Laboratory sessions: Weighing Scale

Goals:
- *Design and build the analogue circuit of a weighing scale.*
- *Quantify its performances in terms of precision and accuracy.*
- *Get acquainted with the technical literature and the data sheets of components.*

Note: this text is just a rough guide. Your initiatives will be welcomed and circuit variants can be tested (for example, in the last parts concerning filters and offset compensation).

I – Introduction

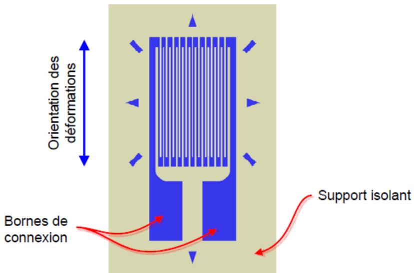

Figure 1: Strain gauge.

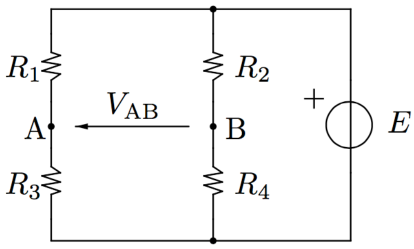

Figure 2: Example of a Wheatstone bridge (constant voltage excitation), from [BCC20].

The working principle of the weighing scale is to have a deformable spring, on which strain gauges have been attached. The strain gauge [BCC20] is an element composed by very thin conductors on an insulating substrate, which is deformed. When they are glued to the spring, conductors will be subjected to the same deformation of the spring. They are pulled or pushed, following the applied force. The resistance of the conductors will be changed as follows:

$$\frac{dR}{R} = G\frac{dl}{l}, \tag{1}$$

where G is the gauge factor, R is the wire resistance and l its length.
Gauges made in constantan (55% Cu, 45% Ni) are quite common and for example their gauge factor is 2.1. In practice, $\frac{dl}{l} \approx 0.01\%$ and therefore the change in the resistance is tiny. Its determination requires the use of a Wheatstone bridge, as shown in figure 2. The bridge can include a single gauge, two gauges or four gauges, the elements that are not sensitive to the deformation being fixed resistors.
The sensitivity of the bridge, often expressed in mV/V - i.e. the output voltage in mV over the supply voltage in volts for a full-scale deformation of the spring - is proportional to the number of the sensing elements in the bridge and it is a characteristic of the system.
The sensor that has been chosen for our laboratory sessions is shown in figure 3 (have a look to the datasheet [DF2S1KG]). The load cell is composed by the sensing elements mounted in a Wheatstone bridge configuration: the four elements constituting the bridge have a nominal resistance of 1 kΩ (see for example [AN43]). From the datasheet, we know that the maximum bridge supply is 5 V and that the sensitivity is about 1.8 mV/V for a full-scale weigh of 1 kg. The output signal from the bridge is amplified by an AD8223B (some of you will use the MAX4194), which will be part of our circuit: those two elements constitute the heart of the weighing scale.

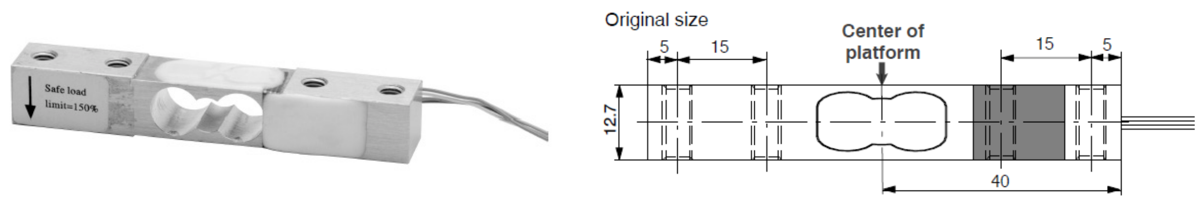

Figure 3: A "load cell": a spring associated with strain gauges mounted in a Wheatstone bridge (from [DF2S1KG]).

CAREFUL: our sensor can withstand a maximum charge of 1.5 kg. During all manipulations, you must NOT put a weight above this limit on the sensor, because it will deform in an irreversible way the load spring!

The electronic schematic you will use is shown in figure 4. It is somehow imposed, in the sense that you will be given a printed circuit board on which you will have to solder the components. Therefore, you shall not modify too much the circuit. However, you will have to choose the right values for the passive elements (resistors, capacitors). You will have to study the characteristics of the sensor as well as those of the amplifier, so that the input range of the analogue to digital converter is covered appropriately. In other words, when a weight from 0 g to 1000 g is put on the scale, the input voltage at the input of the converter should be from about 0 V to 3.3 V.

