LTZ1000CH voltage reference – A simplified version of Wavetek/Fluke 7000

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If you follow the discussions on eevblog you have come across the thread „ Wavetek 7000, the hidden gemstone.“ User chekhov provided a reverse-engineering of a Wavetek 7000 voltage standard to the community showing the complete circuit [1].

But what’s so special about that particular voltage standard?

It is based on an LTZ1000 with a slightly different circuit implementation compared to the LTZ datatsheet. Furthermore, it uses a special conditioning circuit driving the heater of the zener diode to recover the output voltage after a power down. It makes excess use of resistor networks to set the oven temperature and to scale the voltages of the 10 V and 1 V/1.018 V outputs [2], [3], [4].

And finally, it uses a high-isolation, low leakage current DC-DC converter to power the unit from a linear wall adapter [5], [6], [7].

In the Wavetek 7000 and earliy units of Fluke 7000 the driving transformer circuit was build discrete, while in later Fluke 7000 the driver is based on the LT1533.

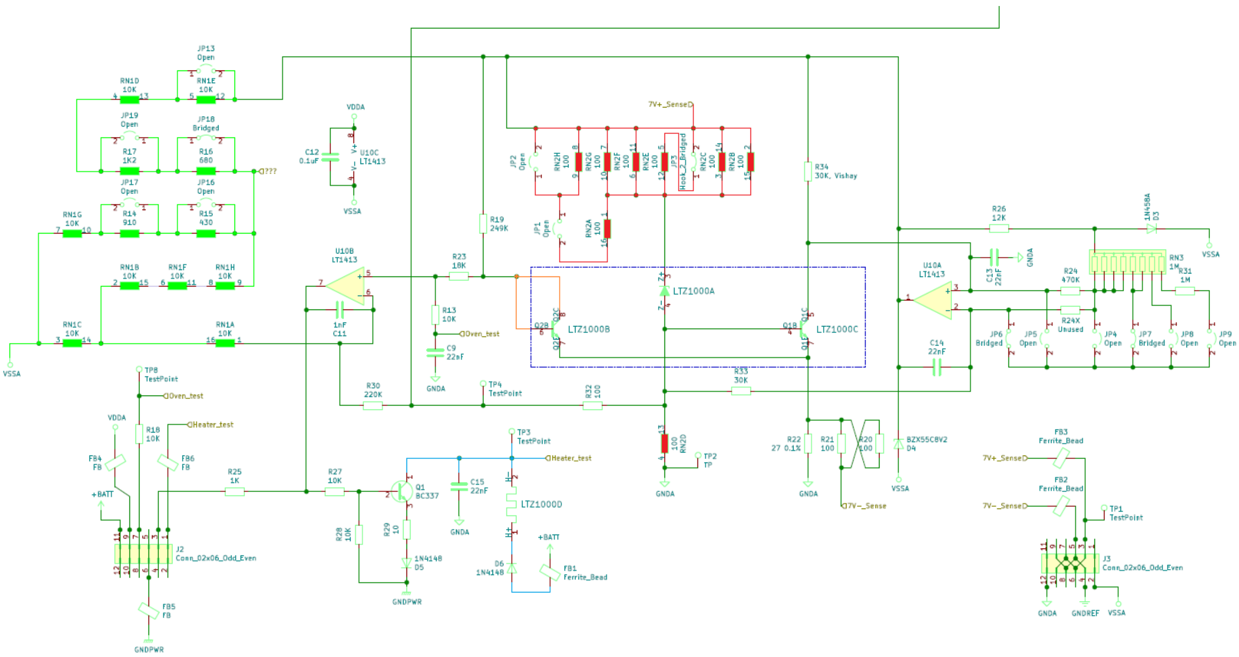

Figure 1: Reference schematic of W/F7000 [1]

Looking at the basic reference part in the mentioned schematics provided for the W7000 (see figure 1), what first comes to the eye is it uses the temperature sensing transistor as a diode (orange). Second, a small resisitor at the cathode is added (red). Both differences to the standard datasheet schematic can also be found in [8], while the datasheet explains that such a resistor at the cathode can be used to reduce the temperature coefficient (t.c.) of the unheated zener [9]. This is achived by shifting the parabolic t.c. curve along the temperature axis. However, there is still only a specific temperature at which the temperature coefficient is zero and small next to it on the left and on the right side. That means, if the t.c. of the unheated zener is reduced from 50 ppm/K to a much lower value also the requirements of the oven temperature setting resistors are decreased. In the 7000 voltage standard an 8x 100 Ω resistor network TDP16031000 is used to create an adjustable resistor at the cathode with the following values (see table 1):

