Meas. Sci. Technol. 1 (1990) 687–690. Printed in the UK

The Ultra-Zener . . . is it a portable replacement for the Weston cell?

P J Spreadbury

Cambridge University Engineering Department, Trumpington Street, Cambridge CB2 1PZ, UK

Received 15 December 1989, in final form 15 February 1990, accepted for publication 25 April 1990

Abstract. Twenty-four samples of the so-called Ultra-Zener, an integrated circuit containing a buried Zener junction, type no LTZ 1000, have been tested since March 1988. To measure the promised low rate of change of voltage with time (aging), a voltage measuring system with a resolution of 0.1 μV at the 7 V level has been developed and is described. Preliminary results are that half of the samples have an aging rate of less than 1.5 PPM/year from about two months after being assembled onto their circuit boards. Both intermittent operation and setting a lower chip temperature have been found to reduce the aging rate. The standard deviation of a set of 24 readings of the Zener voltage over half a minute is typically 0.05 PPM (0.3 μV on a 7 V level).

For a 'serious' voltage standard, a 1 PPM/year aging rate has been stated to be a desirable maximum level. This is attainable with the Ultra-Zener. In addition, its low noise, excellent portability and good electrical robustness make it a replacement for a standard cell bank as a voltage transfer standard.

1. Introduction

The so-called Ultra-Zener is an integrated circuit containing a buried Zener junction, a heater and two sensing transistors all in a small area of silicon. It has data sheets (type LTZ 1000) which promise very low noise and a very small change of voltage with time, typically 2 μV kh$^{-1/2}$. For a 7 V device, this is about 0.3 PPM/month or about 1 PPM/year. This is a great advance on the 20 PPM/month promised in the LM 199A data sheet from National which was the previously available integrated circuit with a buried junction.

There is always a demand for better accuracy, lower drift with time, a better temperature coefficient, good resistance against thermal shock and low source resistance from a voltage reference element. It is simplistic just to test a new product with the best voltmeter available because this basically compares one Zener with another. If a burst of noise is seen, is it from the Zener under test or from the test equipment? At least, a good voltage standard is needed with which to check the voltmeter periodically. A little expansion of this technique gives a very powerful measurement system indeed, which will be described first.

Preliminary test results are given and the most important features of the Zener circuit are mentioned.

2. Description of the system

The computer-aided measurement system is shown in figure 1. At its centre is a Datron 1071 voltmeter which can resolve 10 μV on its 10 V range. So direct measurement of a 7 V Zener diode will not yield the resolution desired. Instead, a known fraction of the voltage of a 10 V standard is derived from resistive voltage dividers, and 6.67, 7.14 or 7.0 V are available with dividers made of 3, 7 and 10 resistors, respectively. Now the voltmeter on its 0.1 V range can be used to measure the difference between the Zener diode and the 'divided-down stan-

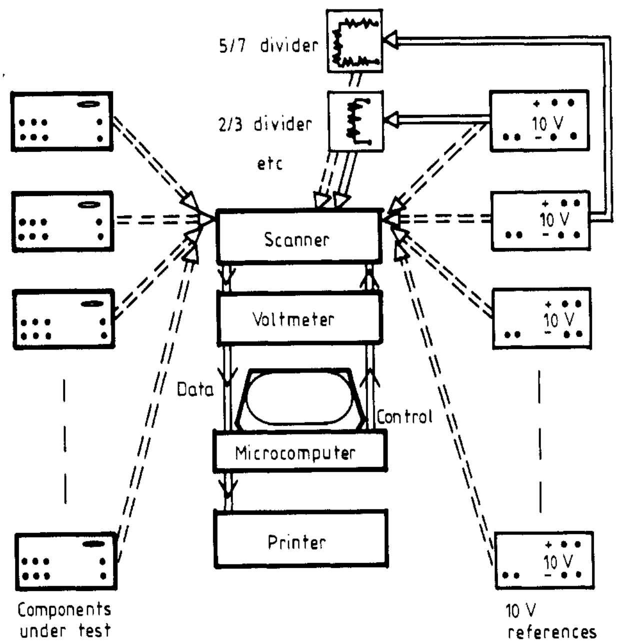

Figure 1. Computer-aided measurement system.

dard' and it does so with a 0.1 μV resolution. The voltmeter needs very high input resistance to avoid loading errors.