II – Description of the circuit

The schematic circuit (shown in figure 4) is constituted by 3 integrated circuits which have already been chosen by your professors and whose datasheets are at your disposal on Chamilo [AD8223B, MAX4194, MCP3425, TC1015]. The role of each circuit is as follows:

- AD8223B (or MAX4194) is an instrumentation amplifier, meant to amplify the voltage coming from the sensor output.
- MCP3425 is an analogue to digital converter (16 bits), whose output is an I^2C bus with an internal voltage reference.
- TC1015-3.3V is a voltage regulator able to deliver 3.3 V from a 5 V input.

The analogue to digital converter will be mounted, and a digital board has already been prepared (see part IV of this document) to show the results of the conversion.
A printed circuit board is shown in figure 5. During the fabrication of the circuit, one of the difficulties will be to correctly solder the devices, which are modern surface mount (SMD). You will have to be extra-careful during the soldering operations, and you might verify with the multimeter that everything has gone smooth after you have finished. Short-circuits might harm the devices, so try to avoid them as much as you can. **The best strategy you can adopt is probably to solder a few devices and test the circuit step by step**. You might proceed in the following way:

- Start from the 3.3 V (TC1015) regulator. Power the circuit with 5 V. Is the output voltage stable and reasonably close to 3.3 V?
- Solder the connector for the sensor. How much is the differential voltage output? Is there a relation with the weight put on the platter? How much is the common mode voltage?
- Solder the AD8223B (or MAX4194) instrumentation amplifier and choose an appropriate gain. Is the output the one you expect?
- The MCP3425 may be soldered after that the entire analogue circuit has been successfully tested. By employing the digital motherboard discussed in section IV, check the whole circuit.

