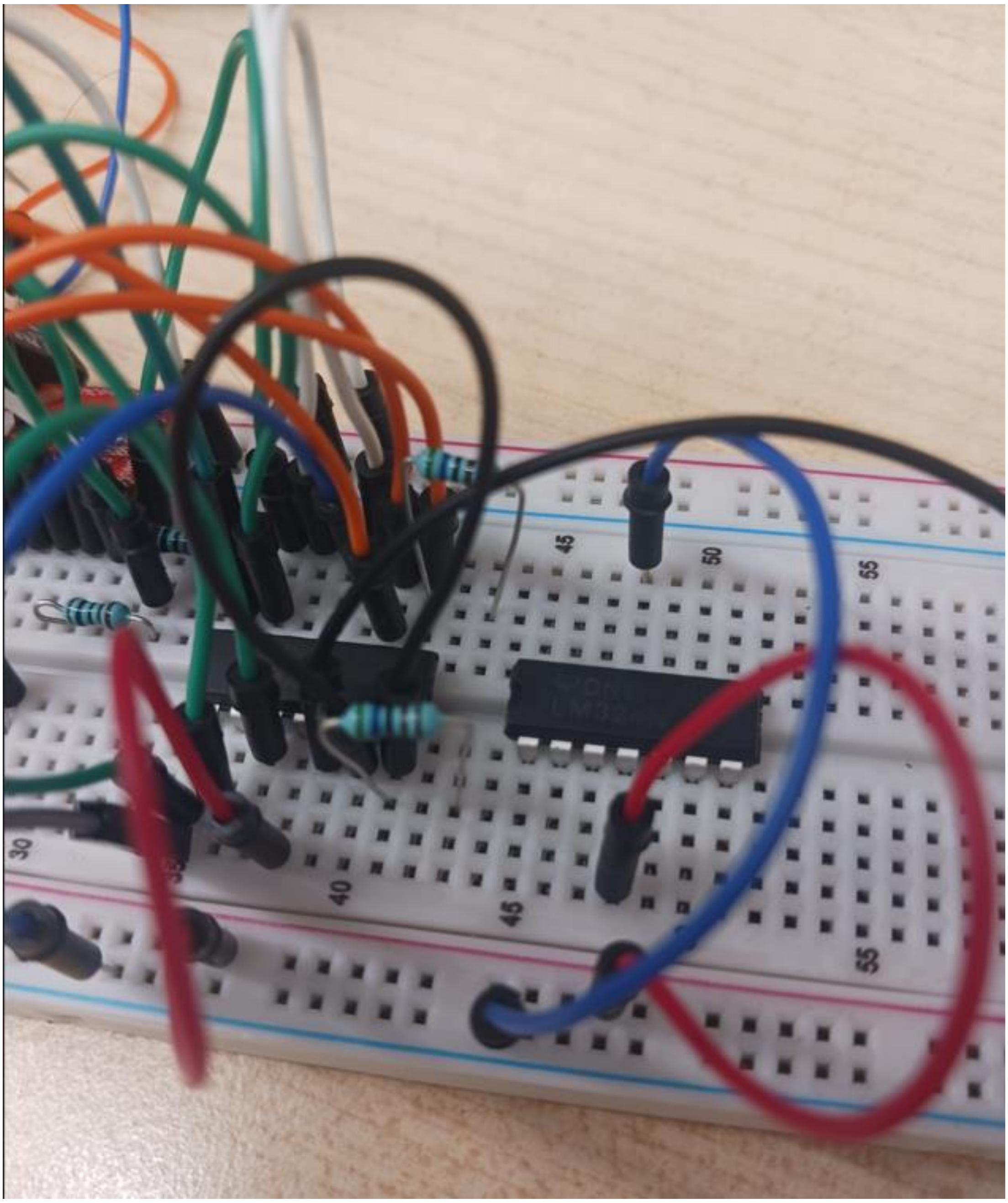
Step 32) At next, the buffer off for the reference electrode (RE), i.e. block D), is created. The yellow wire in the next figure is the internal connection of the RE to the non-inverting input of one op.amp. The black wire in position 63d is the external lead for the RE which is used for measurements/connection to the cell.



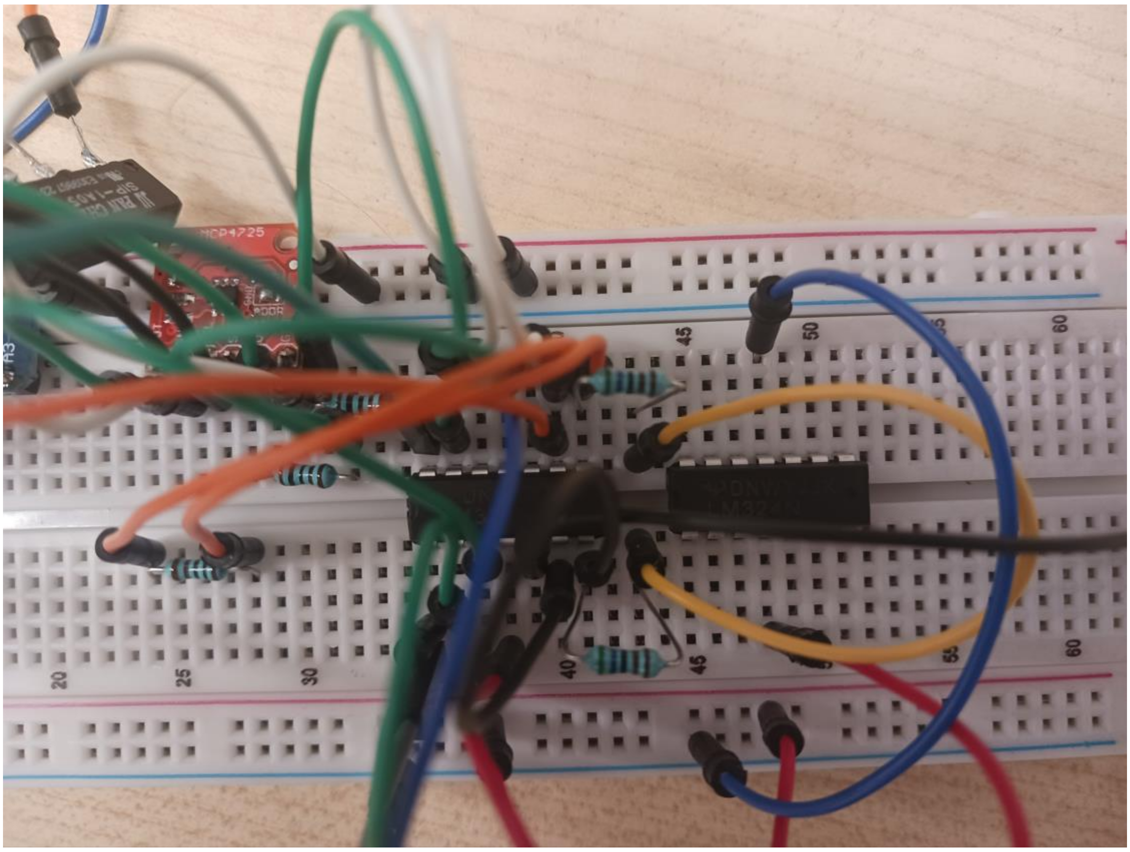
Step 33) Now, the feedback loop of block D) is created. This is done by connecting the output with the inverting input. This completed block D).



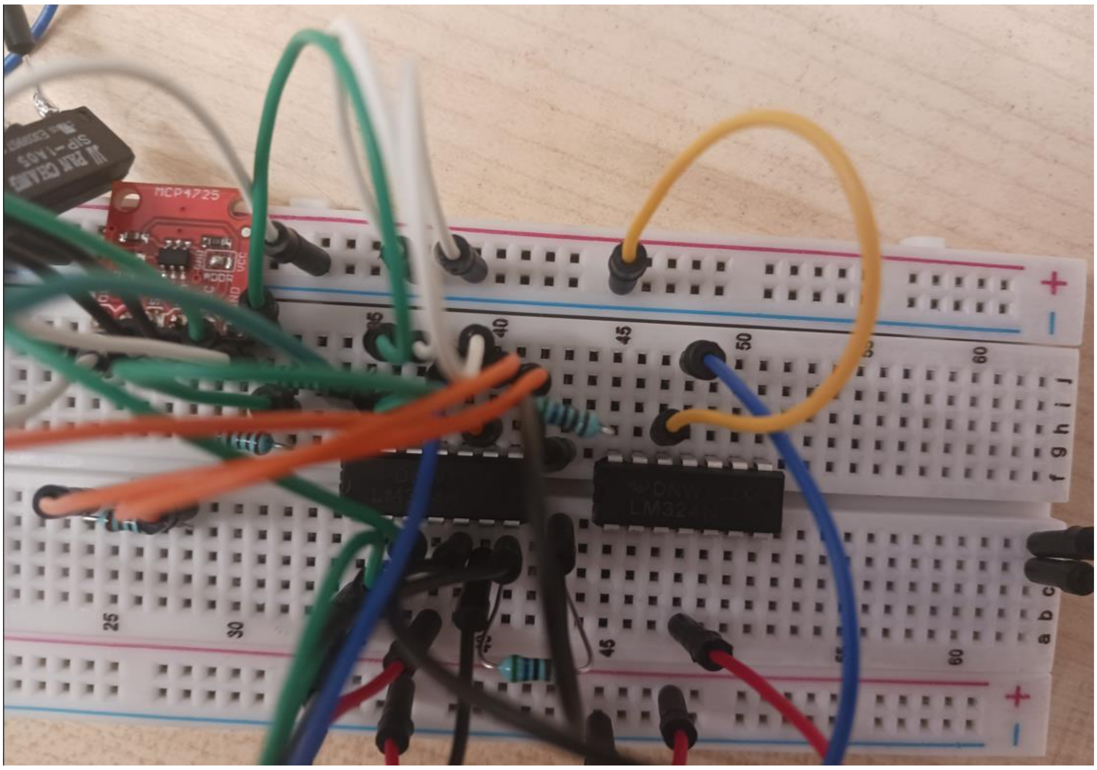
Step 34) Now, R7 is inserted at the output of block D). Note, we already made the one-sided connection of R8 in step 31.



