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T0003-EN mN ratiometric EPFL - 2014-07-16.docx

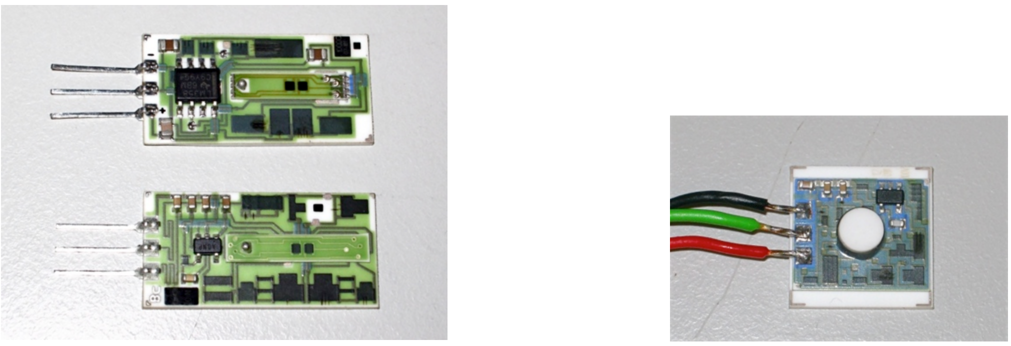
T0003 – MilliNewton & CentoNewton force sensors Deviation from ratiometric behaviour

Thomas Maeder, 16.7.2014 (replaces version 2004-04-22)

This document concerns the deviation of the output of MilliNewton and CentoNewton force sensors from ideal ratiometric behaviour. These sensors nominally operate from a single +5 V supply voltage and, as they have no voltage regulator, their output response should be ideally "ratiometric", i.e. proportional to supply voltage, within the operating range of the used amplifier chip. However, due to the amplifier characteristics (nonlinear offset), a substantial deviation of the sensor offset (zero-load output) from this ideal behaviour can appear if the supply voltage strongly deviates from 5 V. On the other hand, the span remains essentially ratiometric, and sensor functionality is maintained.

1. Introduction

Sensors with ratiometric output (figure 1) allow good precision while being simple and low-cost in applications where the sensor is locally connected to a microcontroller with an A/D converter. By using the same voltage regulator for the sensor and the converter reference voltage, variations of the regulator output cancel out, and a precise measurement is obtained without needing a precise – and expensive – voltage reference.
The resistors which make up the measurement bridge are very linear at the low electric fields used. This is however not the case of the amplifier offset, which is not proportional at all to the supply voltage.



(a) (b)

Figure 1. MilliNewton-A/B (a, haut/bas) and CentoNewton-B (b) sensors.

2. Experiments

The offset voltage of MilliNewton-A/B [1,2] and CentoNewton-B [3] force sensors (figure 1) was measured as a function of the supply voltage, which was varied according to the amplifier chip (see table 1) [4-6]. Span was also measured for MilliNewton-A.
The offset shift vs. ratiometric behaviour Δs_0 was calculated as follows:

$$\Delta s_0 = (u_0 - u_{0n}) / S$$

where : $u = U / U_a$

u_0	ratiometric offset
u_{0n}	ratiometric offset at nominal supply voltage
S	ratiometric span
u	any ratiometric voltage
U	any measured (absolute) voltage
U_a	supply voltage

For all sensors tested here, the nominal output values are u_0 = 0.100 and S = 0.600.

Sensor	**Reference**	**Amplifier chip [4-6]**	**Number of tested sensors**	**Nominal / max. supply voltage [V]**	**Tested voltage range [V]**
MilliNewton-A	6800-6809	LM358	10	5.0 / 30.0	4.0 … 10.0
MilliNewton-B	2014m234	MAX4400	10	5.0 / 5.5	2.0 … 5.5
CentoNewton-B	2014c131	MCP601	7	5.0 / 5.5	2.0 … 5.5

Table 1. Data on tested sensors. Going above maximal supply voltages will likely damage the amplifier chips.