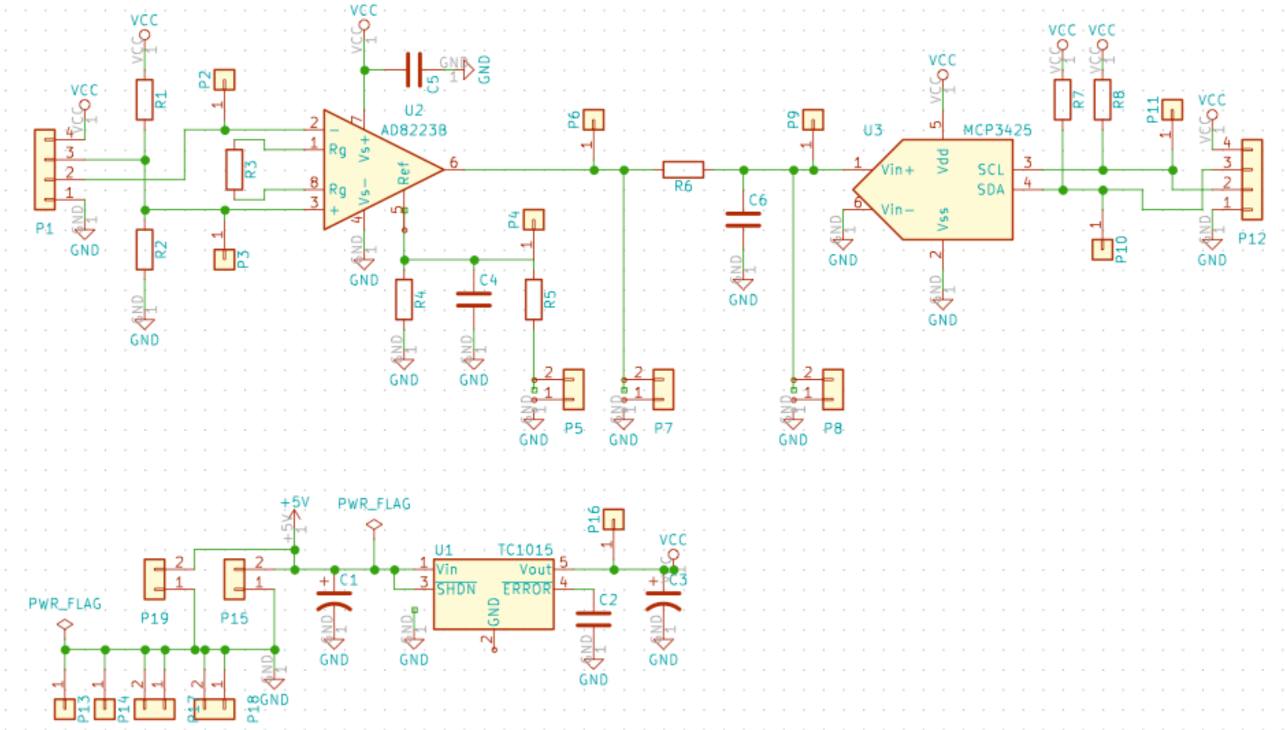

Figure 4: The schematic.

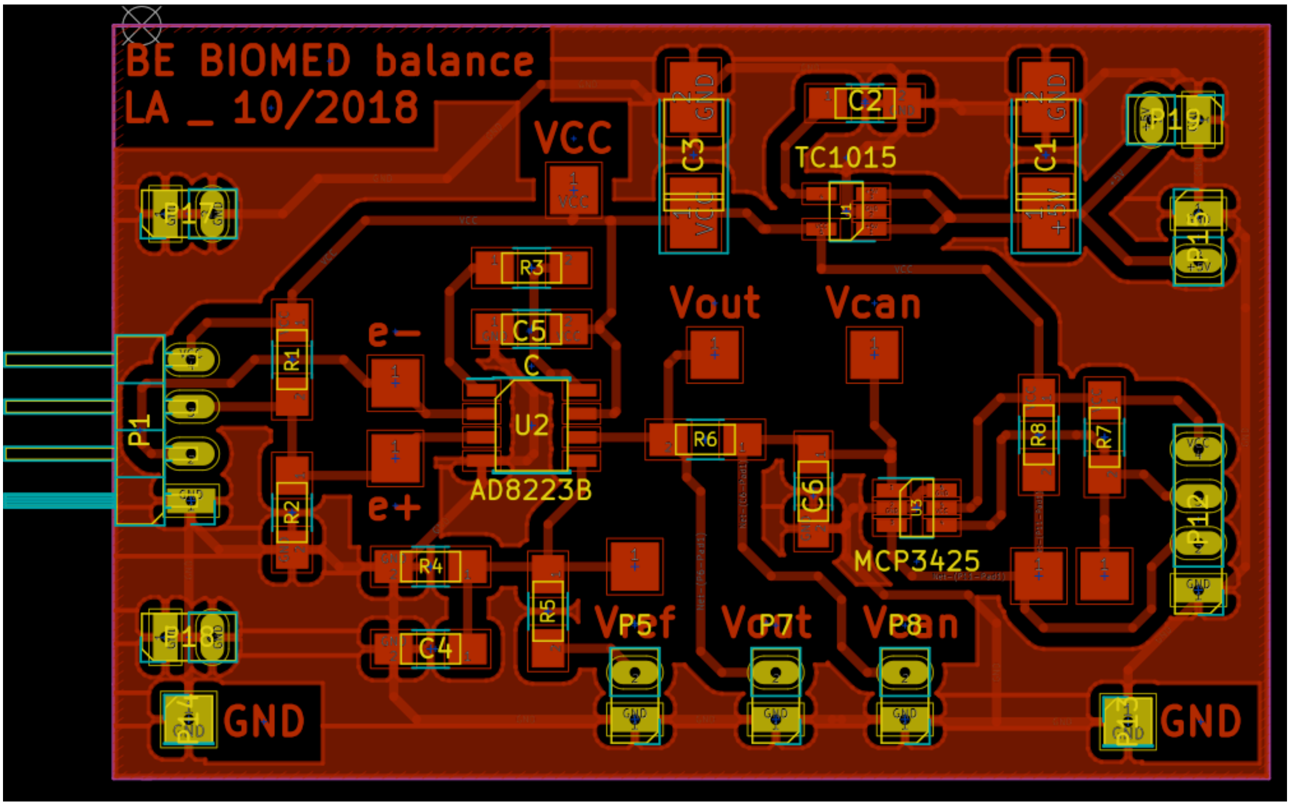

Figure 5: Layout of the Printed Circuit Board (PCB).

