

# Automated reversing switch and monitor for high accuracy voltage standards

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**Abstract** - In the following a device for automated polarity reversal and acquisition of the environmental parameters that affect the output voltage of a zener reference standard is described. The reversal is made with a mechanical switch whose thermal emfs are a few nanovolt. The alignment of the switch is supervised by a microprocessor that controls an electrical motor and identifies the switch position by means of angular and axial sensors. The microprocessor is also connected to ADCs and humidity and temperature sensor, and is capable of communicating with a PC, providing thorough information about the operating conditions of a zener voltage standard.

## I. Introduction

Solid state DC voltage references are suited to routine operation, automated measurement systems, and lend themselves as reliable inter-laboratory transfer standards. Owing to their importance for electrical measurements and their high intrinsic accuracy, they are widely used in metrology, both in primary institutes and calibration laboratories.

The high performances of these standards set tight requirements in the measurement system, which has to be designed and realised with great care, in order to guarantee that the high accuracy attainable by the standard is not degraded by the measurement system itself.

The most important and common source of uncertainty in DC voltage measurement is a thermoelectrically effect, i.e. the generation of a voltage (or thermal electromotive force,  $e_{th}$ ), whose magnitude depends on the thermal gradient across dissimilar metals of an electrical contact or junction maintained at different temperatures. This effect was discovered by Thomas Seebeck, a German physicist, in 1823.

To explain how  $e_{th}$  affects measurements a simple circuit is shown in Fig. 1, with a dc source and a voltmeter connected with a pair of wires. Every junction in this circuit is a thermocouple generating a dc voltage dependent on the thermal gradient and on the Seebeck coefficient of the metals in the electrical contact. It can be seen that the measured voltage is the sum of signal and thermal voltages.

Wire and electrical contact in the measurement instruments are normally made with different metal or alloy. In order to minimise such effect, alloys and metals with a low Seebeck coefficient must be used. In addition, whenever possible, the voltage measurements should be performed inverting the connections to the source by means of a switch. With this technique, the thermal voltages  $e_{th}$ , that don't change during the inversion, are cancelled out, not affecting the measurement.

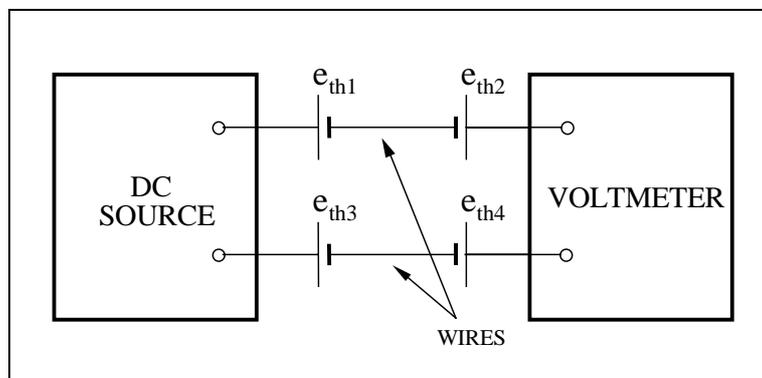


Figure 1. – Example of connection of a DC source to a voltmeter. The voltage  $e_{th}$  are across the junctions between wires and connectors of the equipment.

The adoption of the reversing method is mandatory in primary metrological work, and makes it possible to take advantage of the high performances of top level voltage references.

Nevertheless, when ultimate accuracy is aimed, even the performances guaranteed by manufacturers' specifications may be not sufficient. Since specifications are given for worst-case, it is possible to obtain significant improvements, if the effect of environmental conditions are reduced [1]. This can be done in two ways: a) operation in a controlled environment; b) correction for the effect of parameter variations. Owing to practical reasons both must be used for optimum results. To apply the proper corrections, all parameters affecting the standard output voltage have to be monitored at measurement time and a record of parameters measurement must be available to calculate the sensitivity coefficients of the standard.

In the following we present a device which is capable of performing both switching and parameter monitoring, automatically, by computer control.