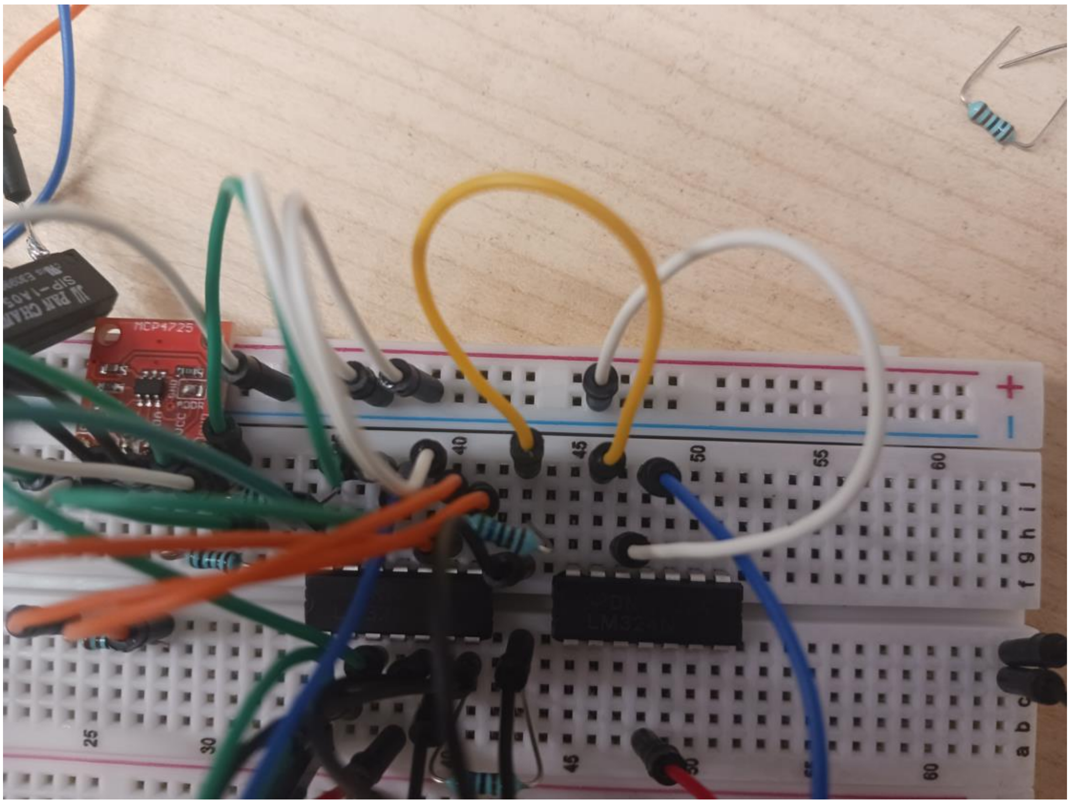
Step 35) Now, the open terminals of R7 and R8 are connected. This is the beginning of the setup of block E).



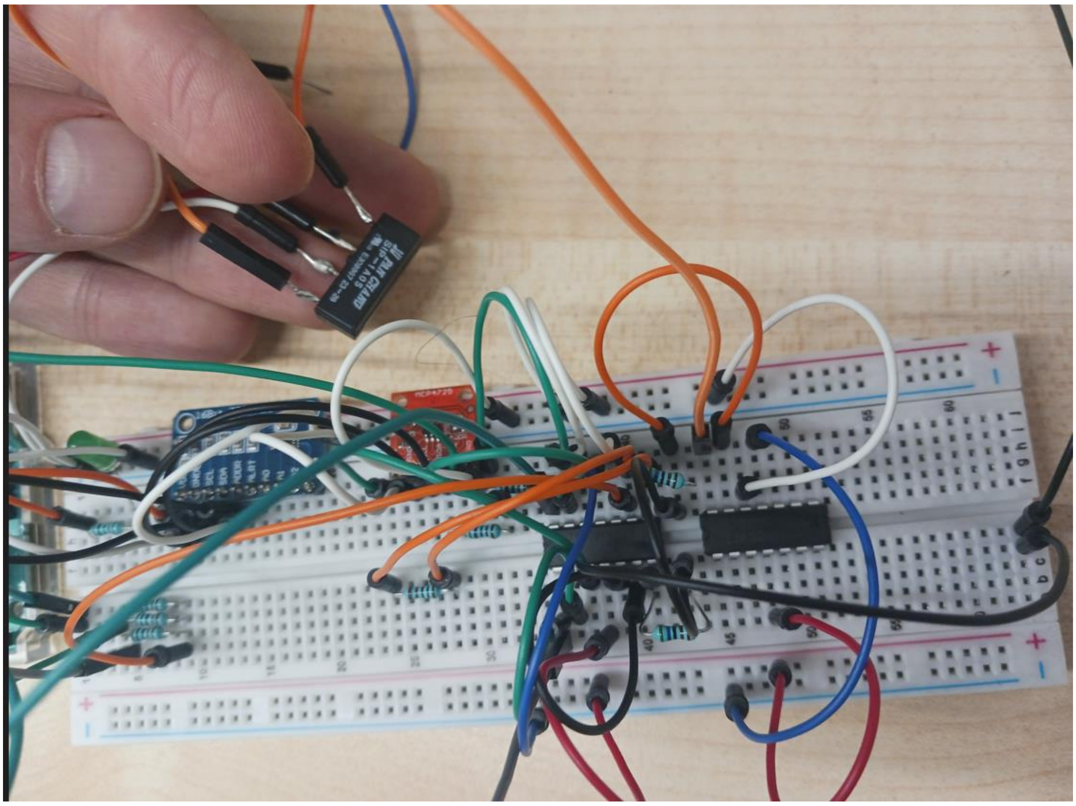
Step 36) Now, the non-inverting input of the op. amp. of block E) is connected to ground.



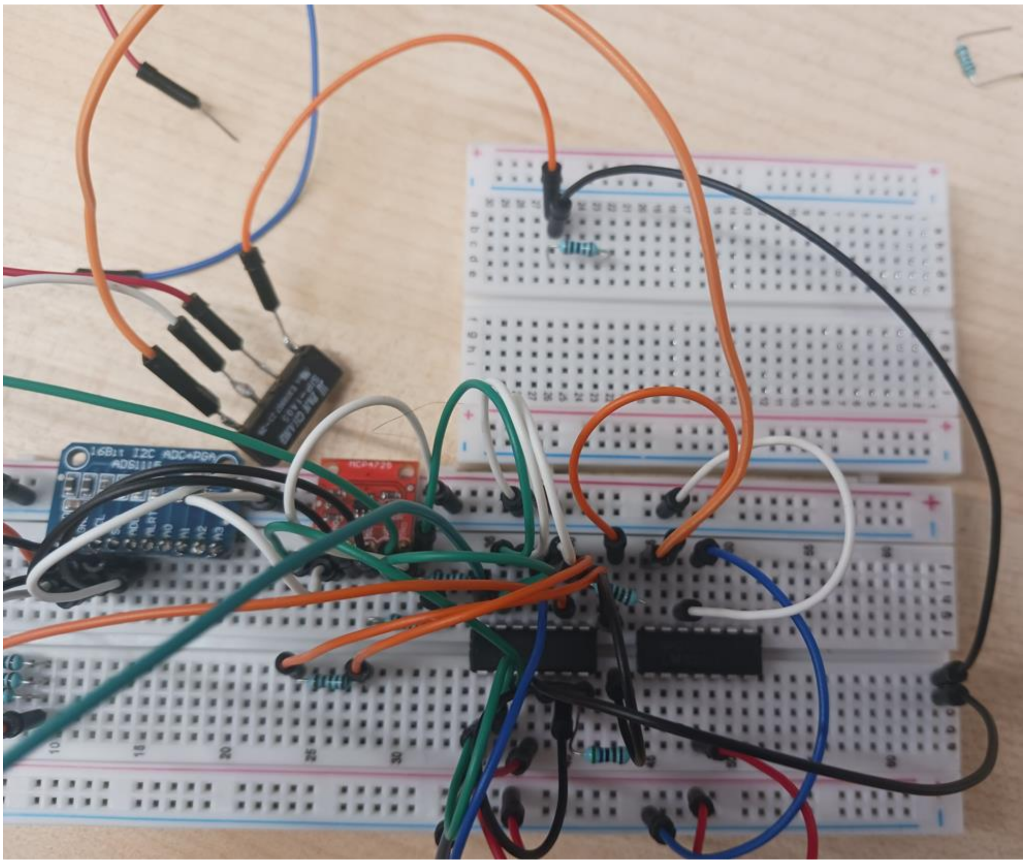
Step 37) In this step, the connection of R7 and R8 is fed into the inverting input of the op. amp. of block E), which already completed block E).



