Experiments with V_{ref} ovens

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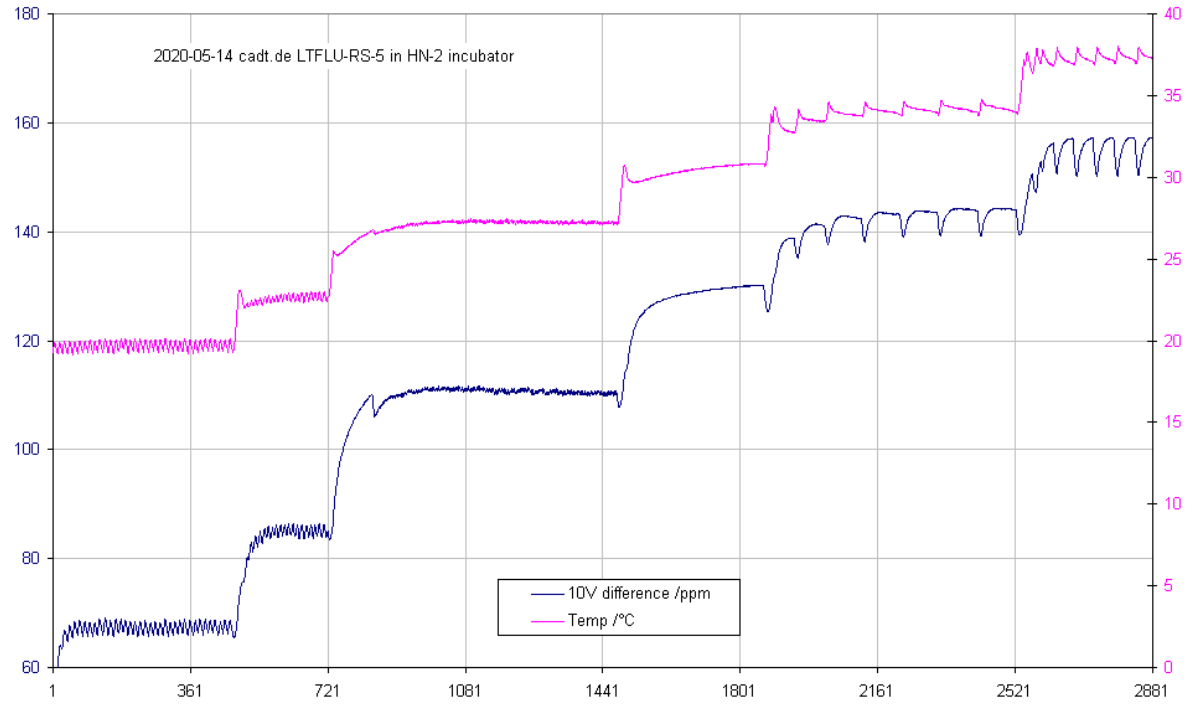
Our new reference is similar to what i did before, but it has a voltage divider made of DALE RS-5 wirewound resistors that we had in a drawer (150R+180R and 750R plus 0.6% fine tuning). This divider exhibits a low TC of about 1 ppm/K and the resistors seem to be extremely stable when used in the 50 mW region. They are huge but fit onto the existing PCB that was originally designed to be used with a Nomca 1603 array as divider. This time i am using an OPA2140 instead of a chopper amplifier, a J111 FET as output driver instead of a BC546B and 4x 47uF MLCC caps to reduce RF sensitivity.