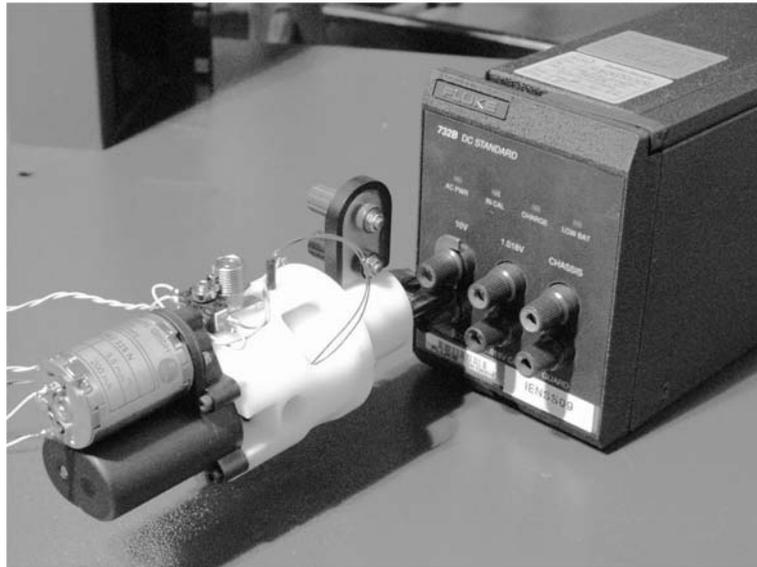


Figure 2. – The switch applied to a solid state voltage reference

## II. Construction and operation of the switch actuator

The polarity inverter is built around a rotary switch, that can be applied to any generic source or detector. Rotary switches are more difficult to automate than relays but have relevant advantages: greater reliability of the contact and much higher thermal capacity. Consequently temperature fluctuations and thermal gradients in the switch are kept to a very low level, and they introduce much lower  $e_{th}$  in the circuit. In the switch we used  $e_{th}$  are within few nanovolt, according to specifications. The switch makes contact in four positions, corresponding to the angular positions:  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ ,  $360^\circ$  and performing a reversal of the polarity at every  $90^\circ$  rotation.



Figure 3. – Internal view of the mechanical actuator. The white parts are made in Delrin, while the

worm and the positioner are made in steel.

The switch is housed in a tube (A) with a flange at one end. The knob is embedded in an extractor device (B) in which a worm (C) can be screwed completely. The worm is joggled on the driving shaft of the gear box of the motor (D). The switching of the position is performed in three steps. In the first step the rotation of the worm extracts the knob from one of the normal positions. In the second step, when the knob is completely pulled out, the extractor starts to turn. When the necessary position is reached, the positioner (E) blocks the extractor and the motor unscrews the worm. When the worm is completely unscrewed the rotary switch makes a contact. The status of the actuator and the position of the switch are monitored by means of two limit-switches and a reed relay. The whole commutation process takes approximately 25 seconds.