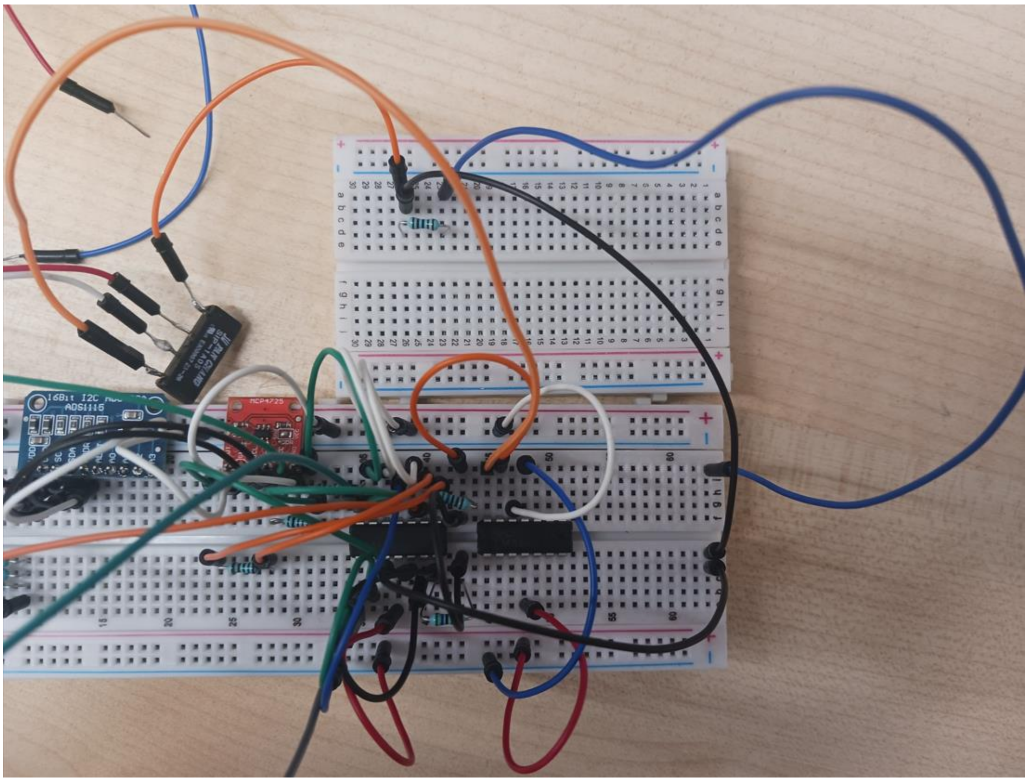
Step 38) In this step, we connect the output of block E) (see previous step(s)) with one of the terminals of the SIP1A05, which was left open in the very beginning of this guide. The other terminal which was left open is the lead of the counter electrode, which needs to be connected to the cell or the system under investigation.



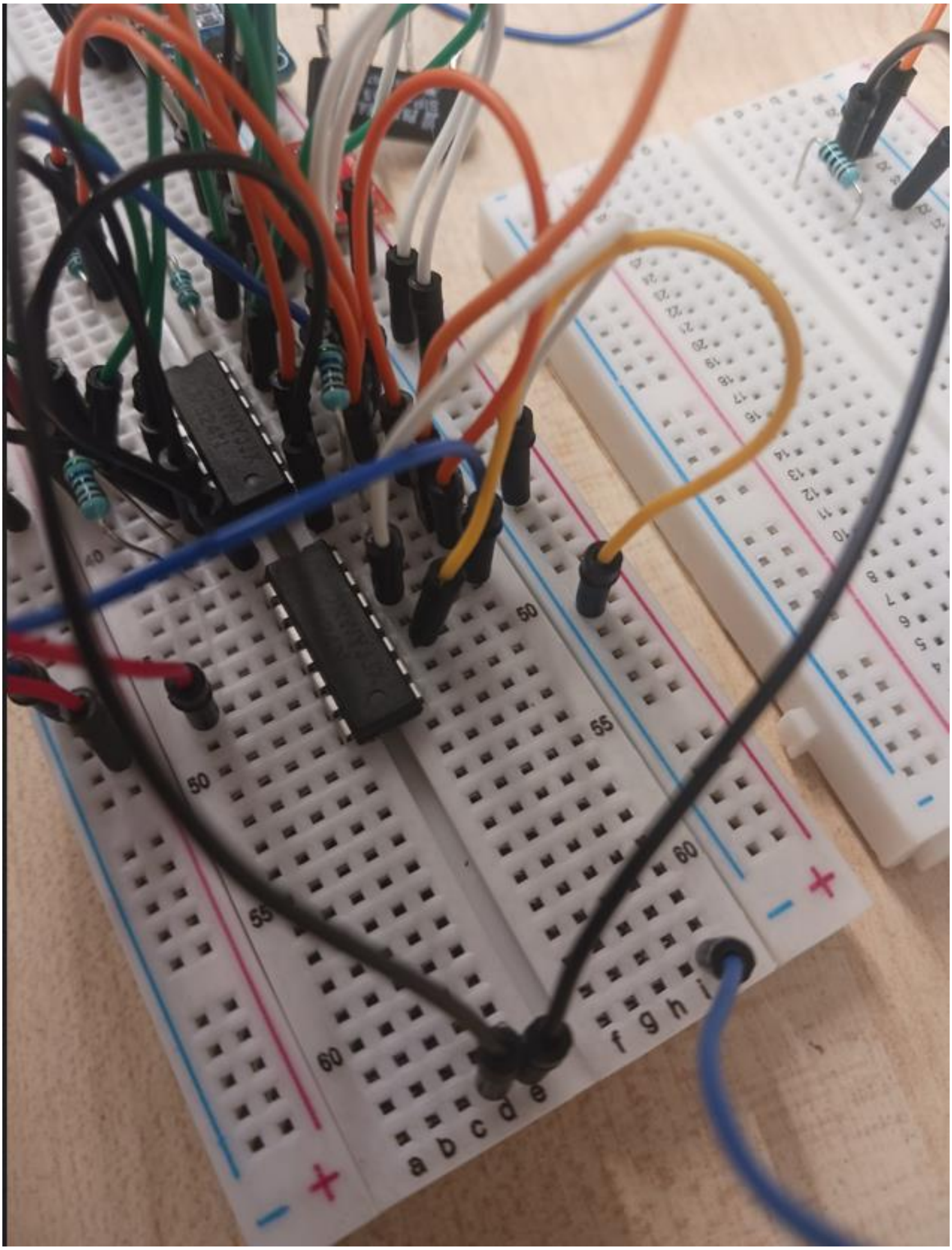
Step 39) This step is not related to the internal circuit of the PolArStat. In contrast, it will make the connections of RE/CE to an external system (here a 1 kOhm resistor on another breadboard).



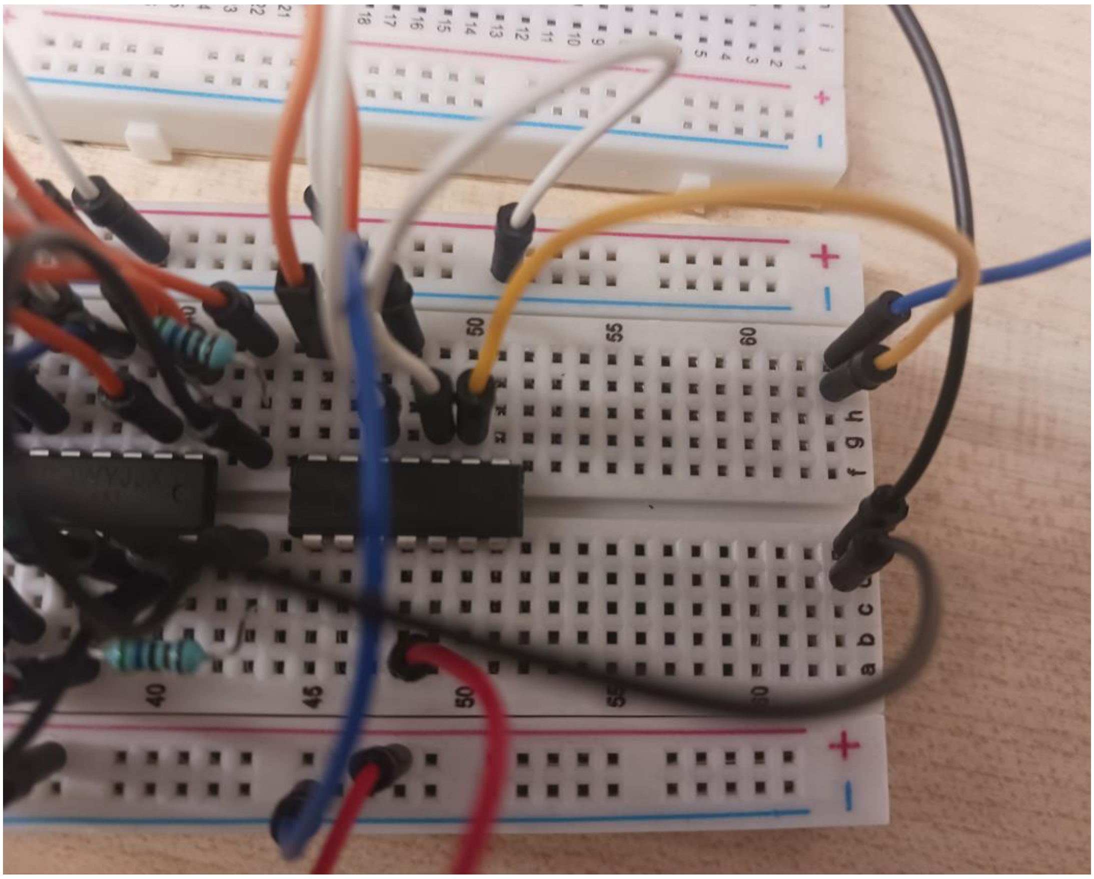
Step 40) As step 39, this step dos not do anything for the internal circuit of the PolArStat. In contrast, it introduced the connection of the working electrode (WE) to the system under investigation (here the 1 kOhm resistor on the second breadboard).