Table 1: resistor settings with the solder links

	SL1	**SL2**	**SL3**	**SL4**
33.333 Ω				
28.571 Ω				X
25.000 Ω	X			
25.000 Ω		X		
25.000 Ω			X	
22.222 Ω	X			X
22.222 Ω		X		X
20.000 Ω	X	X		
20.000 Ω	X		X	
20.000 Ω		X	X	
18.182 Ω	X	X		X
16.667 Ω	X	X	X	

by setting corresponding solder links in the 7 resistor arrangement, while the 8th resistor is used between anode and ground. This allows to shift the z.t.c. temperature into a range where the t.c. is low or even zero at an 50 °C oven temperature. This temperature in fact is small, but still leaves enough headroom for higher ambient temperatures. On the other hand one wants to operate the oven at low temperatures to save energy, but also to decrease longterm drift of the reference, as per Arrhenius equation the longterm drift about halves to quarters with every 10 K temperature reduction.

Now that the zener is operated near to or at z.t.c. temperature, a 10 kΩ resistor network with reduced requirements, here a TDP16031002, is used to set the oven temperature (light green). The TDP1603 resistor series has a specified absolute TCR of ±25 ppm/K, while the tracking TCR of the 8 resistors is specified to be ±5 ppm/K, but performs much better in reality. The benefit of a low requirement for the oven temperature setpoint resistors combined with a resistor network with low tracking TCR eliminates the demand for high quality, high stability, low TCR hermetically sealed resistors. Compared to the datasheet circuit with the typical R4 = 13 kΩ and R5 = 1 kΩ for the temperature setpoint, a 100 ppm change of the resistor ratio leads to a 1 ppm change of the zener voltage, since the reference is operated on the rising slope of the t.c. curve. When it comes down to noise all of the resistor networks mentioned in this article are performing superior as pointed out by [10].

Third, the heater is in the collector instead of the emitter (light blue). This allows to turn on and off the heater. And finally, it uses a small trick to adjust the residual t.c. to almost zero, which will be kept a secret, while it is up to the intent reader to find out how.

With this basics in mind a simplified version of this zener reference circuit was designed, which means that the conditioning part was ignored and the reference has a fixed 10 V boost stage. It makes use of resistor networks and instead of adjusting the output voltage by a DAC it trims individual resistors of the network in the 10 V boost stage. It follows the approach that you would do with any other temperature compensated zener reference, that is: Adjust the zener current so that the zero t.c. is at or at least close to the temperature you want to operate the oven at, only slightly above the maximum room temperature, but with enough headroom for the temperature regulation to eventually save energy and to allow for long battery operation.

For the 100 Ω resistor network a TOMC1603 was used, as it was the only network with low noise and 100 Ω resistors in one package available at that time. For the temperature setpoint divider a TDP16031002 resistor network was used, but a TOMC16031002 or NOMC16031002 would have worked too. For the ease of layouting the board 2x LT1006 where used instead of 1x LT1013 or the more modern LT1413. Finally, the output stage uses an ADA4522 and a filter at its input with another trimmable TDP16031002 resistor network to adjust the final gain to roughly 1.4. Figure 2 shows an image of the preassembled board missing only the 10 V boost stage.