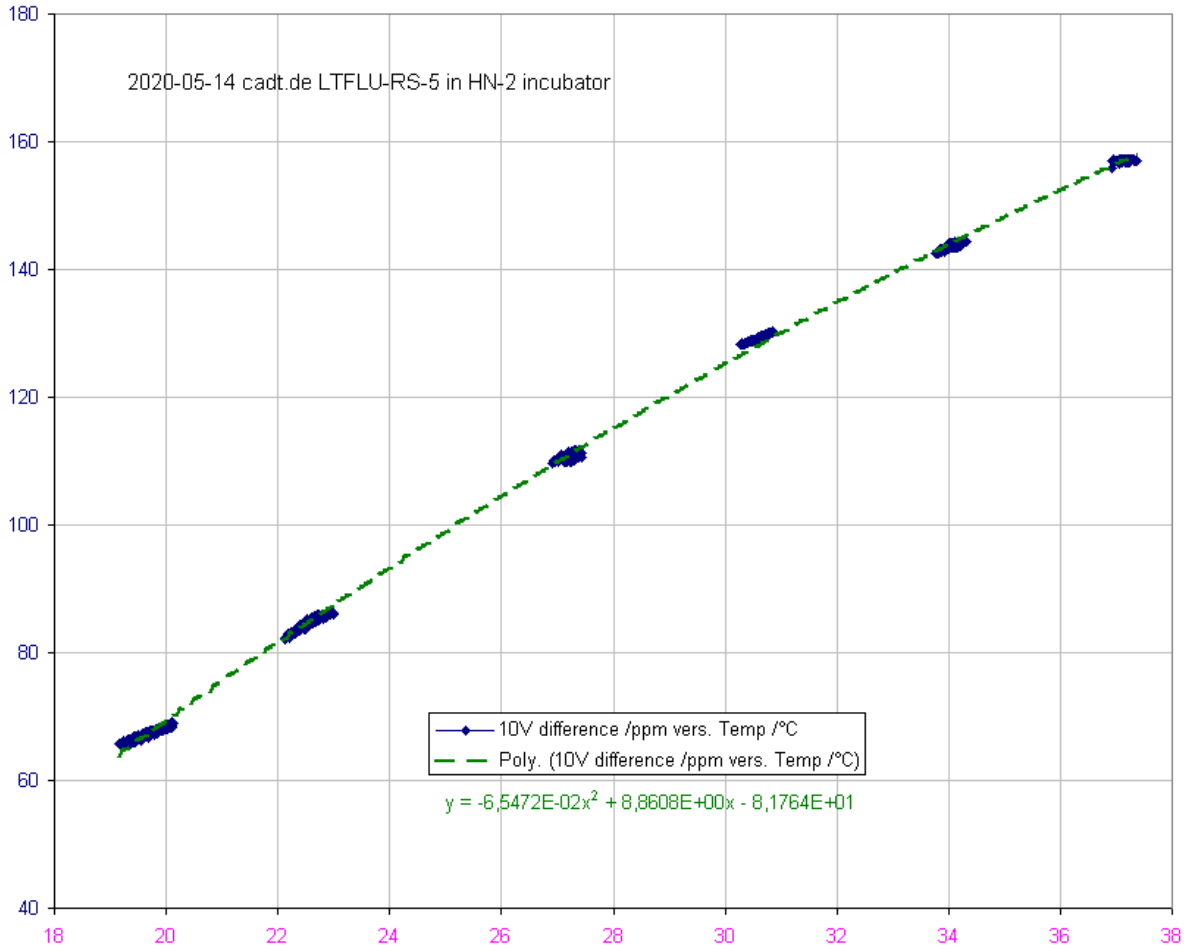
I am comparing the new reference to another ovenized LTFLU-1 reference that i made in January and whose divider is made of 10x 100R UPF50 metal film resistors.

I started recording the 10 V difference at various temperatures with the new reference in a NH-2 incubator. This is a „naked“ reference board with some wires soldered to it. The diagram shows a temperature log made with a SHT31 sensor inside the incubator and voltage differences as mesasured with HP 3456A. The horizontal axis is the measurement number (one measurement every 10 seconds). Measurements were taken at six different temperature settings of the incubator between 20 and 38 °C. The temperature controller in the incubator is very simple and the red curve clearly shows its imperfections. Yet we can see the 10 V offset shifts almost 100 ppm.



Note: The vertical scale of these measurements is only valid within one such run and there is no calibration in this better than +/- 20 ppm.

Then i made a diagram of all „steady state“ results and fitted a parabola. Besides a general positive TC of about 5 ppm/K the parabola shows a slight curvature with the extrapolated maximum at about 67,7 °C.



With the temperature measurement circuit i have for the LTFLU chip temperature i can try some TC fine adjustment.

The idea is to compensate the linear term in the TC parabola. That results in a parabola centered at T = 0 °C. When running the reference at that temperature it will react very little to small temperature variations. But 0 °C is no good, since the TEC cooler isn't capable to reach 0 °C at normal ambient temperature. A preferable operating temperature will be around 25 to 30 °C. At a lab temperature of 23 °C the heat generated by the reference circuit will automatically increase temperature to be in that intervall. So the TEC oven power consumption will be very small, like 30 to 100 mW and it can be run on a small battery.