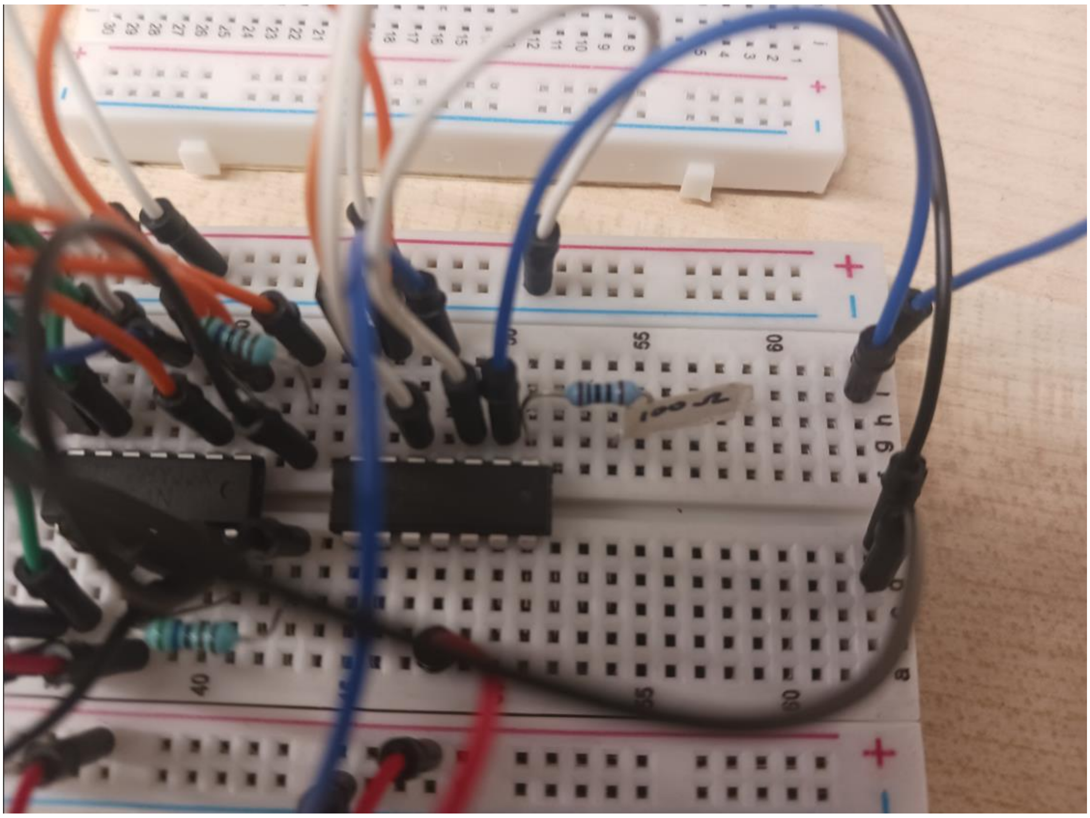
Step 41) In this step, we will start to assemble block F) – the current-to-voltage-converter of the working electrode (see original paper, figure 1). For this, connect the non-inverting input of one op. amp. to the circuits´ ground.



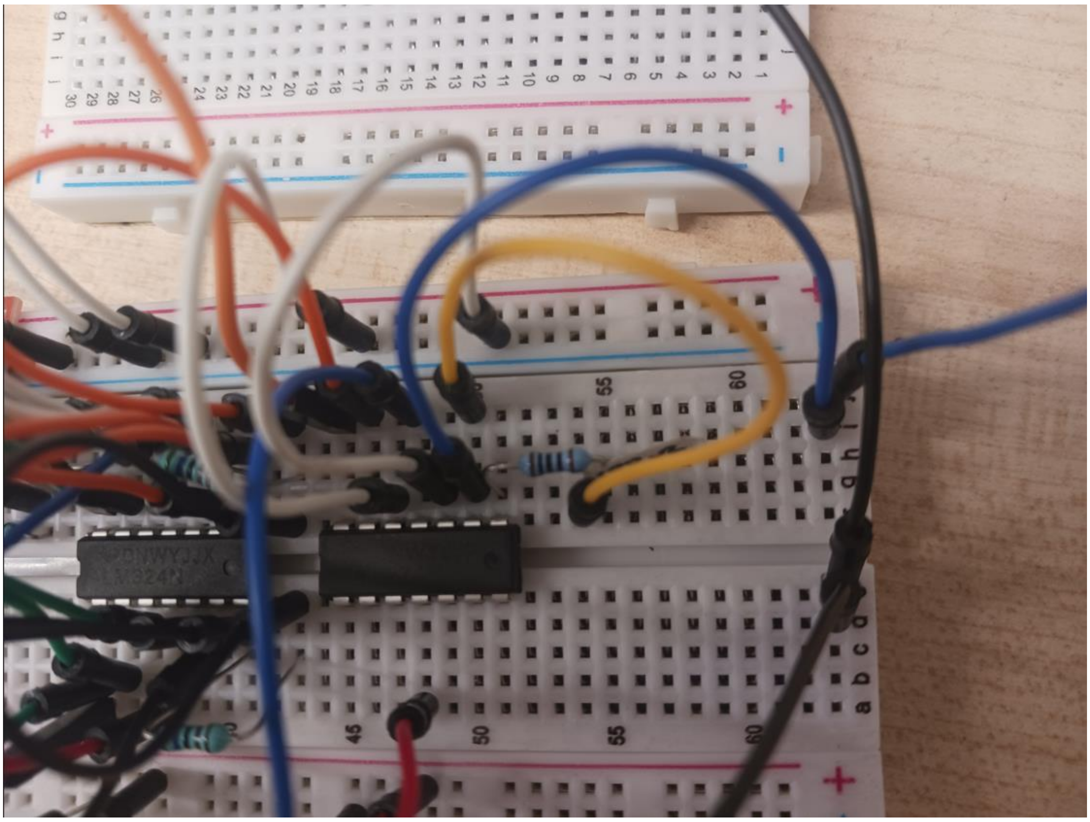
Step 42) Connect the lead of the WE to the inverting input of the op. amp. of step 41.



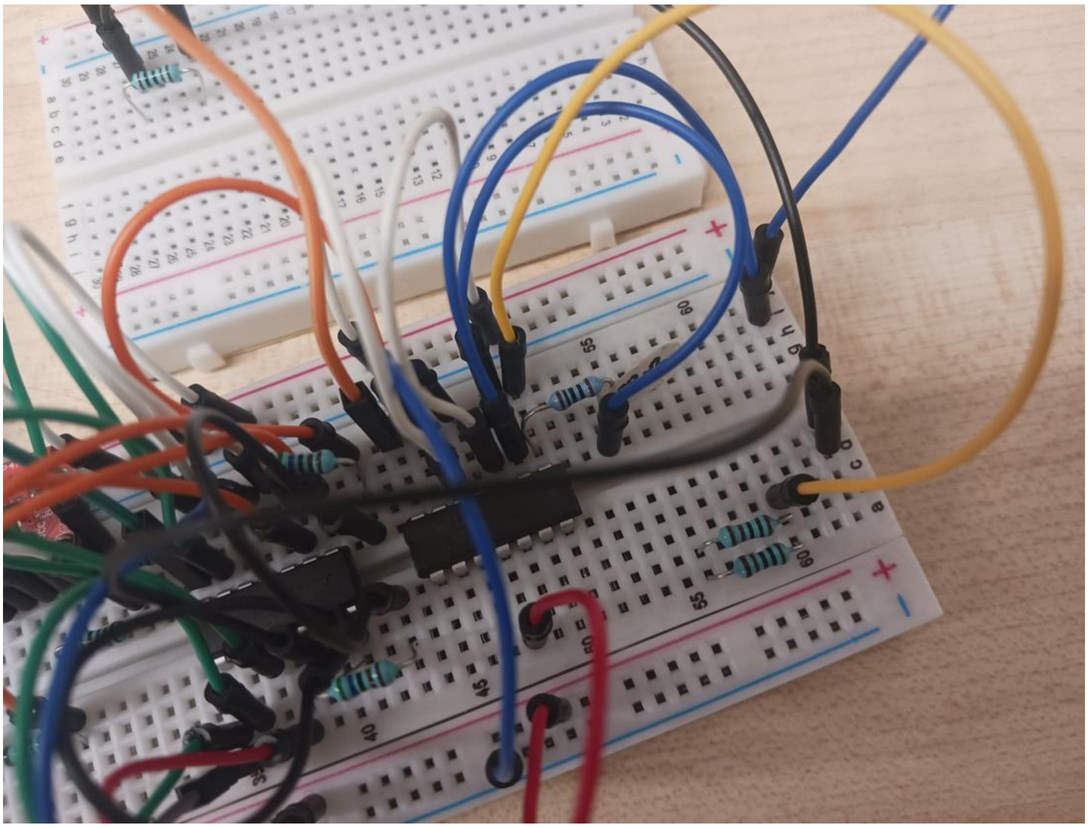
Step 43) Now, the feedback resistor (called R-read in Polarographica) is inserted. In this particular example, we use a 100 Ohm resistor. This resistor is connected to the output of the op. amp. of step 41.



