Complete Characterization of Zener Standards at 10 V for Measurement Assurance Program (MAP)

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Abstract[*]

A complete characterization of Zener standards for temperature, pressure, and humidity is being performed to improve the uncertainty of a MAP that uses 10 V Zeners as travelling standards. The procedure and equipment used for this work is briefly described. We will report results of evaluating our available pool of Zener standards.

Introduction

The most demanding instrument specifications for dc voltage measurements are seen at the 10 V level. The demand from industrial laboratories for lower uncertainties of 10 V primary standards used for maintenance or instrumentation calibration is thus increasing. Although an in-house Josephson voltage standard (JVS) can offer calibrations with the lowest uncertainty, the JVS is still not practical for widespread use and the majority of standard laboratories are still using Zener references or standard cells as their primary voltage standards. Most laboratories have shifted to the use of Zener standards for 10 V level calibrations to increase workload turnaround rate and to avoid shipping problems inherent with standard cells. NIST has been offering a MAP service at 1.018 V for many years. It is now time to expand the NIST MAP to 10 V, and to improve the NIST Zener calibration service to an expanded uncertainty of 5×10^{-8} ($k = 2$).

There have been a number of Josephson voltage standard (JVS) interlaboratory comparisons in the past that used a set of travelling Zener references. The uncertainties of these comparisons indicate the feasibility of this uncertainty level, which is mainly limited by the noise of Zener references and some environmental effects. Establishing a 10 V MAP at NIST based on Zener references will support JVS intercomparisons in the future and provide a backup voltage standard for the JVS systems.

It has been reported that Zener standards are subject to changes in their output values that are due to environmental temperature, barometric pressure, and relative humidity changes [1,2]. It has been also observed that several models of commercial Zener standards exhibit seasonal changes both in their 1.018 V and 10 V outputs. In the Zener MAP, a set of Zener standards is measured at NIST and then sent to a customer laboratory to be measured using the customer's system. After a specified number of measurements have been made, the travelling standards are then returned to NIST for further measurements. The traceability of the customer's standards to the U.S. representation of the SI volt then can be derived from an analysis of the NIST and customer data. Often, the environmental conditions at NIST and the customer's laboratory are different. Having no knowledge of the response of the travelling Zener standards to varying environmental conditions can result in a mis-estimation of the overall uncertainty of the MAP. The purpose of this work is to characterize a set of transportable Zener standards for voltage variations due to environmental effects and provide an accurate statistical model that will achieve the best uncertainty for this MAP procedure.

Complete characterization of Zener standard

Three environmental conditions, namely temperature, T, barometric pressure, p, and relative humidity, H, may have influence on a Zener's output. The Zener output can be expressed by

$$U(t,R,p,H) = U_0 + c_t t + f(R) + g(p) + h(H) + \varepsilon \quad (1)$$

where U_0 is the Zener value at an initial time, c_t is the drift rate of the Zener output with time, $f(R)$ is the correlation function with Zener thermistor value R for temperature effect, $g(p)$ and $h(H)$ are the correlation functions for barometric pressure and relative humidity, and ε is the intrinsic noise of the Zener standard. Once a Zener is characterized for $f(R)$, $g(p)$ and $h(H)$, Eq.(1) can be simplified as

$$U(t) = U_0 + c_t t + \varepsilon' \quad (2)$$

where ε' is the noise including all sources, and $U(t) \equiv U(t,R,p,H) - f(R) - g(p) - h(H)$, which is the Zener reference output corrected for environmental conditions and is independent of their influences. The uncertainty of the MAP is then determined by the intrinsic noise of the travelling Zener standards, the measurement systems at NIST and the customer's laboratory, errors in the correction factors, and the transfer factors of the Zener standards.

At NIST, a pressure chamber and a temperature / humidity chamber have been set up to characterize the three correlation functions $f(R)$, $f(p)$ and $f(H)$. A 10 V Josephson voltage standard (JVS) system is dedicated to measuring the Zener outputs under variable environmental conditions to avoid drift in the measurement system and further complication of the data analysis. It is assumed in a first order approximation that these three correlation functions are independent of each other. When one of the correlation functions is being measured, the other two environmental conditions are maintained as constants. Since the emphasis is to establish a 10 V Zener MAP, all of the measurements are made at the 10 V level.

The pressure chamber is a cylindrical vessel of 20 cm in diameter and made of Plexiglas. The chamber pressure is monitored by a digital barometer with an accuracy of $\pm$ 0.2 hPa and controlled by a mechanical pump with a gas handling system. The pressure stability inside the chamber during a Zener calibration can be maintained within $\pm$ 0.3 hPa. The temperature / humidity chamber has an approximate test volume of 1m x 1m x 1m. It can hold several Zener standards for testing, such as the Fluke 732B[**]. The temperature stability in the test chamber is $\pm$ 0.1 °C in the temperature range of this work. The relative humidity inside the chamber can be regulated from 10 % up to 98 % with a stability of $\pm$ 2.5 %. Table 1 lists the test ranges for pressure, temperature, and humidity that are used in characterizing the Zener standards. These measurement ranges were chosen by considering the environmental conditions of some metrology laboratories located at high altitudes with low barometric pressures, environmental conditions during the Zener transportation process, laboratory conditions in

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[**]Certain commercial equipment, instruments, or materials are identified in this report in order to facilitate understanding. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

tropical areas with high relative humidifies, and probable seasonal humidity.