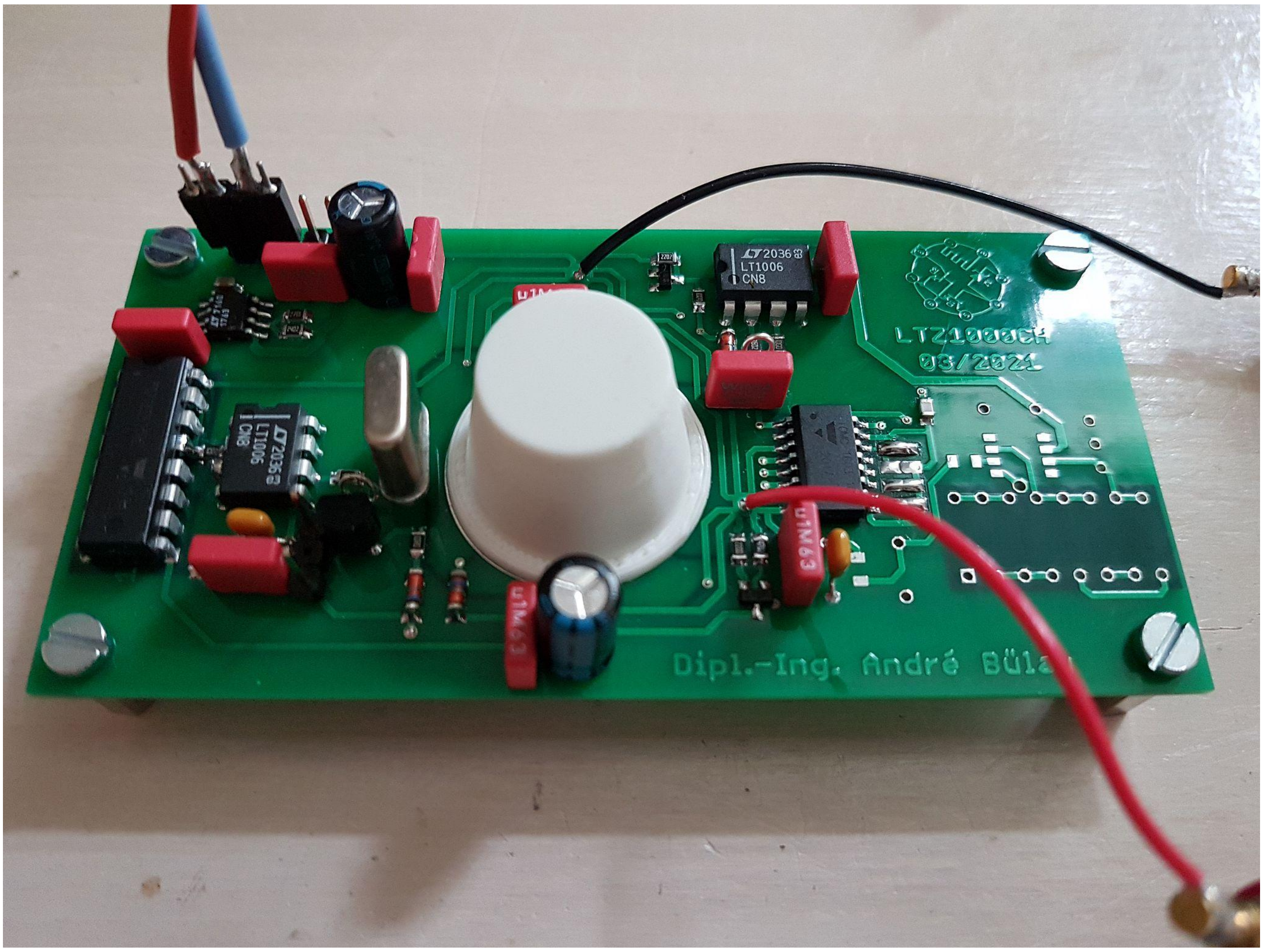

Figure 2: Preassembled reference board

First temperature profiles were measured with the internal LTZ heater turned off to find the proper resistor value at the cathode. Therefore, the solder links were set accordingly. As can be seen in figure 3 a resistor value of 18.18 Ω worked best with the z.t.c. temperature found at 48 °C, which corresponds to a voltage of 0.54 V at the temperature diode. A resistor value of 20 Ω shifted the z.t.c. temperature to lower and a resistor value of 16.667 Ω to higher temperatures. The diagrams are in ppm scale with respect to the output voltage at 23 °C.

