LTZ1000 DC reference standard without heater

The LTZ1000 is already several decades old, but is still used in high-performance measuring devices. The special feature of the LTZ is that it has an internal heater that keeps the reference at a constant temperature. This is not a new invention and has already been used with the LM199, among others. There are advantages and disadvantages to this method.
With the LTZ, the control for the heater has been moved to the outside, giving you better options for controlling the heating individually.

Today we want to look at a method in which we do not use the internal heater. There are a few good reasons why I would like to recommend this to you. You can find many circuits and application examples of how to use this reference on the Internet. But the circuit I want to present to you here is hard to find on the net. As I said, the special feature of this circuit is that we do not use the internal heater. I would like to briefly explain the reasons for this.
Before I go into the circuit itself, I would first like to show you how I compensate the LTZ1000 without a heater. The aim is to achieve the smallest possible TC, which should ultimately have this 1ppm/K.

First of all, a few general remarks on the subject.

Certain requirements are placed on a DC reference standard.
Here are the most important features of a DC reference standard:
The output voltage of the DC reference standard should...
1. have good long-term stability
2. have a good temperature coefficient
3. have low noise and therefore good short-term stability
4. have a low output impedance

For me, point one is particularly important, as the reliable value is the most important thing for a standard. The temperature coefficient naturally also has a high priority, but there are ways of compensating for this value with an empirically determined correction factor. The noise behavior is very important. High noise means that the output voltage always flickers and is therefore problematic for calibrations. This effect can be reduced by integration and averaging. However, this increases the measurement time, which is not particularly desirable.
A low output impedance of the output voltage means that the output current can be slightly higher in order to be able to connect low-impedance devices or components without the reference voltage changing significantly. This would be useful for low-impedance voltage dividers or resistors, for example.

Here are a few guide values for the parameters for a high-performance DC reference:
Long-term stability <= 1ppm/year
Temperature coefficients <= 1ppm/K
Noise < 20 µV/ss (0.01 - 10 Hz)
Output impedance <= 1 mOhm
If you achieve these parameters with your DC standard, then you are not far away from Fluke's 731/732 DC reference standards.

The small standard I am presenting here comes quite close to the characteristics just mentioned. The interesting question is why I operate the LTZ without a heater. What advantages could there be for this?
It is generally known that the ageing of semiconductors is greater at higher temperatures. However, since we want to minimize aging in a reference standard, it makes sense to operate the reference at the lowest possible temperatures. If we characterize the reference standard according to the

temperature, we can create a correction table with which we can correct the effective reference output voltage if the room temperature differs.
However, it is advisable that the room temperature does not change by more than approx. +/- 3...5 C.
This should be the case for most applications.
Such corrections are also made today, for example, with high-quality resistor standards.

First I would like to show you how to compensate the temperature coefficient of the LTZ in this circuit. I have mounted the LTZ on a small test PCB for this purpose.

Let us now take a look at the circuit. The heart of the circuit is the LTZ1000. Here we can see the Z diode, which is supplied by the output voltage via R9 and R10. The resistors R7 and R18 are located at the base of the Z diode. The total resistance is 150 R and closes the circuit to GND. Due to the difficulty of obtaining a 150 R value, I have assembled the resistor. You can of course also use a good foil resistor with the corresponding value. R7+R9+R10+R18 determine the Zener current of approx. 4 mA.

R1, R6 and R8 are used for temperature compensation of the Z diode with Q1. The fine adjustment of the required value is achieved by connecting the resistors in parallel. All resistors mentioned so far influence the output voltage and should therefore be very high-quality types, preferably metal-foil resistors with a small TC. The compensated Z voltage of approx. 7.1V is tapped at the collector of Q1 and fed to the non-inverted input of the OPV. The OPV amplifies the Z voltage to the output voltage / reference voltage of 10V. This is achieved by the voltage divider R13/R14 which divides the output voltage to the Z voltage and is fed to the inverted input of the OPV. An emitter follower (Q1) is connected to the OPV as an impedance converter (current amplifier) and Q2 as a current limiter with R4. As a result, the reference voltage can be loaded with approx. 5mA and is short-circuit protected by Q2.

The voltage divider R13/R14 is finely adjusted with the resistors (*) and connected to GND via JP4. There is also a temperature sensor TH1 on the circuit board which we lead out to the corresponding terminals for temperature control.

Now let's take another look at the circuit board. I have chosen the size so that it fits into a small aluminum housing, which can then also be used as a thermostat.

The view here is a top view - component side. The LTZ is on the far left, with the foil resistors next to it. Above it is the temperature sensor, which has no connection to the circuit. In the middle is the OPV. If you use the low-noise chopper type OPA189, you have to solder it to a small DIL8 adapter for this circuit board. On the right you can see the two output transistors. The resistors at the top (*) are adjusted for fine tuning. The exact value depends on the Z-voltage of the LTZ and the external resistors. The circuit board is designed so that all ground lines end in a common point, this prevents so-called current loops, which are unwanted fault currents. The circuit board is then sensibly installed in a small metal housing to prevent air circulation. We also create a balanced temperature environment. I use 2nF feed-through capacitors for all connections that I lead out. You can make the circuit board one-sided and realize the bridge with a wire.

Now we come to the results. I'll show you here how I adjusted and calibrated this reference. I make a voltage comparison with a highly accurate standard. In this case, a Fluke 732A standard that I have been using for two decades and therefore has a long history. Its drift is approx. 0.1 ppm/year and is therefore a very accurate source for the voltage comparison. Measurements are taken with a zero meter or equivalent measuring device, which we can use to record differences in voltages in the uV range. At 10V, a difference of 1uV corresponds to a deviation of 0.1 ppm. With a 5-digit multimeter, you have a resolution of 1 ppm at best in the DC 200mV range. A zero meter usually has a smallest measuring range of 1...3 uV and would be the better option for this measurement. I used a Prema 6001 for this measurement, with a resolution of 100 nV. I control the multimeter via the GPIB bus using measurement software written for this purpose and use the built-in scanner to alternately measure the differential voltage and the temperature inside the circuit. The room temperature is also recorded.

Now I'll show you the values measured with my measurement software.

As I said, the temperature shown in red is the temperature inside the circuit, determined by the sensor. As the device in this version does not have a thermostat, the interior temperature naturally fluctuates according to the room temperature. The measurements have been running since the end of March and as the room was only slightly heated, the temperatures are relatively low (approx. 18 grdC). Later on, the outside temperatures become higher and finally we had a hot spell. As you can see, the reference voltage always follows the temperature. We could create a correction table from these values and adjust the reference voltage by this correction value depending on the internal temperature. The advantage of this method is that all components work at a low temperature and therefore exhibit very little ageing.

If you want to improve the TC of the reference and be more independent of the external conditions, you can then install this circuit in a thermostat with a control accuracy of 0.1 grdC and then improve the TC to 1/10.