To ensure reliability and good measurement repeatability each divider must be regularly calibrated and all the 10 V standards must be intercompared and assigned values. This is what the rest of the system comprising a 16-way four-pole scanner, a simple 16 K Commodore computer and a $6\frac{1}{2}$-decade voltmeter perform in a three-step process using the IEEE-488 bus to interconnect the system.

3. Measurement process

Three substantial refinements have been introduced on the system described at the British Electromagnetic Measurements Conference in 1983:

(i) The group of eight 10 V standards contain three portable units which are calibrated against standards traceable to the National standard of voltage about every nine months. Four of the group of 10 V standards, selected as being those of lowest noise, are intercompared continuously by the double-difference method. This allows any noise to be unambiguously traced to the unit causing it.

(ii) *Two* separate resistive dividers across two of the 10 V standards are calibrated at the start of every measurement session and if necessary during the session to give accurately defined 7 V and 7.142 V levels. The nominal output of the Ultra-Zener is about 7.1 V.

(iii) Lastly the voltage differences between each Zener reference and both calibrated dividers are taken 24 times in sets lasting about half a minute. From this is calculated a mean voltage for the Zener and a standard deviation for each set of readings. The latter is typically 0.3 μV on the 7 V level and contains contributions from the 10 V standard, the divider *and* the Ultra-Zener.

The computer uses a cross-correlation program which is actually fed with the *average* voltage of the two dividers. After calculating the voltage of each Zener, the program calculates the mean of the group of Zeners being measured. Then the results of step (iii) of the process are used in reverse to calculate back to the voltage of *each* divider tap. If these are not both correct to 0.5 μV, the measurement is repeated (or the DVM calibration is checked or the dividers recalibrated). This back check is an important component in giving confidence to the measured data.

4. Results

Typical data for a day taken at random are:

14 June 1989:
Given mean of divider voltages = 7.071 427 5 V
Calculation of Zener voltages
T.01 = 7.105 147 7 V SD 0.45 μV
T.02 = 7.107 429 1 V SD 0.35 μV
and four others
Calculation back to dividers
7/10 = 7.000 072 6 V 0.4 μV mean residual
5/7 = 7.142 782 3 V 0.4 μV mean residual.

Since the actual results from the divider calibrations were 7.000 072 4 and 7.142 782 7, these data are satisfactory, and they are put into a data file.

A linear least squares line fit to the measurements will give an 'aging' rate (see figure 2). More importantly, the *errors* from a constant voltage or a constant smooth change will indicate the suitability of the device to be used in a voltage standard. It is now held that no more than 1 PPM per year for the rate of change of voltage is