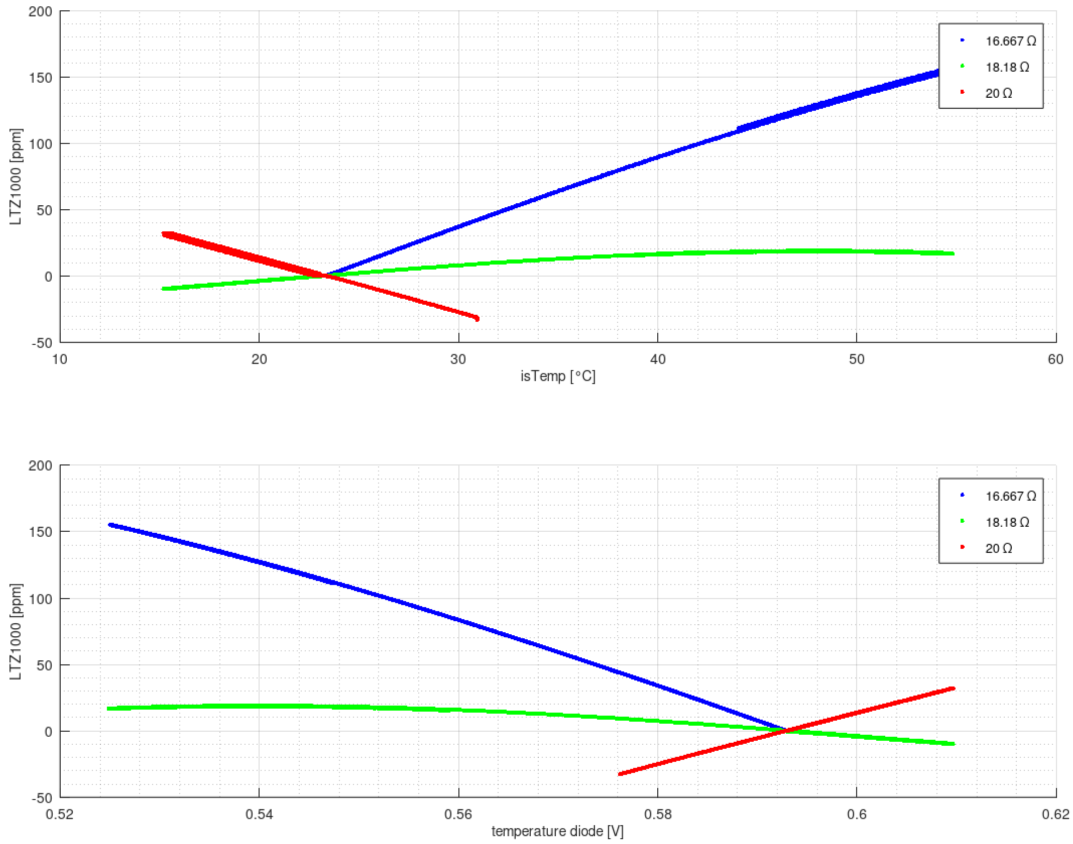

Figure 3: t.c. of the zener voltage for different resistor values in the cathode

Next the LTZ1000 heater was turned on and the temperature setpoint resistor network trimmed so that a voltage of 0.54 V at the temperature diode was present. This was done by using a decade resistor box parallel to corresponding elements of the resistors network and replacing it later by a proper fixed value resistor with 10 ppm/K. Another temperature profile was run to find the residual t.c. of the circuit. As it turned out a positive t.c. of 0.175 ppm/K was observed (see figure 4), that was compensated and thus reduced to -0.0106 ppm/K afterwards (see figure 5), not by using a dubious 400 kΩ resistor as mentioned in the LTZ datasheet, but by the aformentioned secret.