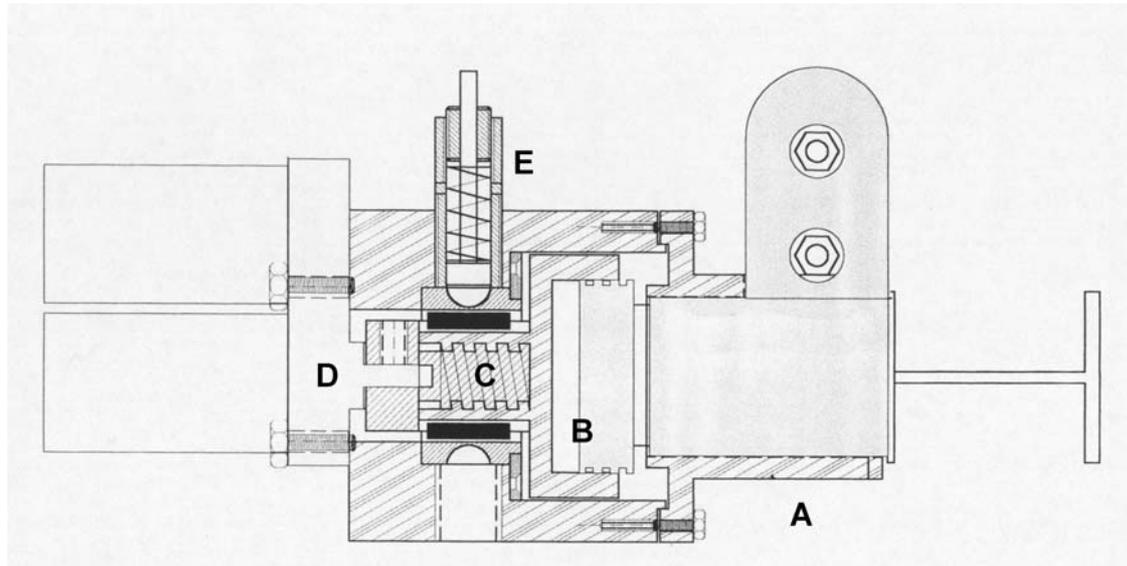


Figure 4. – Sectional view of the assembly to actuate the switch

The motor is completely controlled by a control circuit with a serial interface for the connection to a computer.

### III. Electronics and software for monitoring and control

A second unit hosts the control circuits of the switch and a serial interface RS 232. This system, is suitable for several commercially available voltage sources, and when applied to solid state Fluke references, type B, it offers several further controls. Connecting the system to a PC, by means of a specific program it is possible to: 1) read the status of signals on the frontal panel of the source; 2) turn off, for the measurement time, the source from the mains; 3) measure the temperature of the internal source oven; 4) measure the voltage of the batteries; 5) measure the laboratory temperature [2]; 6) measure the laboratory humidity [3]; 6) carry out charging/discharging cycles for increased battery life and efficiency.

The system for acquisition of the parameters could stay permanently connected to the source. In this way is possible to measure for all time the parameters in order to avoid malfunctions or irregular behaviors of the source before starting a cycle of precision measurements. The acquisition of the parameters could be performed also during the measurements due the isolation between the source and the parameters measurement system. In this way it is also possible determine the moment in which the temperature of the oven that contains the reference reaches the required stability, and the thermal transients have settled down.

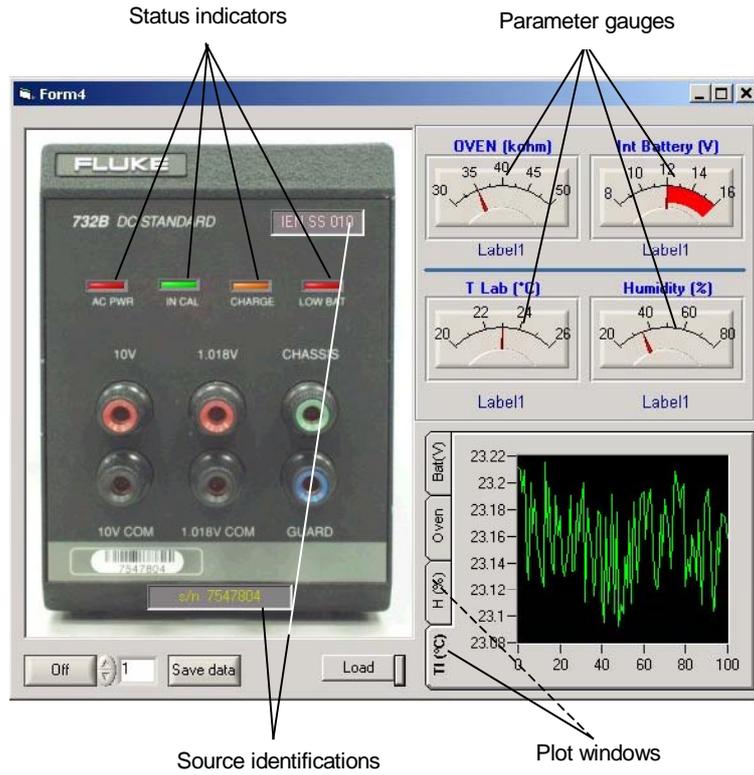


Figure 5. – The user interface synthesizes on the screen the status of voltage reference and reports the values of all relevant environmental parameters

#### IV. Results

To test the performances of the device, the switch input (source/detector side) was connected to a high quality thick copper strip and  $e_{th}$  was measured at the output by means of a high sensitivity nanovoltmeter. The switch was then automatically operated to perform a series of reversals and the emf was recorded during the process.