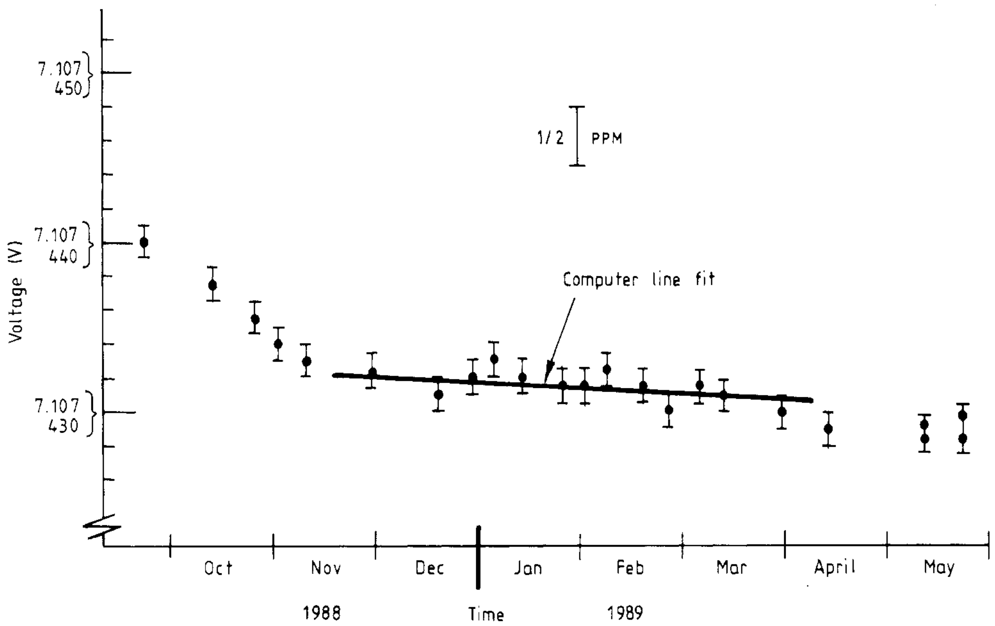

Figure 2. Measured voltage of one sample of the Ultra-Zener over a period of eight months. Computer line fit has a slope of −0.6 PPM/year and 0.14 PPM RSS errors.

desirable. Any errors from a smooth rate of change may of course be caused by uncertainties in the system or environment. A full uncertainty budget for the system has been determined including terms for the thermal EMFS in the scanners, voltmeter range errors and voltmeter common-mode errors (as all the DC differences are taken at various voltages above ground). The root-sum-squares of the uncertainties come to $\pm 3\ \mu$V or just under 0.5 PPM at the 7 V level. In the event, errors of about half of this are inferred from the scatter of points from the linear aging trend (figure 2).

The largest long-term error is caused by the step change every nine months when the 10 V group is traced in value to the National level at the National Physical Laboratory (NPL). Then a new voltage for the mean of the 10 V group is introduced with a new aging estimate for the group which is assumed constant for the next nine-month period. At its worst, the mean value of the group has needed to be changed by 0.3 PPM at this time; this caused a 2 μV step at the 7 V level. This mostly affects aging results which are the result of a line fit over a short period spaced equally before and after such a calibration at the NPL, so such line fits are avoided.

5. Development of the Zener circuit

The Ultra-Zener is assembled on a small circuit board in essentially the same circuit (figure 3) as is given in the maker's data sheet. It is shown in the centre of the diagram with the heater resistor between pins 1 and 2, the Zener between pins 3 and 4, and the two npn transistors. The circuit to the right of the Zener together with the resistor Rl define a constant Zener current in the region of 5 mA. The circuit to the left of the Zener controls the temperature of the integrated circuit using the -2 mV °C^{-1} base-emitter temperature coefficient of the npn transistor as sensor. The choice of R4 and R5 as 12 kΩ and 1 kΩ, respectively, define about 45 °C for the chip, and the temperatures defined by other resistor ratios are shown on figures 3 and 4. R4 and R5 should be in one package to get the best rejection of environment temperature. In order not to degrade the performance of the Zener, three premium-quality components are

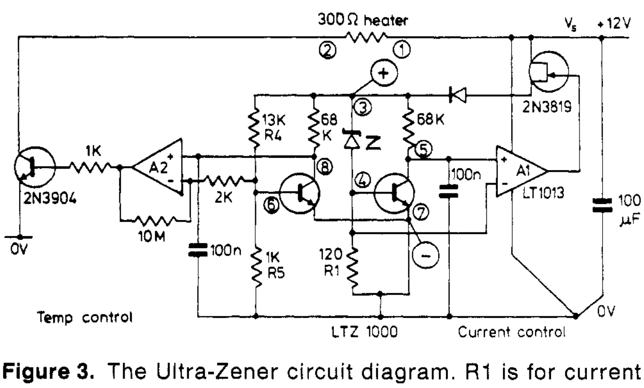

Figure 3. The Ultra-Zener circuit diagram. R1 is for current sensing: tolerance 0.01%, temperature coefficient 1 PPM °C^{-1}. R4:R5 = 13:1 for 65 °C chip and 12:1 for 45 °C chip; matched to 3 PPM °C^{-1}.