3. Results

The results of the offset measurements (average and extreme values) are given in figures 2-4. The amplifiers used can have large offset values, which induces substantial deviations from ratiometric behaviour of offset. On the other hand, sensor functionality was maintained in all cases.
Figure 5 shows the span change vs. supply voltage. Although some change is apparent below 5 V and above 6 V, this is most likely due to a slight loading error (measurement of span is much more error-prone due to the small cantilever) later in the test, as attested from the same results shown in chronological order (figure 6).

4. Conclusions

Offset may substantially deviate from ratiometric behaviour when changing the supply voltage, due to the nonlinear amplifier chip offsets. Otherwise, the sensor stays functional, with minimal span deviations from supply voltage changes. Therefore, as long as the offset shift can be accommodated (e.g. by calibration), the sensors may be used at voltages other than the specified one (+5 V).

The characteristics of the different amplifier chips do deserve a few cautionary notes:

a) **MilliNewton-A at low supply voltages.** Substantially decreasing supply below +5 V will remove the top part of the measurement range, as the LM358 output saturates at ca. 1.3-1.4 V below supply.

b) **MilliNewton-A at high supply voltages.** Although the LM358 chip allows this variant to operate at high voltage, one must expect some thermal drift due to the increased measurement bridge and amplifier power dissipation (at 30 V, the sensor will dissipate ~150 mW).

c) **MilliNewton-B and CentoNewton-A/B**. The amplifier chips feature rail-to-rail outputs, so are not sensitive to the output restriction issue of the LM358 discussed in (a). However, the input common-mode range is not rail-to-rail, therefore a minimum supply voltage of ~3.0 V is recommended to guarantee trouble-free operation (although lower voltages seem possible from the results). Going above the nominal 5 V supply voltage is not recommended, as this may easily damage the low-voltage amplifier chips used for these products.

d)

5. References

[1] Datasheet, MilliNewton-A, EPFL-LPM, Lausanne (CH), version 2004-04-22.

[2] Datasheet, MilliNewton-B, EPFL-LPM, Lausanne (CH), version 2012-08-24.

[3] Datasheet, CentoNewton-B, EPFL-LPM, Lausanne (CH), version 2013-01-11.

[4] Datasheet "LM158/LM258/LM358/LM2904 Low Power Dual Operational Amplifiers", National Semiconductor (USA), 1999.

[5] Datasheet "MAX4400-MAX4403 Single/dual/quad, low-cost, single-supply, rail-to-rail Op amps with shutdown", Maxim Integrated, 19-1599, rev. 3, 2001.

[6] Datasheet "MCP601/1R/2/3/4 2.7V to 6.0V Single Supply CMOS Op Amps", Microchip Technology (USA), DS21314G, 2007.

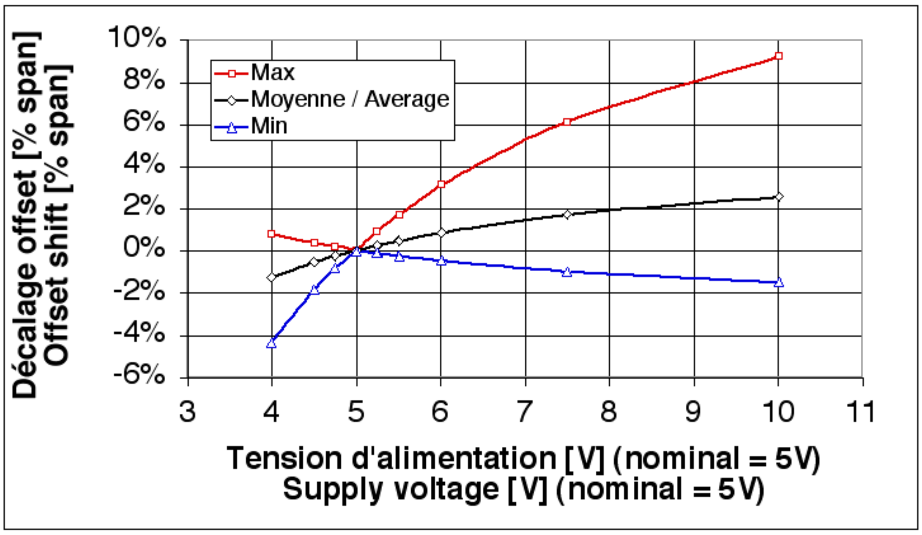


Figure 2. MilliNewton-A: offset deviation from ratiometric behaviour.