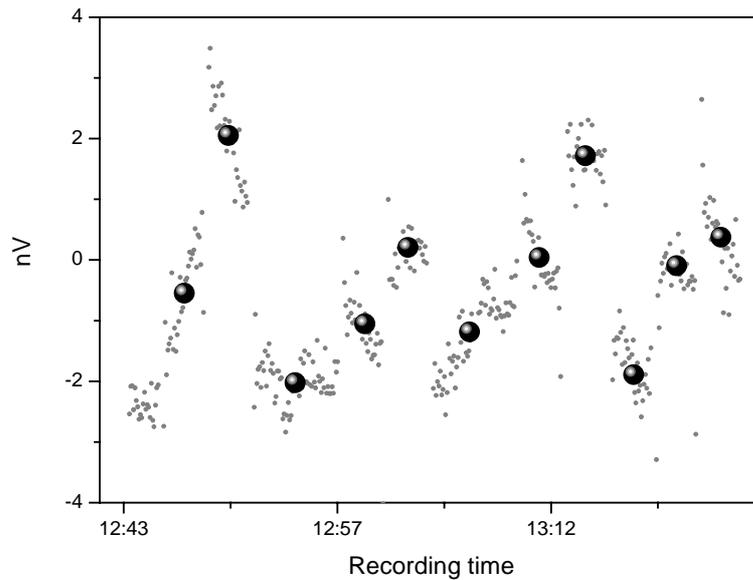


Figure 6. – Electromotive force measured with the switch making a polarity reversals on a high quality short. Small dots are measurements data, big circles show the average  $e_{th}$  for every polarity.

The recorded data are shown in the following Figure. It can be seen from the graph, that average  $e_{th}$  for all polarity reversal is well within  $\pm 2$  nV. Switch performances are then not degraded by the electromechanical system for automated operation. Indeed, as the  $e_{th}$  are lower than the values in the specifications, the automatic actuator is presumably advantageous over manual switching, the human operator being a heat source with non negligible effects on the internal temperature and gradients of the switch.

The figure 4 reports both the trend of the oven temperature of a source and the battery voltage for a period of 24 hours. During the acquisition the source has been disconnected from the mains for about 3 hours causing a variation of the temperature of the oven.

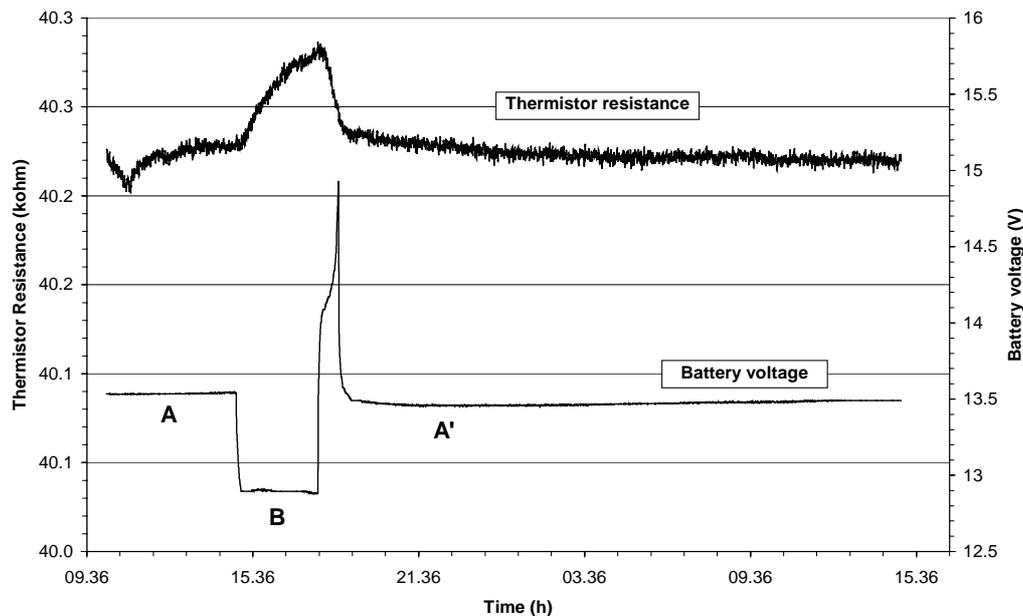


Figure 7. – Behavior of the oven of a source during a period of about 24 hours. In the plot the trace A and A' represent the source connected to the mains, while during the B time it was powered by means of his internal battery. In correspondence of the B time the temperature of the oven decreases with a transitory that require about three hours to be exhausted.

### Acknowledgments

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### References

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