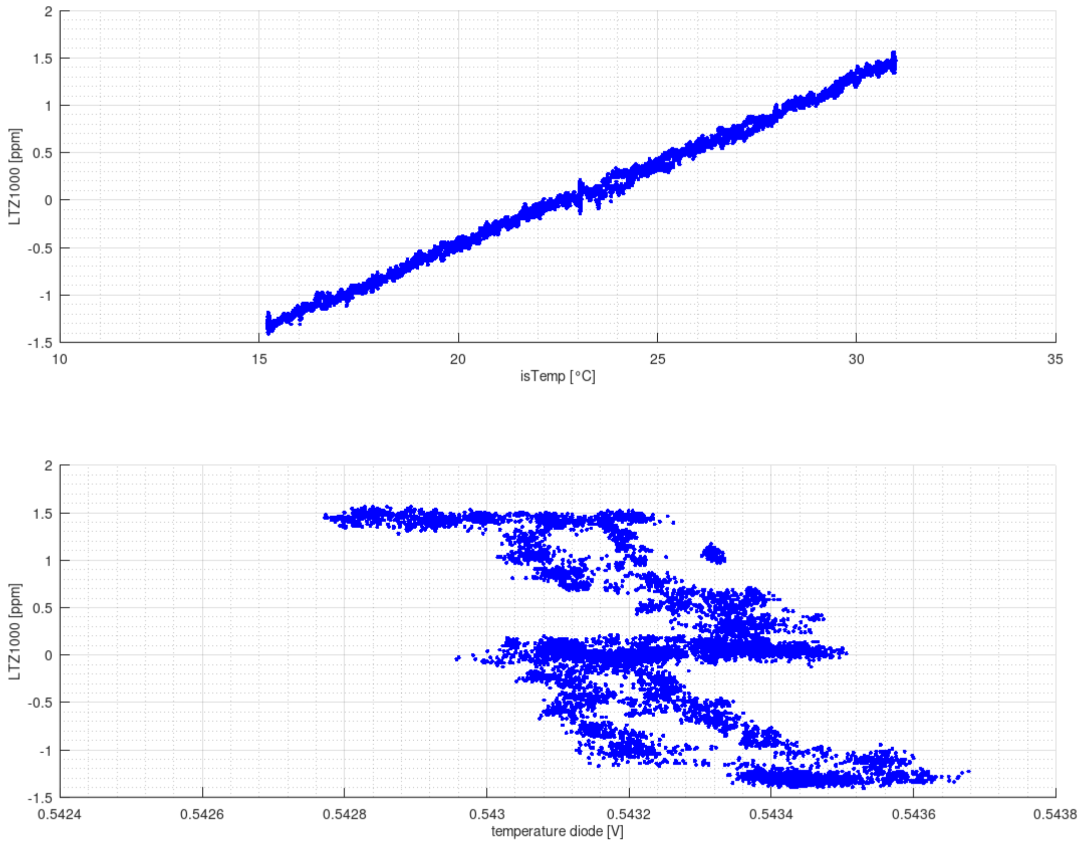

Figure 4: residual t.c. of the zener voltage with the heater turned on

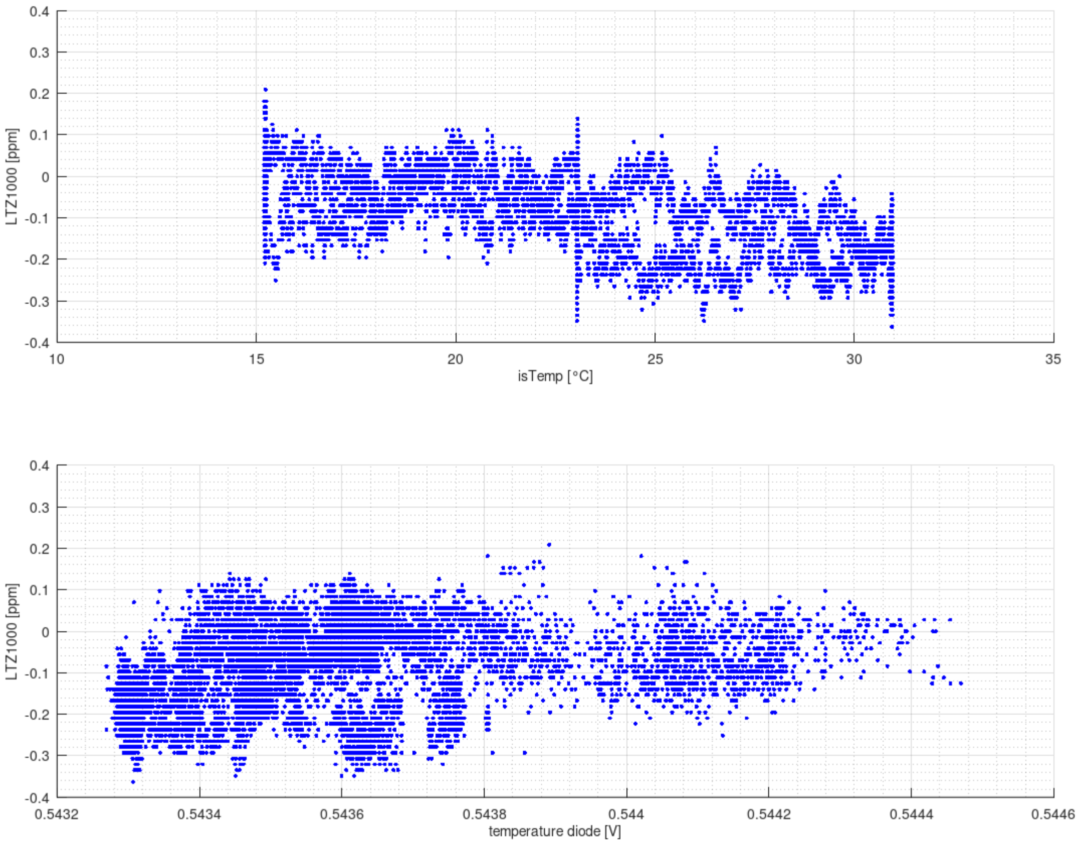

Figure 5: residual t.c. of the zener voltage after t.c. compensation

Next the amplifier stage was populated to get the zener voltage to 10 V. This stage again needed t.c. trimming, but also trimming of the output voltage itself, which influence each other. In figure 6 the output voltage of this simplified F7000 is compared over temperature to an F7000 voltage standard sitting at room temperature during the measurement.