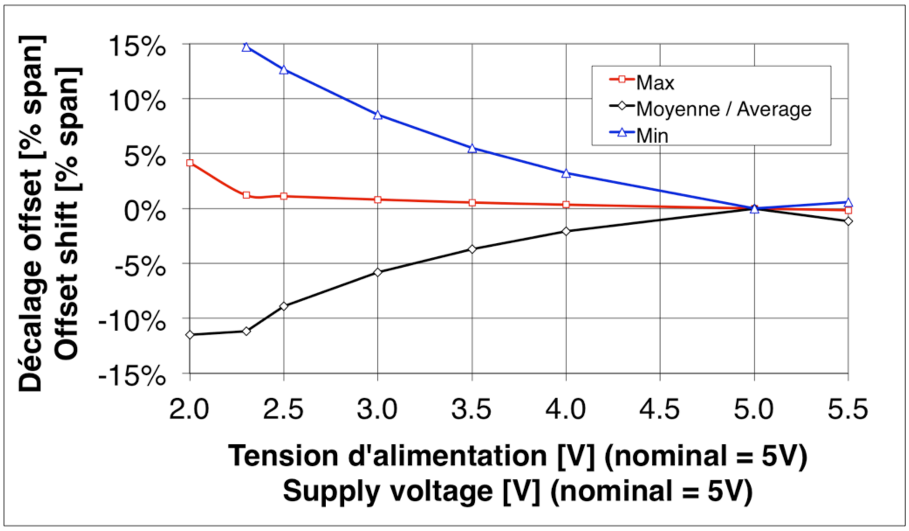


Figure 3. MilliNewton-B: offset deviation from ratiometric behaviour.

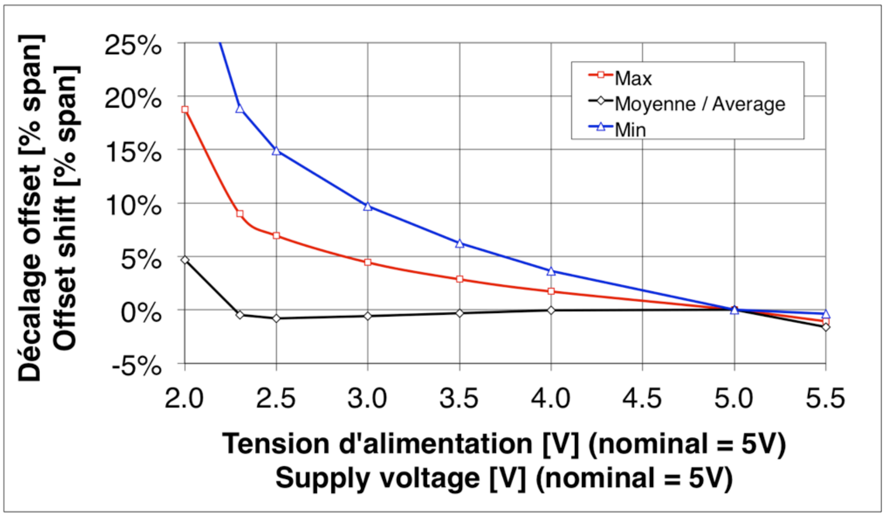


Figure 4. CentoNewton-B: offset deviation from ratiometric behaviour.