Table 1 Environmental condition ranges in characterizing Zeners' correlation functions

	Pressure (hPa)	Temperature (°C)	Humidity (%)
Max.	1000	31.5	70
Min.	740	16.5	25

Results

We are reporting the results available to date at the writing of this paper.

1. Pressure correlation function, g(p)

Figure 1 shows a typical calibration result of a Zener standard. The measurements were made usually within 4 h, so that the Zener drift in the measurement period is negligible. We found the following results from the 17 Fluke 732B Zener standards that were tested. First, there is no noticeable hysteresis effect of a Zener output due to pressure changes Second, the pressure correlation can be fitted by a linear function as $g(p) = c_p (p - p_0)$, where p_0 is a reference pressure. Third, there are two groups of Zener standards with different responses to pressure changes. Most Fluke 732B Zener standards manufactured in recent years have pressure coefficients in the range between 10 nV/hPa and 20 nV/hPa with most being around 20 nV/hPa. Another group of Zener standards has pressure coefficients around –1 nV/hPa. These standards were manufactured in earlier years using different component.
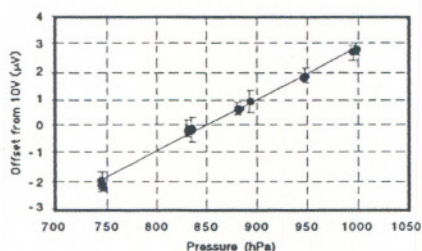

Figure 1. A typical Zener output vs. pressure. The data points "♦" were taken with pressure ramping downward, and data points "•" with pressure ramping upward. The error bar is one standard deviation of root-sum-square (RSS) value of the Type A uncertainty of the measurement and the Type B uncertainty of the JVS system.

2. Temperature correlation function, f(R)

In the following example, we describe a procedure to measure the temperature correlation function, f(R), with the thermistor resistance of the Zener standard as the variable instead of the environmental temperature. While f(R) is being measured, the humidity inside the chamber is maintained at a constant level, e.g. 50 %. The chamber temperature can be changed and reaches a stable state in 5 min. During a week of measurements, the chamber temperatures were adjusted in a sequence of 22.5, 27.5, 22.5, 31.4, 19.5, 22.5, 16.5 and 22.5 (°C). The temperature 22.5 °C was used as the base temperature to monitor the Zener drift in a relatively long duration measurement process. Every time the chamber temperature was changed, the Zener voltages were continuously measured against the JVS. Meanwhile, the thermistor changes were also recorded by a DVM. The time it took for a Zener thermistor to reach a stable state after a temperature change was approximate four hours. The Zener was measured for at least 6 h after attaining a stable state. Figure 2 shows the results of a Zener standard's measurements during this process. All of the data points shown were the Zener voltages, after the thermistor reached a stable state, corrected for pressure changes. The line shown in the figure was a least sum of squares (LSS) fit to the data taken at 22.5 °C. A mean difference between the measurements at another temperature and the predicted Zener value based on the LSS fit at the time of the measurements was then calculated. The temperature correlation

function f(R) can be determined from the mean differences described above and thermistor readings as shown in Fig. 3. For the four Zener standards we measured, f(R) can be expressed as a linear function $f(R) = c_R (R-R_0)$, where c_R is the temperature coefficient, R is the thermistor reading, and R_0 is the thermistor reading at a reference temperature. The temperature coefficients of the four Fluke 732Bs, that we measured, ranged from approximate 1.6 nV/Ω to 5.4 nV/Ω. The uncertainty of the coefficients ranged from 0.1 nV/Ω to 0.8 nV/Ω, and is mainly determined by the noise level of the Zeners.
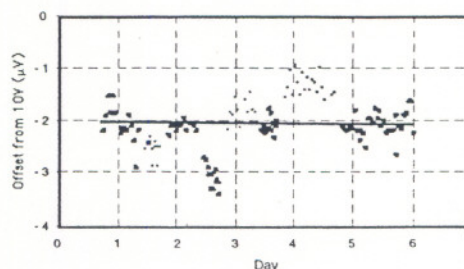

Figure 2. A process for measuring the temperature correlation function, f(R). Each cluster of the data indicates the Zener outputs at specified temperatures after the thermistor reaches a stable state.
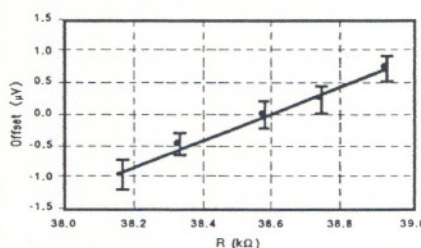

Figure 3. A linear LSS fit of thermistor reading vs. Zener offset from a reference point corresponding to the environmental temperature of 22.5 °C. The error bar is one standard deviation of data corresponding to the clusters in Figure 2.

3. Humidity correlation function, h(H)

The effect of humidity on a Zener standard has a very long time constant. We are now in the process of determining h(H).

Conclusion

We have characterized pressure and temperature coefficients for several Zener standards. The drift rate and noise characteristics of the Zener standards can be evaluated from the data collected from the measurements described above. The study of the humidity impact on Zener standards is still in progress at the time of this report. We expect to realize a set of fully characterized Zener standards to be used as travelling standards in a 10 V MAP that will have an improved uncertainty of 5 x 10^{-8} ($k = 2$).

Acknowledgement

References

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[2] Thomas J. Witt, "Pressure Coefficients of Some Zener Diode-Based Electronic Voltage Standards", IEEE Trans. Instrum. Meas., Vol.48, pp. 329-332, April 1999.