THE ULTRA-ZENER ....
A PORTABLE REPLACEMENT FOR THE WESTON CELL ?

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Abstract

24 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. With some circuit modification, half of the samples have been found to have an ageing rate of less than 1.5 ppm/year, and all have ageing less than 4 ppm/year.

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. The latter feature is about 4 times less than that achievable by certain other good reference Zeners.

There is always a demand for better accuracy, lower drift with time, a better temperature coefficient and resistance against thermal shock, and low source resistance from a reference element. The circuit suggested by the makers has been modified to reduce the controlled temperature at which the Zener junction operates and to reduce low frequency noise.

It is desired to test a group of 7V Zeners for noise at the 0.05 ppm level and voltage rate of change with time (ageing) at the 0.3 ppm/year level. This has needed a specially developed measuring system, whose readings are traceable to the National 10V level. It is equipped with a measure of "intelligence' to give confidence in the data produced.

Development of the Zener Circuit

The Ultra-Zener is assembled on a small circuit board in a slightly modified circuit, Fig.1, to that given in the makers 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 R1 defines a constant Zener current in the region of 5mA. The circuit to the left of the Zener controls the temperature of the integrated circuit using the -2mV/^{o}C base-emitter temperature coefficient of the npn transistor as sensor. The choice of R4 and R5 as 12k and 1kohm define about 45^{o}C for the chip. Temperatures defined by other resistor ratios are shown in Fig.2. R4 and R5 should be in one package to get best rejection of environment temperature. Together with R1, which defines the Zener current, and the op-amp type LT1013, premium quality tested componen ts are wanted so as not to degrade the performance of the Zener.

Tests on Zener Ageing

Some investigation has started on the device ageing and how it varies firstly with Zener temperature, and secondly with the Zener either continuously powered or normally unpowered (except for 4 to 8 hours on each measurement day). Some results of these tests are shown in Fig.2.

All devices are run continuously at the start. I did not have the same value resistor pairs R4 and R5 for all of the samples tested so some devices were run cooler than others. The trend, shown dotted in Fig.2, is for the ageing doubling for each 10^{o}C rise in temperature and this could be argued to be some sort of fit to the results.

Next some of the devices which were ageing at about 4 ppm/year were taken off continuous power and were only powered one day in ten when they are measured. Provided that they are turned on 4 hours before a measurement, negligible change of voltage over the next 4 to 8 hours is found. The much lower values for ageing are shown in Fig.2 for the devices operated like this.

The Measurement System

My computer-aided measurement system contains

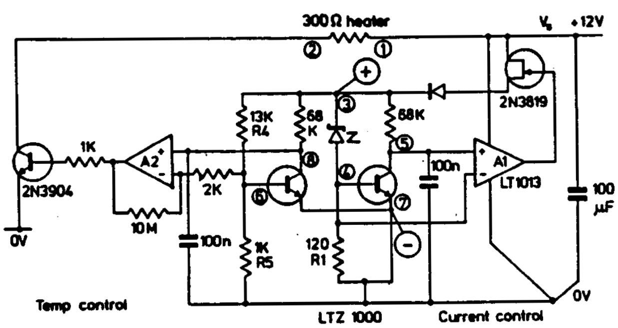

Fig.1. The Ultra-Zener circuit diagram. R1 is for current sensing; tolerance 0.01%, 1 ppm/^{o}C temperature coefficient R4:R5 = 13:1 for 65^{o}C chip and matched to 3 ppm/^{o}C.

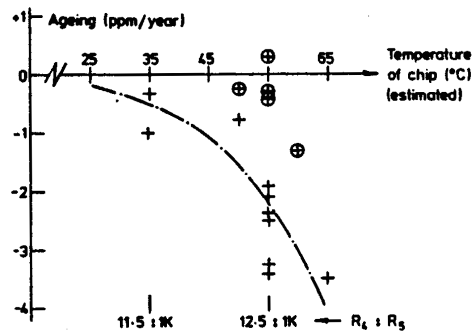

Fig.2: Ageing of 14 samples of LTZ 1000 at various chip temperatures: continuous operation except for devices denoted by ⊕ .

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at its heart a high grade voltmeter. It is simplistic to use this directly as this just compares the Zener under test with the reference in the instrument: if noise or a step change is seen, it is not certain which Zener has caused it. Instead, a known fraction of the voltage of a 10V standard is derived from resistive voltage dividers, and 7.14 or 7.0 V are available with dividers made of 7 or 10 resistors respectively. Now the voltmeter on its 0.1V range can be used to measure the difference between the Zener diode and the "divided-down standard" and it does so with a 0.1 µV resolution. The voltmeter needs very high input resistance to avoid loading errors. The 6½ decade voltmeter used for 10 years has just been changed to an 8½ decade type, whose lower noise and calibration errors, etc., should give smaller measurement uncertainty.

To ensure reliability and good measurement repeatability each divider must be regularly calibrated and all the 10V standards must be intercompared and assigned a value. This is what the rest of the system comprising a 16/way 4 pole scanner, a personal computer and a printer perform in a 3 step process using the IEEE-488 bus to interconnect the system.

Step 1. A group of eight 10V standards contain three portable units which are assigned a value traceable to the National standard of voltage about every 9 months. Four of the group of 10V 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.

Step 2. Two separate resistive dividers across two of the 10V standards are calibrated at the start of every measurement session and if necessary during the session to give accurately defined 7V and 7.142V levels. The nominal output of the Ultra-Zener is about 7.1V.

Step 3. 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 of each reading set. The latter is typically 0.3 µV on the 7V level and contains contributions from the 10V 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 3 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.

Results

A line fit to the measurements will give an "ageing" rate, see Fig.3. 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 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 as ±3 µV or just under 0.5 ppm at the 7V level. In the event, errors of about half of this are inferred from the scatter of points from the linear ageing trend, Fig.3.

The largest long-term error is caused by the step change every 9 months when the 10V group is traced in value to the National level at the National Physical Laboratory.

Conclusion

Initial tests indicate that 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.

References

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[2] P.J. Spreadbury, "The Ultra-Zener", Proceedings of the British Electromagnetic Measurements Conference, National Physical Laboratory, 7-9 November 1989, pp.16.1-16.4.

Fig.3. Measured voltage of one sample of the Ultra-Zener over a period of 14 months.