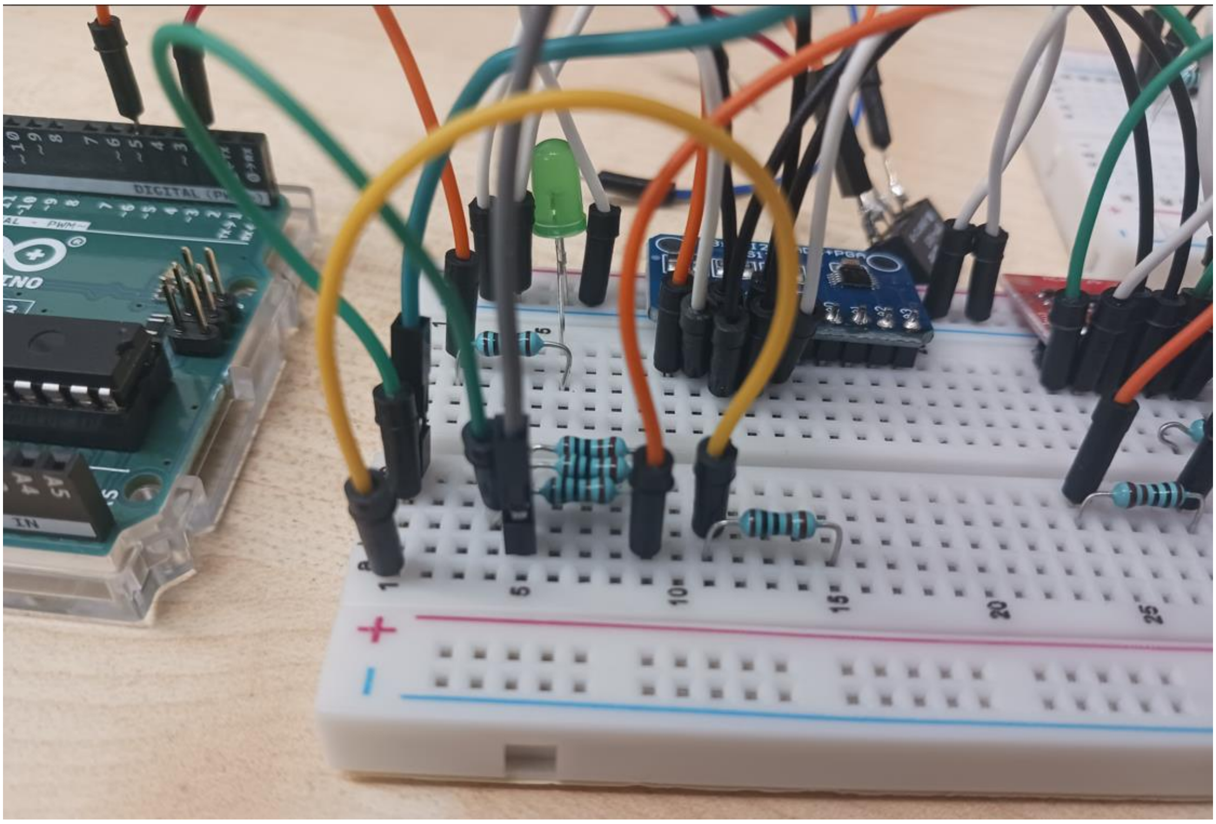
Step 44) To make the 100 Ohm resistor, inserted in step 43 to an actual feedback resistor, the feedback-loop needs to be closed. For this, the open terminal is tied back to the inverting input of the op. amp. This completed block F).



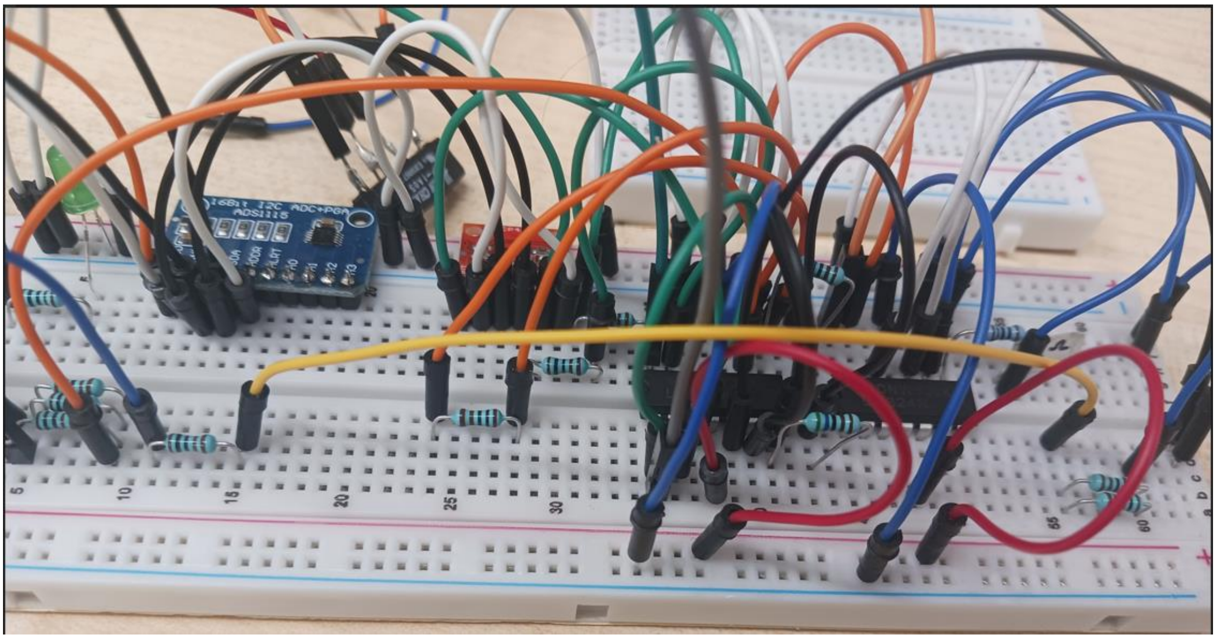
Step 45) The output of block F) will be passed through the parallel connection of R10 and R11 (both 1 kOhm). This connection is set up here.



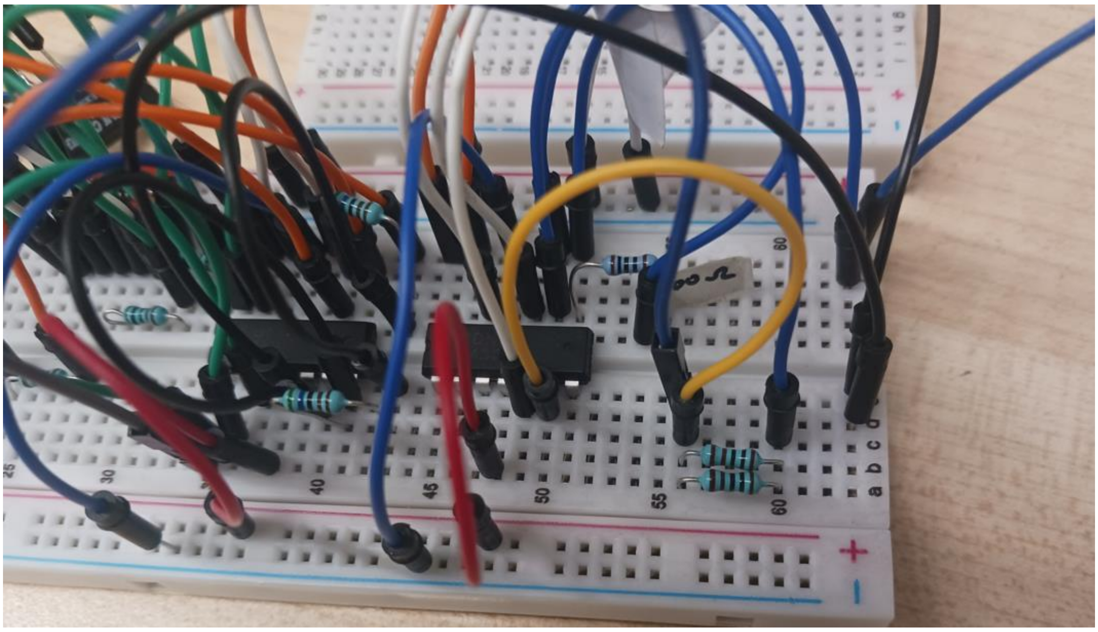
Step 46) In this step, the connection of R9 with the -3.3 V is be established.