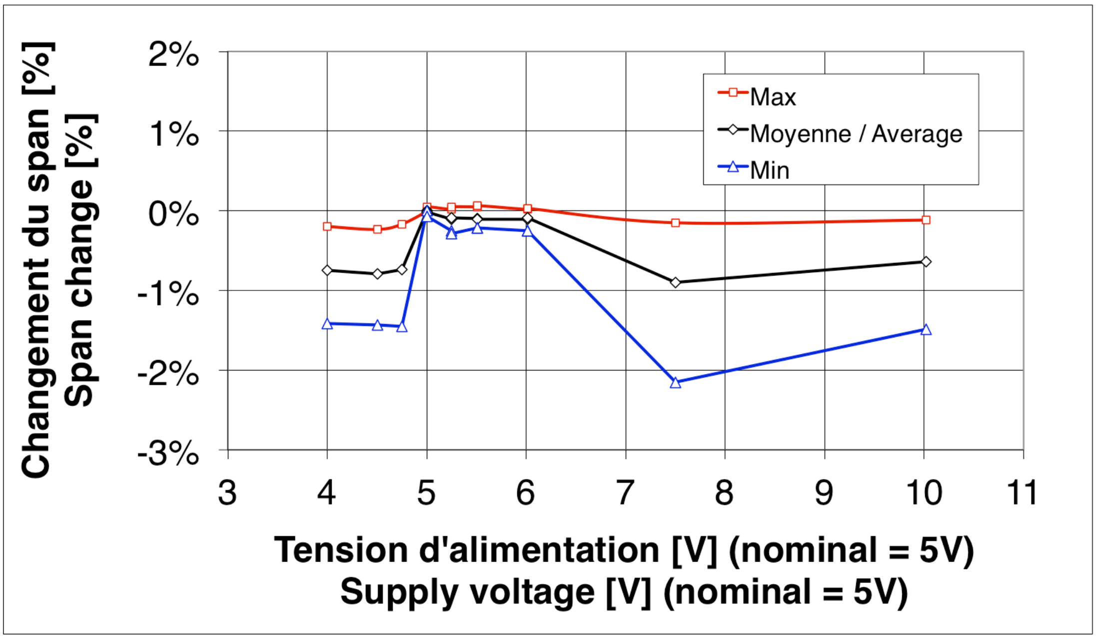


Figure 5. MilliNewton-A: span change vs. supply voltage (in voltage order).

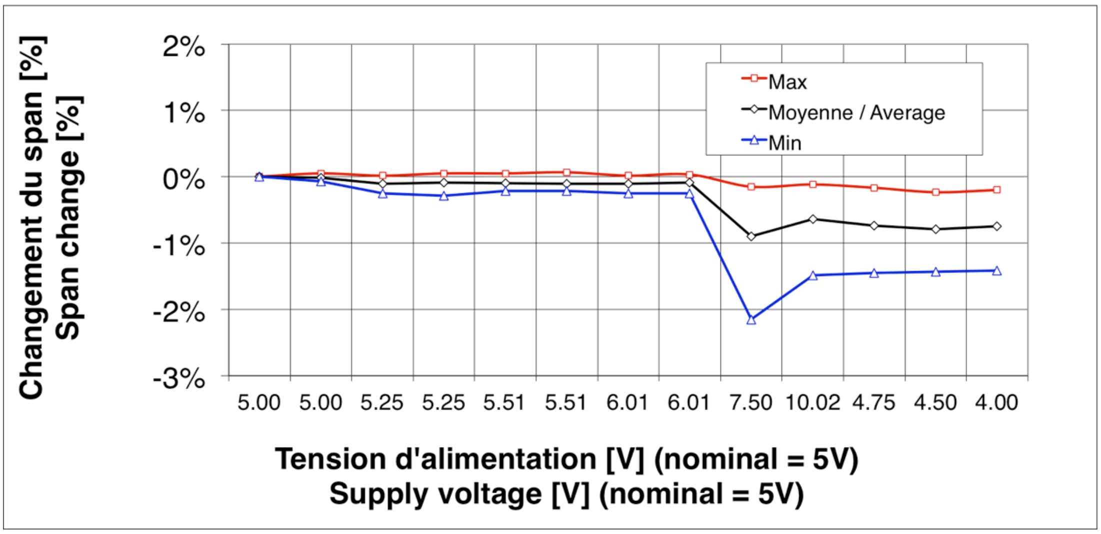


Figure 6. MilliNewton-A: span change vs. supply voltage (in chronological order).