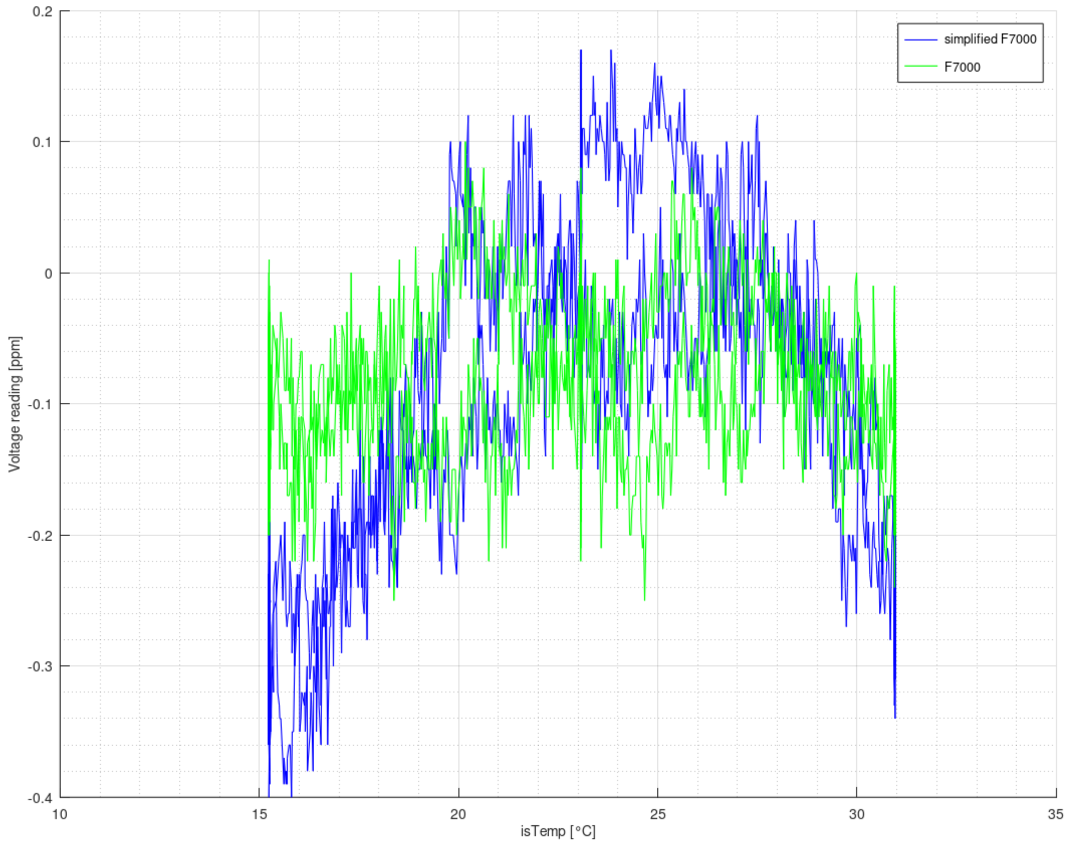

Figure 6: residual t.c. of the 10 V output voltage

Unfortunately, the TDP16031002 resistor network and mainly the output voltage trimming within it by parallel resistors to individual elements, added a small portion of non-linear t.c.. The final result that has been reached is an output voltage of what is believed to be 10.0000054 V right after ACAL of the meter - average over 100 samples - with a linear t.c. of +0.0138 ppm/K, but containing a non-linear component.