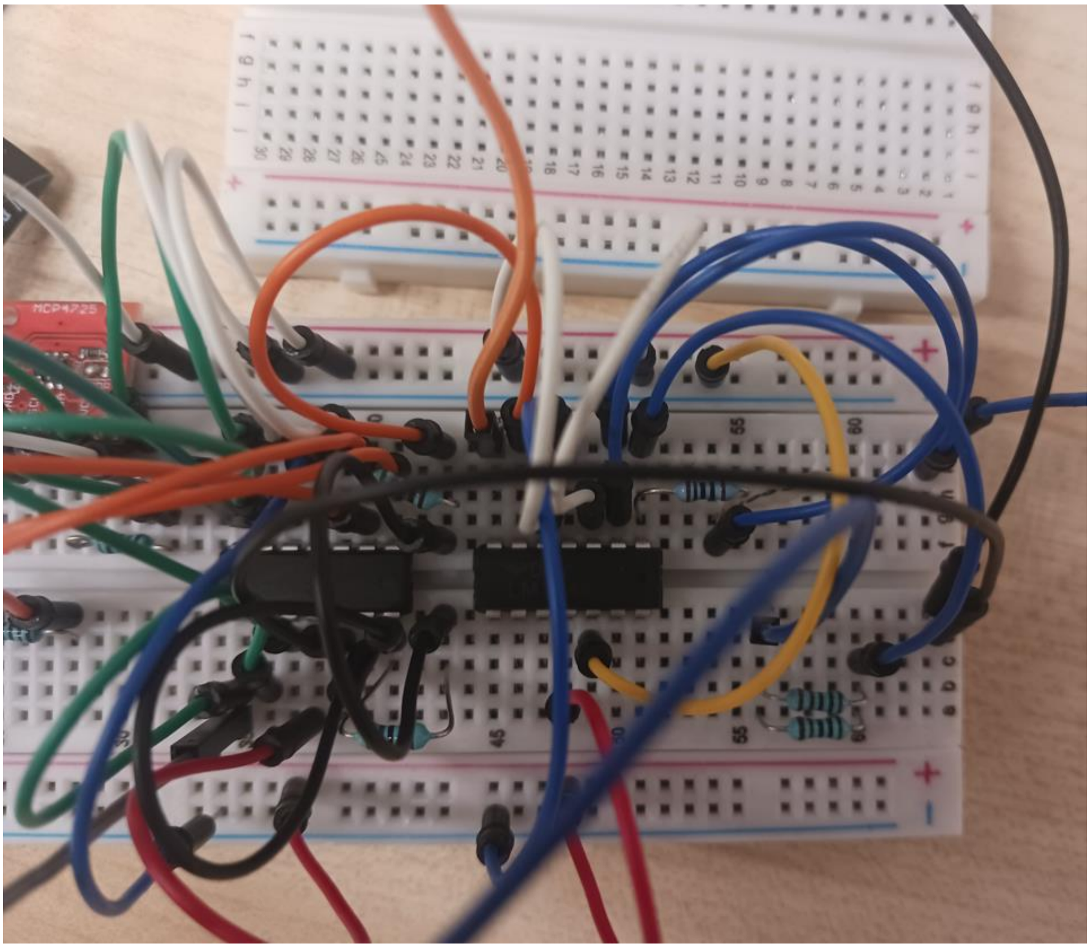
Step 47) Now, R9 is connected to the side of the parallel connection of R10 and R11, which was left open in step 45.



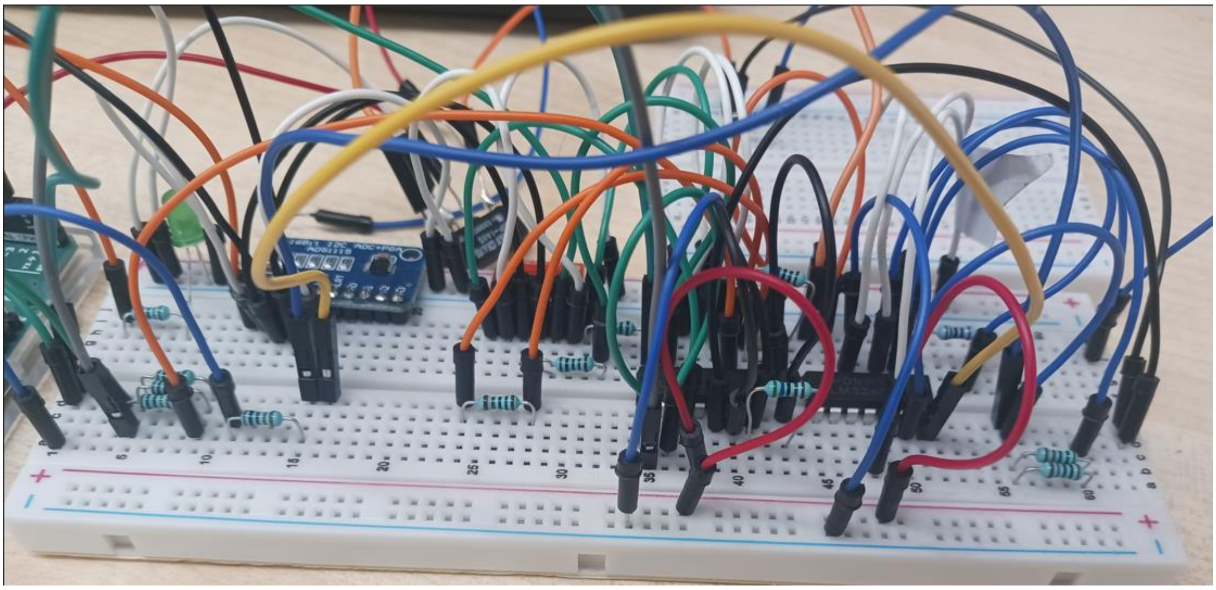
Step 48) The joint side to R9, R10 and R11 is fed into the inverting input of one op. amp. This particular op. amp. is the one of block G) in figure 1 of the original paper.



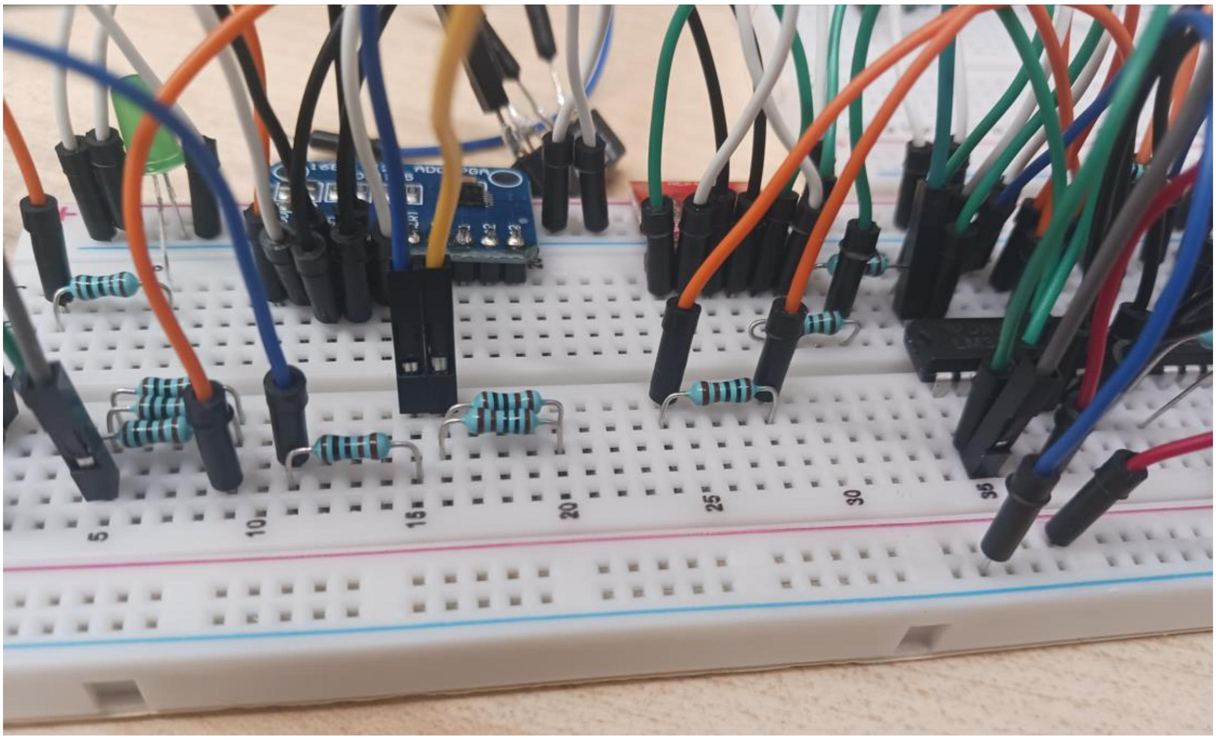
Step 49) The non-inverting input of the op. amp. is connected to the ground of the circuit.



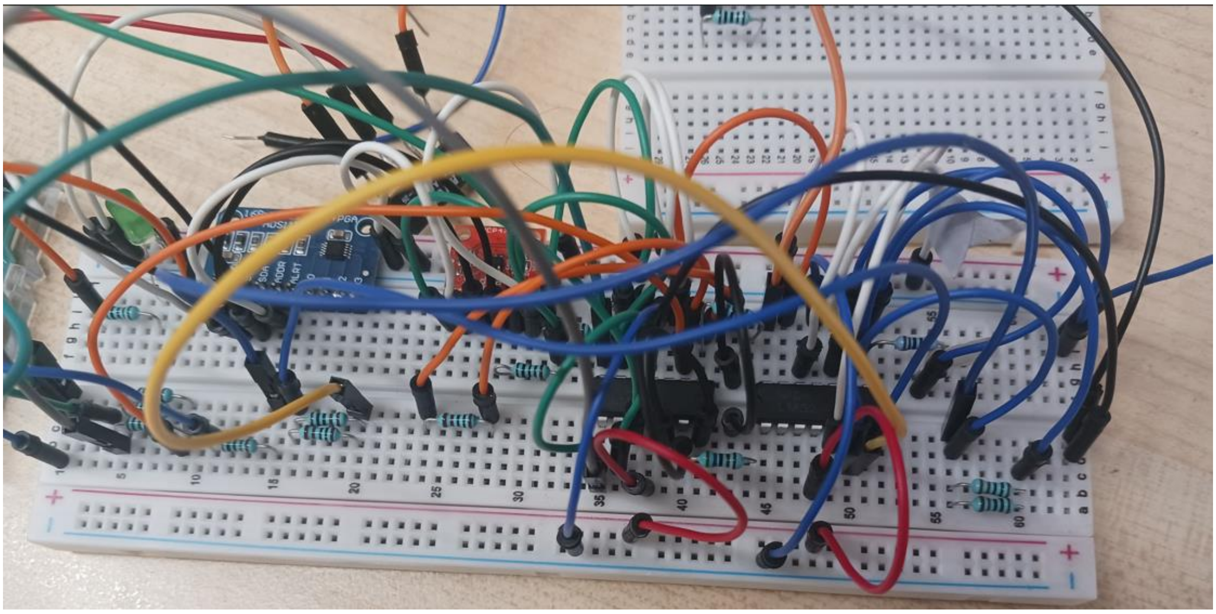
Step 50) We are now left with constructing the feedback-loop of block G), given by resistors R12 and R13 (both 1 kOhm). Due to lack of space, we pull-out the output of block G) to (e.g.) line 16d of the breadboard – see yellow wire.