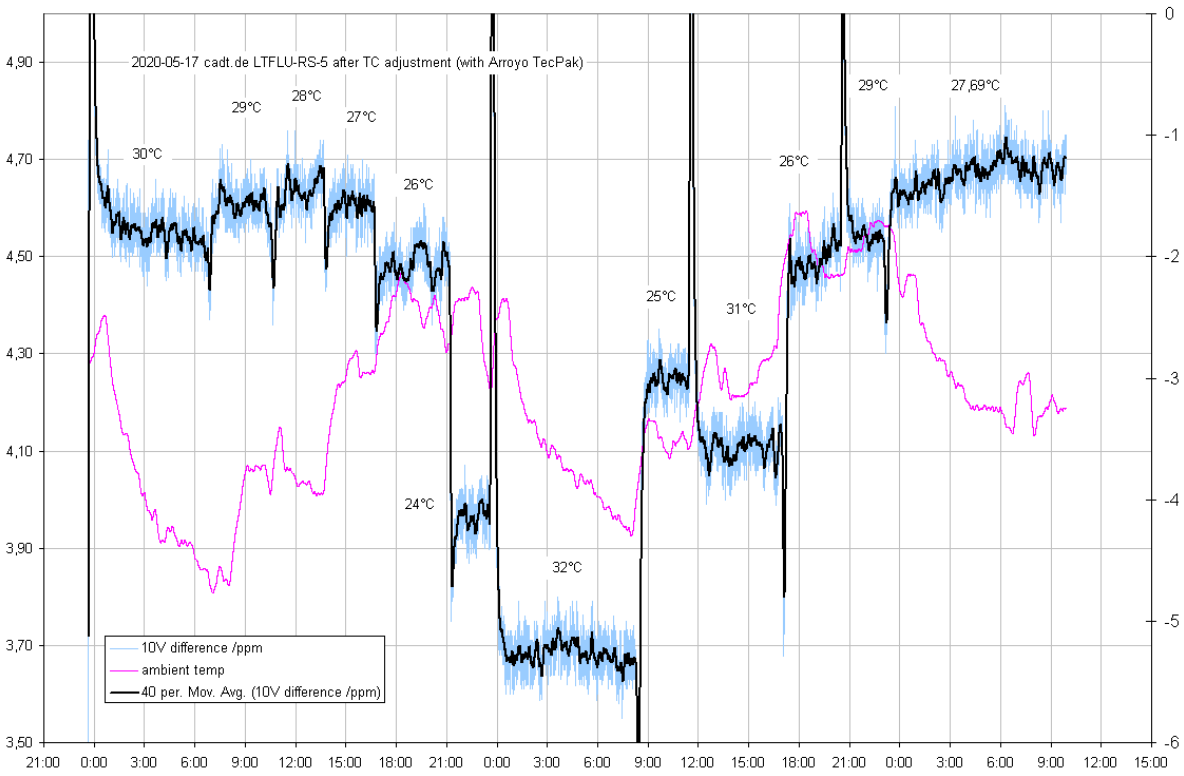
So i want an incomplete TC compensation that leaves the parabola centered at about 25 to 30 °C. Here some TCs at various temperatures calculated from the above fit.

Temp /°C	TC /ppm/K
22.50	5.915
29.00	5.063
37.00	4.016
67.67	0.000

To compensate a positive TC i just have to feed the -200 mV/K temperature output of my reference circuit back to the zener using a resistor. The size of the resistor determines the compensation. It

makes a voltage divider with the zener differential resistance which i don't know from the start. So i first used a 40 KOhm resistor to apply a mild compensation and measure the zener differential resistance to be 1.887 Ohms. In this reference the four LTFLU-1 zeners get a total of about 8 mA.

In the end i arrived at the conclusion that i can use a 10 KOhm resistor and this will result in compensation at around 30 °C. After fine-tuning the reference output voltage and assembly of the reference in its TEC oven i connected the voltage difference measurement again, this time observing low thermal EMF wiring. The TEC oven is driven by an Arroyo TecPAK 585. Now the log looks like this:



Note the vertical scale is 1.5 ppm now and this time there is a calibration to about +/- 1 ppm. You can see that i first tried to verify that i have the parabola top at around 28 °C by „scanning" down from 32 °C to 26 °C. Once i had seen the flat top i tried to tie down the parabola using further out points at 24 and 32 °C, then alternating as recommended by Mr. Pickering (remove hysteresis). The red curve is a log of ambient temperature in arbitrary units (TEC voltage of one of the ovens). The experiment was terminated after about 60 hours.