III – Work to be done

You will be working in groups of two. During the laboratory sessions, you are expected to concentrate yourselves on the fabrication of the circuit and on the measurements you will perform. All the theoretical work (calculations and so on) must therefore be done *outside* the laboratory,

working on your own. The built circuit will be shown to your professor during the last laboratory session and the final mark will take into account the quality of what you obtained.
A detailed report must be written and will be read by your teachers. It may include:

- A theoretical study of the circuit.
- A description of the practical work.
- A bibliography of all sources (books, websites, articles) employed during the work.

The theoretical study must include a detailed justification of all the choices done during the design of the circuit, in particular for the values of all passive devices employed (calculations or from the data sheets). This part must also cover an error budget analysis to estimate the maximum error introduced by all analogue elements of the measurement chain (you might inspire yourself from the second exercise session of the "Electronic for measuring systems" course [BCC20]). All resistors have a +/- 1% tolerance (with a temperature coefficient of 100 ppm/°C). Which devices play the most delicate role for the global accuracy and precision of the circuit? How could the circuit be improved?
The practical work will be mostly tackled during the laboratory sessions: you will have to assemble and test the printed circuit work, while respecting the instructions given in section II (i.e. assemble and test different circuit blocks in a modular way, **write down the measurement results from the very first tests, take screenshots of oscilloscope measurements, etc…**). You will also have to "qualify" the complete system by performing measurements (for example by giving the voltage VoINA versus the mass put on the scale plate).
You might have noticed that the filter proposed for the circuit is a very simple one. You might try to test different filtering solutions to reduce the noise that might be picked up by the circuit. A circuit working in a laboratory bench is in a fortunate situation: there is normally a very low amount of noise! You can artificially add a certain degree of noise by operating a small DC motor close to your sensor and try to filter it out as much as you can.
The bibliography will list all the resources employed during the redaction of the report. Each resource will have a tag, which can be for example a number in square brackets. **All** references must be cited in the appropriate places of the text, by employing the tag. All references should be cited in the text.
All pictures must be numbered; they must have a caption and be appropriately cited in the text.

The final report will be posted on Chamilo in the page "PHELMA 4PMBEM10 BE Electronics for measurement systems" under "Dropbox" or "Partage de documents" and ***the deadline will be one week after your last laboratory session. Penalties will be applied for groups posting late reports.***

IV – How to use the digital board

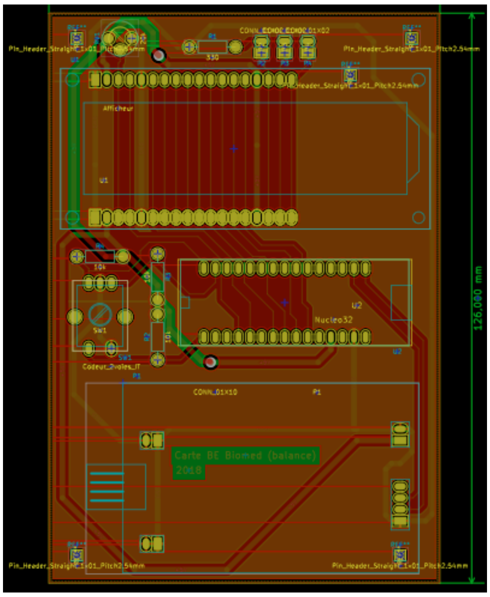

Figure 6: The layout of the digital board, equipped with a programmed ST Nucleo module.

In order to read the output from the MCP3425, your professors have prepared a pre-programmed mother board (visible in figure 6) on which the circuit you are working on can be plugged and that provides every signal that is needed for operating the weighting scale and showing the result of the analogue to digital conversion on the display. If you have connected wires to provide the power supply to the circuit you assembled, do not forget to remove them, as the circuit will be powered by the motherboard.

Good work!

Bibliography

[BCC20] D. Bucci, *Electronics for measuring systems*, Phelma course handouts, 2020

[AN43] J. Williams, *Bridge Circuits, marrying gain and balance*, AN43 Linear Tech. 1990

[DF2S1KG] HBM, DF2S-3/1KG *Load cell* datasheet

[AD8223] Analog Devices, AD8223 *Single supply low cost instrumentation amplifier* datasheet

[MAX4194] Maxim Integrated MAX4194-MAX4197 *Micropower, Single-Supply, Rail-to-rail, precision instrumentation amplifiers*.

[MCP3425] Microchip, MCP3425 *16-Bit Analog-to-Digital Converter with I2C Interface and On-Board Reference* datasheet

[TC1015] Microchip, TC1015-3.3V *Low dropout regulator* datasheet