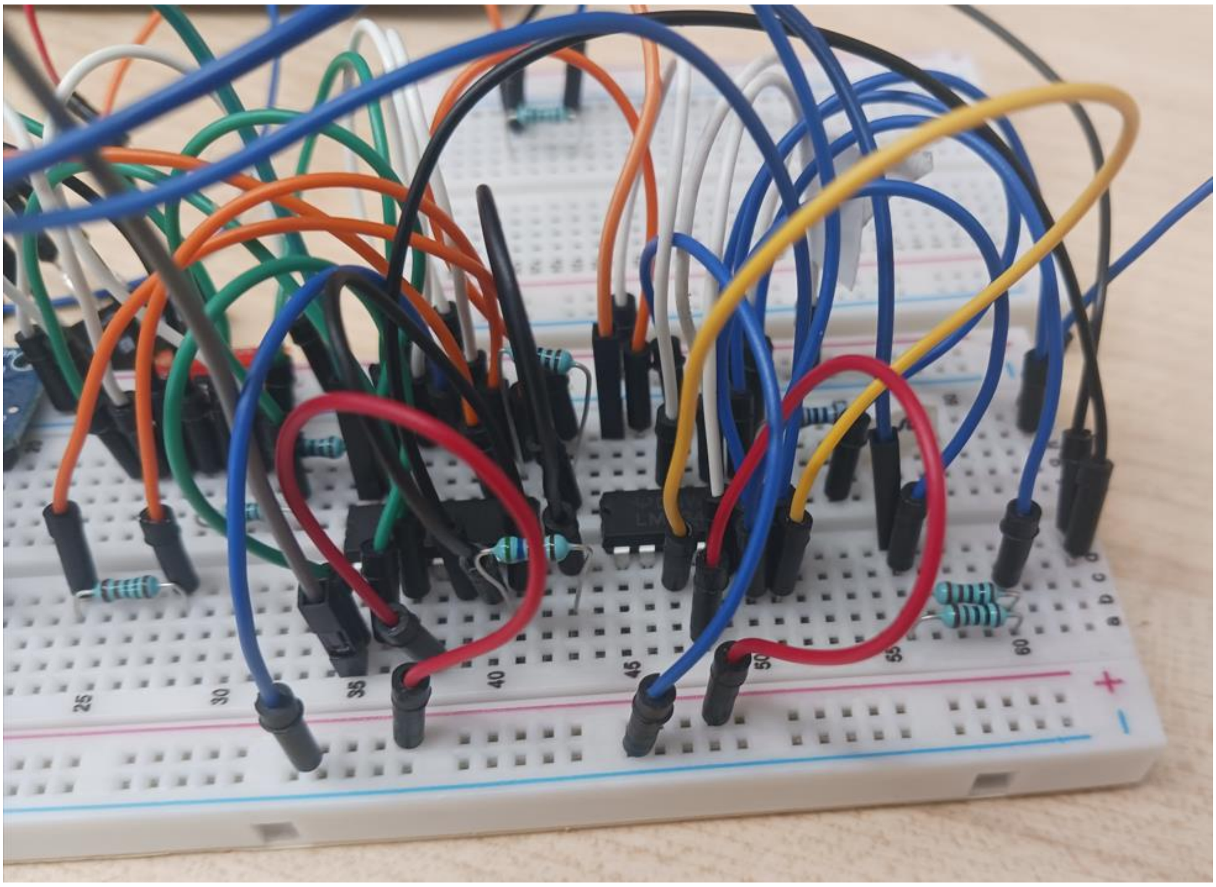
Step 51) At next, the parallel connection of R12 and R13 is established.



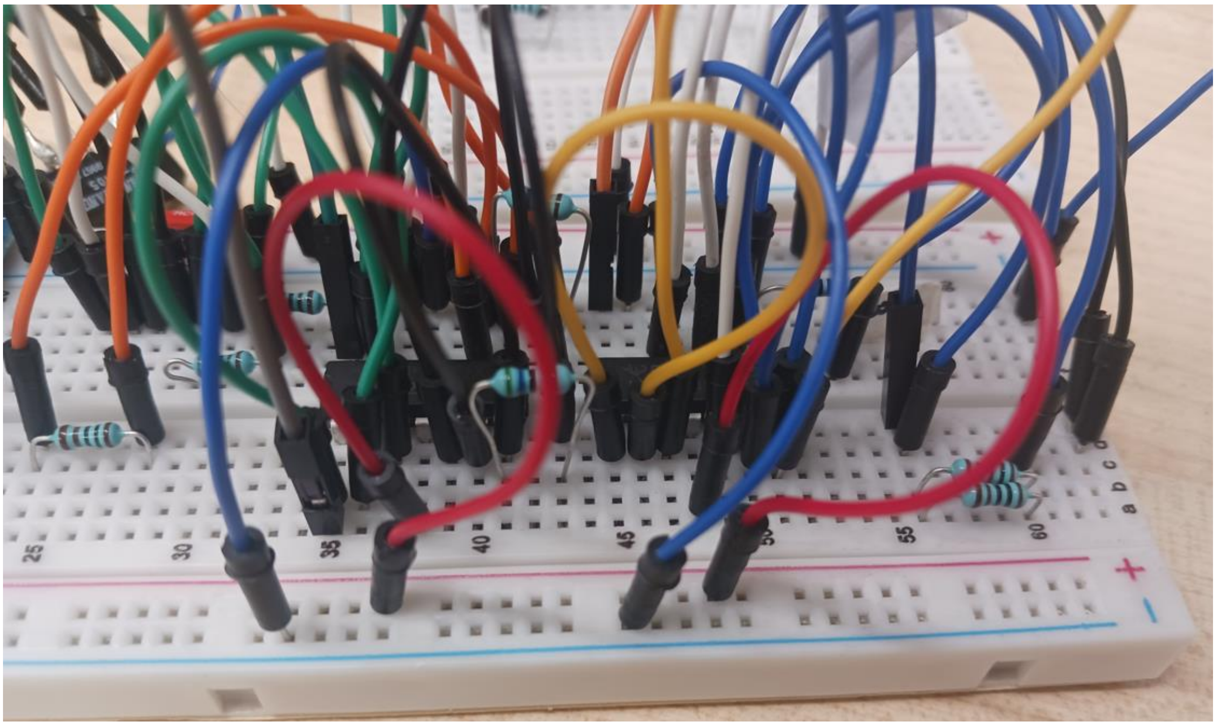
Step 52) Now, the feedback-loop of block G) is closed. For this purpose, the open side of the parallel connection of R12 and R13 in tied back to the inverting input of the op. amp. of block G). This completes block G).



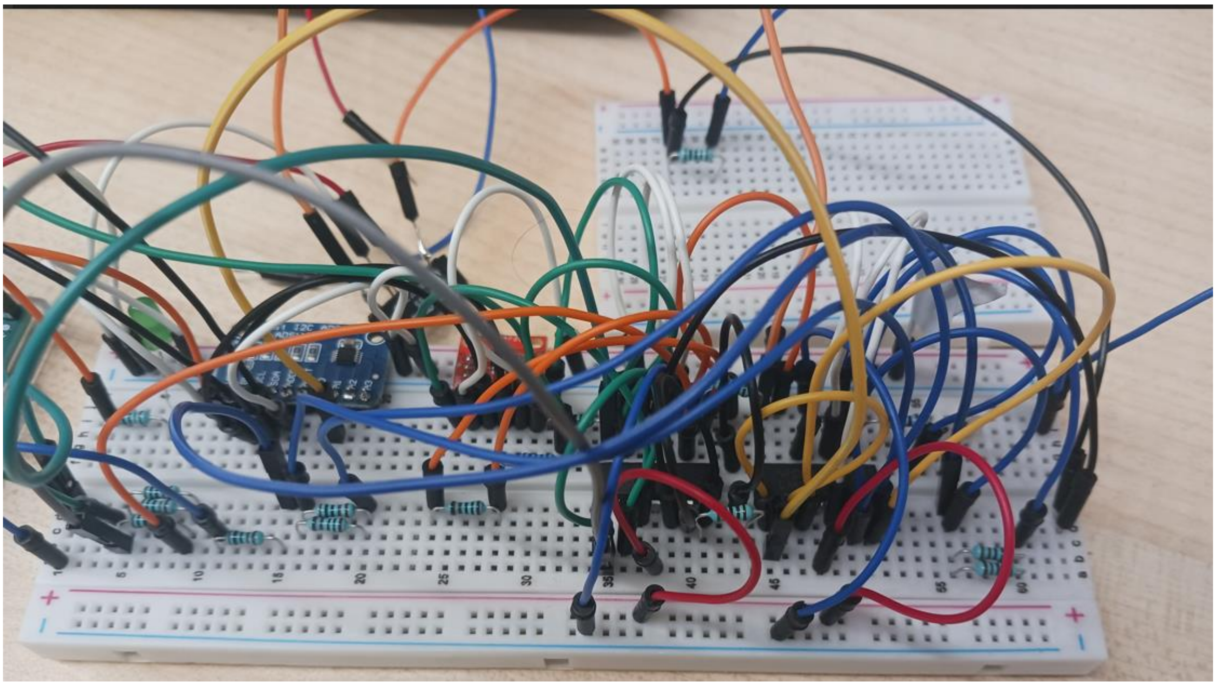
Step 53) In this step, block G) is connected to the non-inverting input of the only remaining op. amp. (i.e. block H).