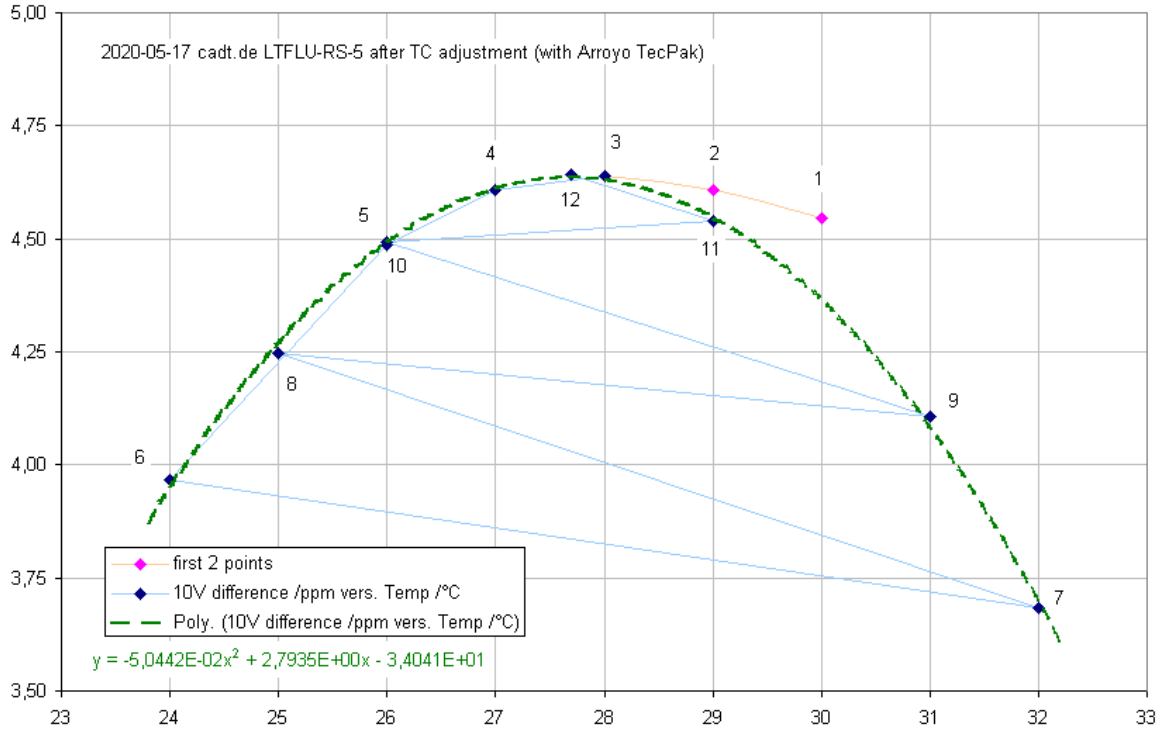
The diagram shows strong deviations (spikes) when changing the oven temperature. While the TEC source needs about 30 seconds for those temperature changes, different parts of the reference react to the temperature step after different delays. So it needs about 40 minutes after each temperature step to establish the balance again. That problem needs to be treated by designing new PCBs for the large DALE resistors.

This time i made the correlation plot with averages determined from stable data after each temperature change. StDev is the standard deviation of the measurements averaged within a constant

temperature interval. It can't be a valid noise determination, since the other LTFLU reference isn't any better than the new one.

No	Date/Time	Temp set /°C	10V difference /ppm	StDev /ppm
1	16.05.2020 04:05	30	4,545	0,033
2	16.05.2020 08:42	29	4,609	0,030
3	16.05.2020 12:38	28	4,639	0,034
4	16.05.2020 15:25	27	4,609	0,032
5	16.05.2020 19:21	26	4,485	0,039
6	16.05.2020 22:31	24	3,966	0,034
7	17.05.2020 04:24	32	3,682	0,034
8	17.05.2020 10:13	25	4,248	0,031
9	17.05.2020 14:34	31	4,106	0,036
10	17.05.2020 19:01	26	4,493	0,039
11	17.05.2020 22:05	29	4,540	0,029
12	18.05.2020 01:23	27,69	4,641	0,032
all data	18.05.2020 04:53	27,69	4,670	0,038

For the parabola fit i put the first 2 points aside. Apparently the reference showed some turn-on drift. Other points repeated almost perfect. The last point matches better if i take the average of the first three hours at 27.69 °C. Later in that night there was an additional drift that shifts the average of all 27.69 °C data up by 0,029 ppm.



Conclusion:

This description is meant as a recipe how to go sub-ppm with a ovenized voltage references. It is largely based on info and discussions in the metrology section at http://www.eevblog.com, where some schematics and photos of the reference boards and ovens used can be found in the LTFLU thread. There is a Fluke 732B tear-down thread. Our references inherit from that construction.