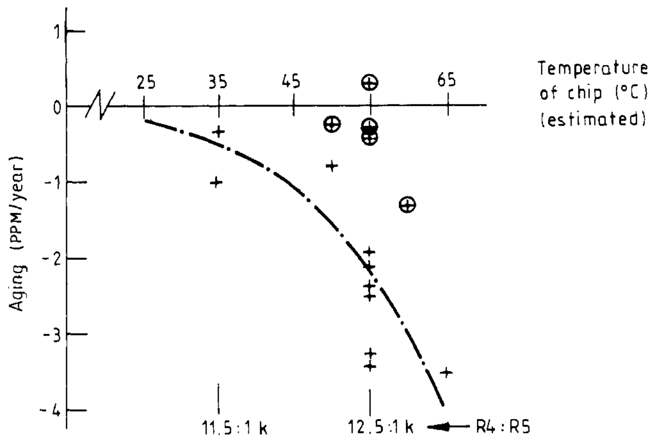

Figure 4. Aging of 14 samples of LTZ 1000 at various chip temperatures: *continuous* operation except for devices denoted by ⊕. Device operating at 50 °C has its aging shown twice.

needed in the circuit. They are the op-amp type LT 1013, R1 which defines the Zener current and the divider, R4 and R5.

6. Tests on Zener aging

Some investigation has started on the device aging (the rate of change of Zener voltage with time) and how it varies firstly with Zener temperature, and secondly with the Zener either continuously powered or normally unpowered (except for four to eight hours on each measurement day). Some results of these tests are shown in figure 4.

All devices are run continuously at the start. The same value resistor pairs R4 and R5 were not available for all of the samples tested so some devices were run cooler than others. The trend, shown dotted in figure 4, is for the aging doubling for each 10 °C rise in temperature, and this could be argued to be some sort of fit to the results. More circuits have now been constructed setting a lower Zener temperature. Results should be available soon to support or disprove this suggested trend.

Next some of the devices which were aging at about 4 PPM/year (a *linear* extrapolation from 1 PPM in three months) were taken off continuous power and were only powered on the one day in ten when they are measured. Provided that they are turned on four hours before a measurement, negligible change of voltage over the next four to eight hours is found. The much lower values for aging are shown in figure 4 for the devices operated like this.

The results of other work, on the best reference Zeners available, are shown in table 1, and they indicate how the Ultra-Zener is in most respects an improvement on the earlier types available. From about two months after being assembled and put onto continuous power, an aging rate of *under* 4 PPM per year was predicted (as a *linear* extrapolation or under 2 PPM per year from a root-time extrapolation) for *all* of the samples tested. In the past, the delay of extensive aging periods and the

Table 1. Features of the best reference Zeners compared. Grading: + + = excellent, + = good, ● = a problem.

Type	Voltage (V)	Temperature coefficient	Aging at 6 months	Noise	R_z	On–off retrace	Cost (£)
Compensated							
7 mA (IN829, BZX93)	~6.3	+	●	+ +	+	+/●	2
2 mA (IN4579, BZV13)	~6.5	+	●	●	●	+	2
Active (LM399, LM299)	~7	+ +	+/●	●	+ +	+ +	7
Simple (BZX88-C5V6)	~5.6	●	+ +	+	●	+ +	0.5
Ultra-Zener (LTZ-1000)	~7	+	+ +	+ +	+ +	+	35

effort of removing all poor devices was a serious and costly problem. It is pleasing that the maker's 'typical' specification is met, though the root-time relation for aging needs further testing to prove.

7. Conclusion

The Ultra-Zener seems to have no serious disadvantages as a voltage standard apart from price and some added circuit complexity. This is a good omen for the performance of several new commercial instruments which contain it.

A four-cell bank of Weston cells has been widely used as a portable transfer standard until now. It has needed a long settling time after transportation and considerable skill from the operators to avoid loading currents being taken. I expect that Ultra-Zener circuits will certainly replace Weston cells as portable voltage standards. Once their ease of use and performance is assessed more widely, I expect that they will be the preferred purchase for many other purposes too.

References

Field B F 1985 A sub-ppm 1-10V-DC measuring system *IEEE Trans. Instrum. Meas.* **IM-34** 327

Roberts D E and Spreadbury P J 1987 Assessment of the performance of Zener references of the very highest quality *Proc. IEEE Instrum. and Measurement Technology Conf. (IMTC)* p 125

Spreadbury P J 1983 Computer-aided voltage measurements *Proc. British Electromagnetic Measurements Conf, National Physical Laboratory, 5 October 1983*