Since the F7000 and it simplified version are tracking each other (see figure 7) the changes in output voltages are mostly due to the stability and t.c. of the meter used.

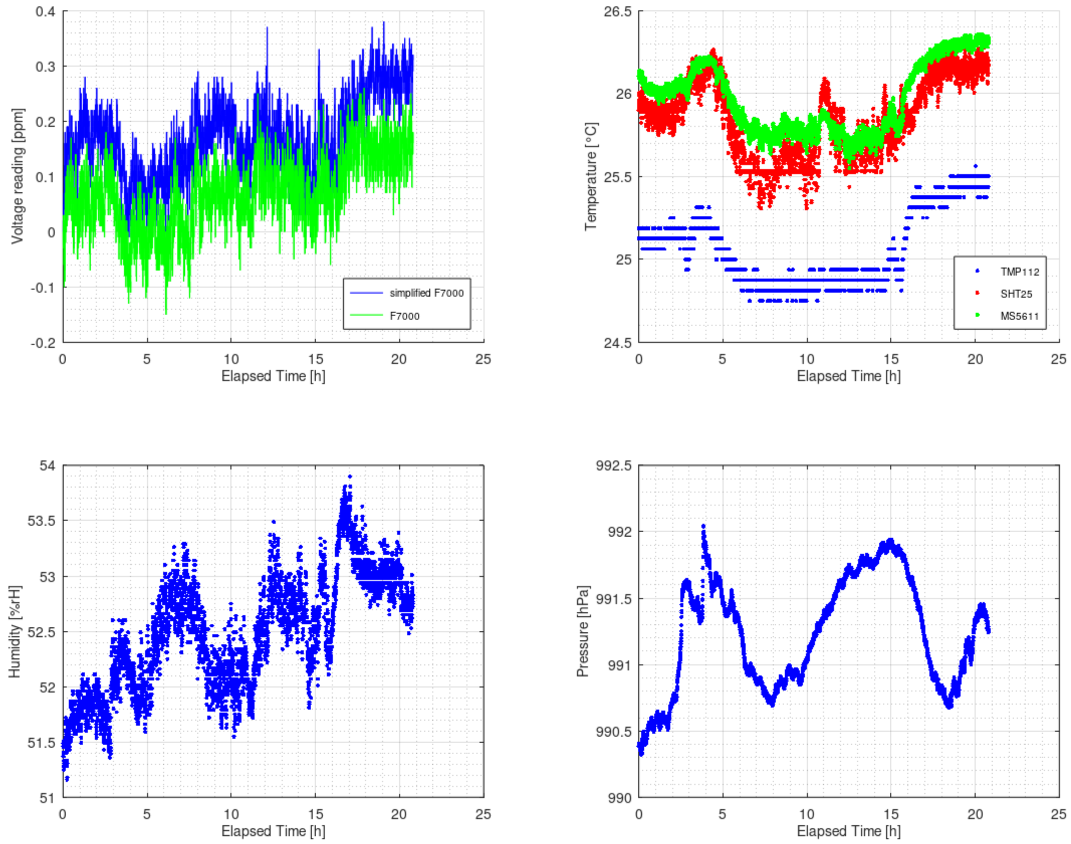

Figure 7: 21 h stability measurement of the simplified F7000 reference compared to an F7000 voltage standard

References

[1] https://www.eevblog.com/forum/metrology/(3300)-wavetek-7000-the-hidden-gemstone/

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[5] John Pickering, „A new compact isolated power supply for electrical Metrology at low signal levels“, 1999

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[7] Gunnar Fernqvist et al., „Design and Evaluation of a 10-mA DC Current Reference Standard“, IEEE TIM, April 2003

[8] Andriy Marusenkov, „Possibilities of further improvement of 1 s fluxgate variometers“, Geoscientific Instrumentation Methods and Data Systems, 2017

[9] LTZ1000/LTZ1000A Ultra Precision Reference datasheet, „Adjusting Temperature Coefficient in Unstabilized Applications“, page 6

[10] Nikolai Beev, „Measurement of Excess Noise in Thin Film and Metal Foil Resistor Networks“, 2021