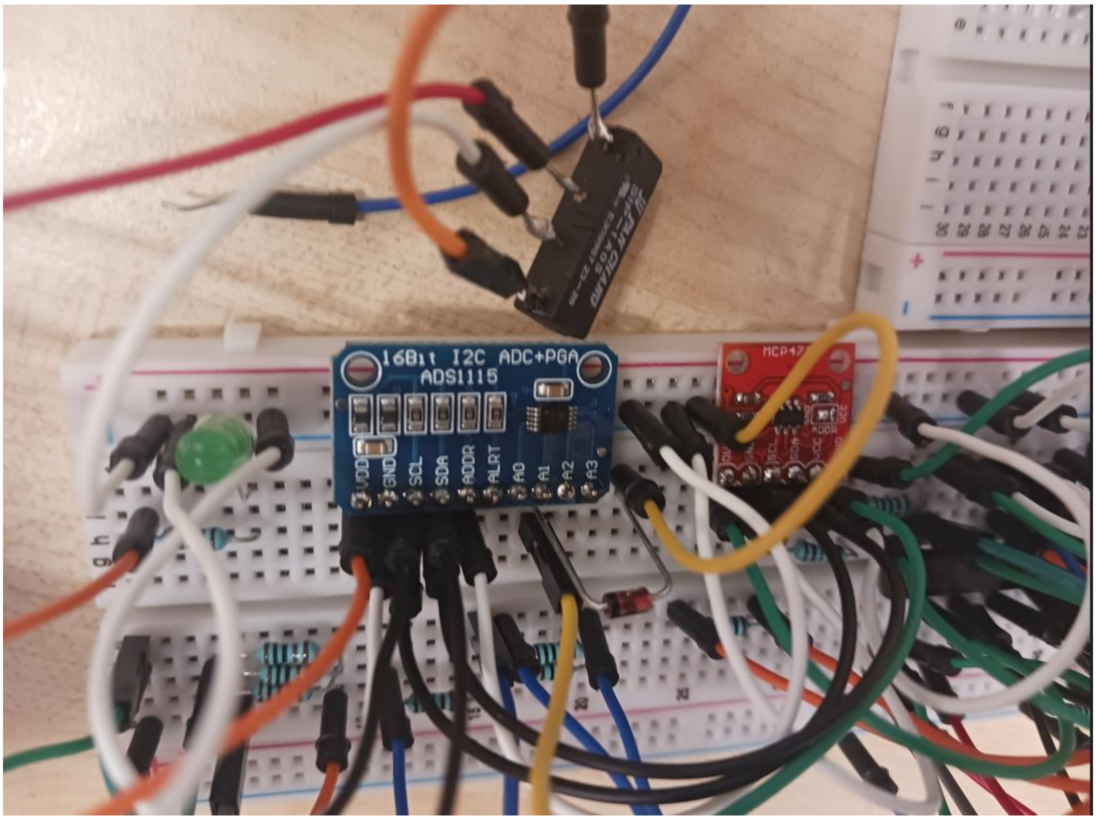
Step 54) Subsequently, the feedback loop of block G) is set up.



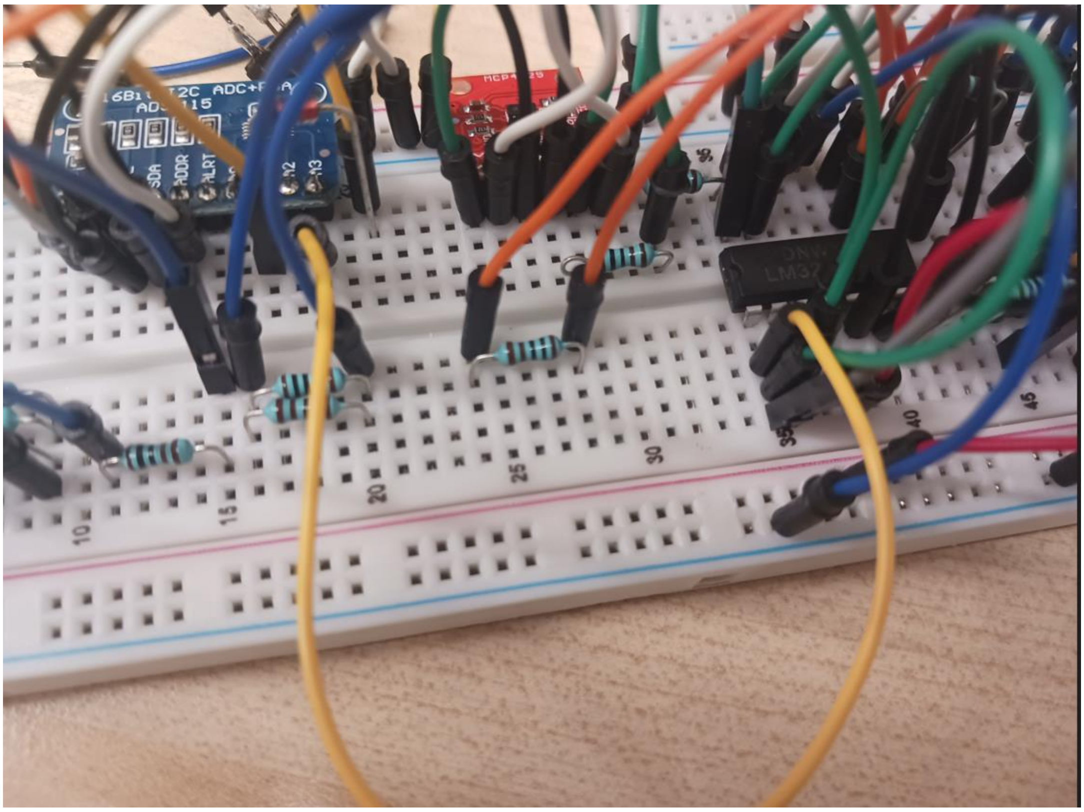
Step 55) Now, the output of block G) is connected to the A1 pin of the ADS1115.



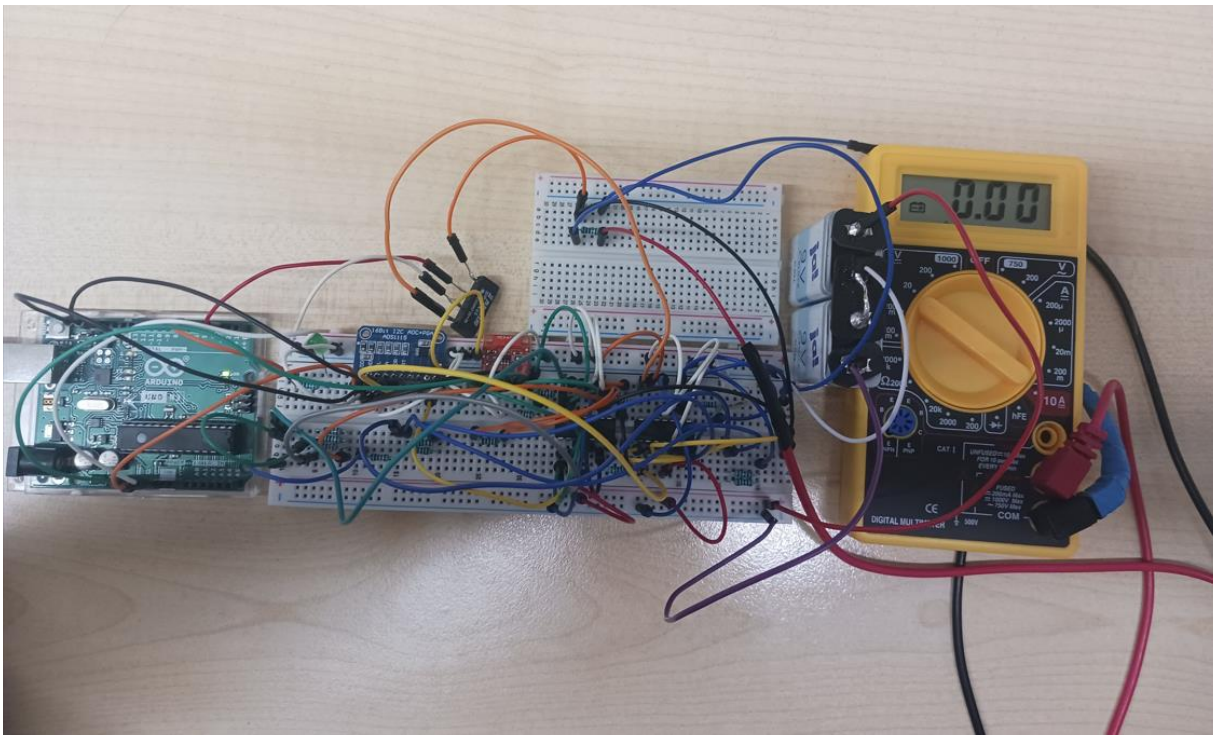
Step 56) In this step, the 3.3 V Zener diode is included between pin A1 of the ADS1115 and the ground if the circuit. MIND THE POLARITY OF THE DIODE!



Step 57) In this step, we will connect the output of block B) to pin A3 of the ADS1115 (for reading the applied voltage).



Step 58) Now, the circuit is complete. To check it, connect a multimeter between WE and CE/RE



Step 59) Run the calibration. You will get -0.5 V in the first step and + 0.5 V in the second step of the calibration process. If this works, everything was done properly.