ZENER REFERENCE TRANSFERS BETWEEN 10-V JOSEPHSON ARRAY SYSTEMS

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Abstract

A multi-Zener reference standard was measured at seven metrology laboratories which operate 10-V Josephson array standard systems. Six laboratories agreed with the NIST-measured voltage to within 0.02 ppm, with typical random uncertainties of less than 0.015 ppm (1σ). One laboratory had a 0.11±0.012 ppm difference.

Introduction

From 1988 through 1991, the number of 10-V Josephson array systems used for calibrations in the U. S. has increased to nine [1]. The accuracy of these systems is potentially better than 0.01 ppm, but this claim could not be verified via transfers of voltage standards [2], since Weston cells are sensitive to shipping and references based on a single Zener diode do not have enough redundancy [3]. Questions also arose about the many versions of the operating software of the arrays, especially in the earlier systems where the original programming was extensively modified by operators in the field.

Over the same time span, a new generation of multi-Zener voltage references has been introduced by several manufacturers. The advantage claimed for these new standards was greater stability, both from improved Zener devices and also from the benefits of incorporating four Zener diodes per box. The claims of both systems were put to the test with the transfer of one of these new Zener references to all the labs operating a 10-V array system at the time.

Volt Transfer Procedure

The volt transfer test was conducted under the procedures of a Measurement Assurance Program (MAP). In this case, these procedures called for the transfer of a Zener reference with a well characterized, highly linear drift rate. Each laboratory measured all four 10-V outputs and the averaging output directly against their Josephson array voltage standard. All transfers were blind; no laboratory had knowledge of the voltage level or drift characteristics. The Zener reference was measured under normal local procedures. The daily room temperature and relative humidity were also recorded. The participants included Lockheed Air and Space, Inc., John Fluke Mfg. Co., Hewlett-

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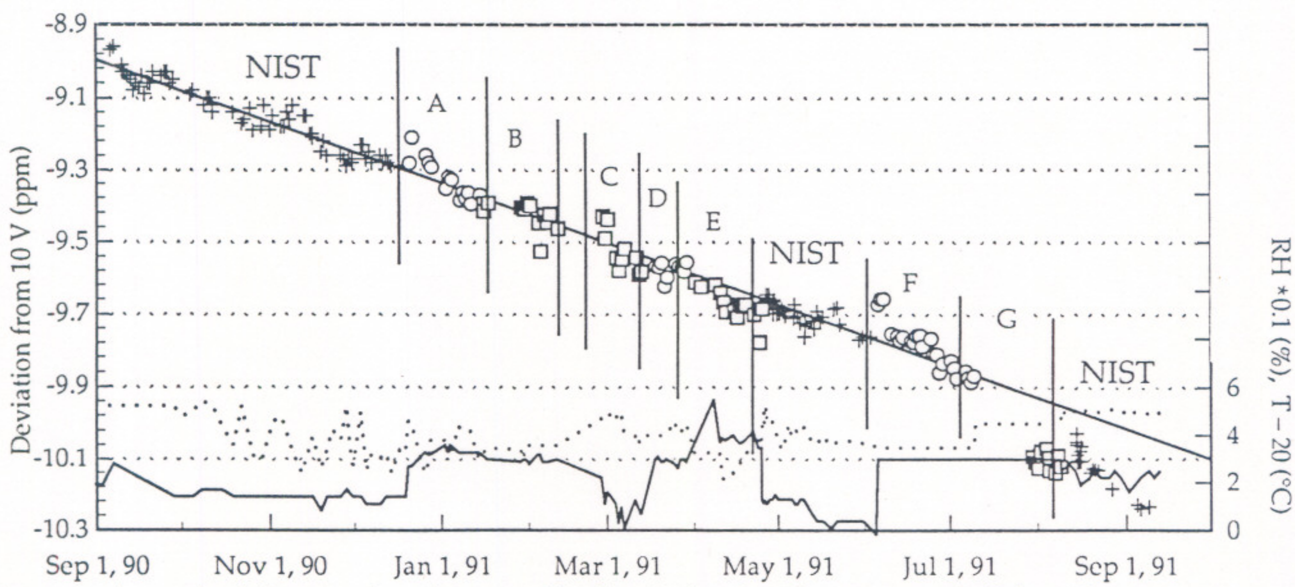

Figure 1. A graph of the complete data set. The line is fitted to the average of all four Zener outputs, using the first two sets of NIST data. The increasing discrepancy of the later data is from the change in drift of one Zener output. Ambient temperature (solid line) and relative humidity (dotted) are plotted along the bottom.

Table 1. The results of the volt transfer, presented as the difference from the NIST data line. Standard deviations are 1σ random.

Test Lab	4 Avg (ppm)	3 Avg (ppm)	St. Dev. (ppm)	SD of mean (ppm)
A	**0.015**	0.056	0.049	0.013
B	**-0.006**	-0.004	0.033	0.009
C	**-0.017**	-0.051	0.034	0.011
D	**-0.010**	-0.016	0.035	0.011
E	-0.043	**-0.019**	0.025	0.007
NIST	-0.013	**0.006**	0.029	0.004
F	0.041	**-0.003**	0.030	0.006
G	-0.151	**-0.113**	0.037	0.012

Packard Loveland Instruments Div., Sandia National Laboratory, Army TMDE Redstone Arsenal, Navy Primary Standards Laboratory-West, and Navy Gauge and Standards Dept.

Prior to this test, the Zener reference was measured over a period of 3.5 months at NIST. This data established that the drift rate of the average of all four outputs was very linear. Thus it was originally decided that the numerical average of the four channels would be the best gauge of the accuracy of the transfer, while recognizing that shifts of the reference or array offsets could be indistinguishable.

Results

We argue here that this volt MAP succeeded in proving some of the claims of both array and Zener reference proponents, but it was not without problems. The measurement results can be seen graphically in Figure 1. The line in the graph is fitted to the first and second sets of NIST data. The Zener reference originally displayed excellent shipping reliability, since there does not seem to be any obvious correlation between the noise and changes in the environmental conditions. The difference between the line and the daily points from each laboratory are averaged for the summarized results in Table 1. The "4 Avg" values in the table take all four Zener outputs into account. The second set of NIST data is included to show that the daily scatter was similar for all locations and systems.

Although the transfer results were initially very good, they did begin to diverge. It may be that the assumption of linear drift was not valid over the course of the year for this particular reference. Also, and unfortunately, the Zener reference twice exhibited a low battery signal for one of the output channels. The battery was changed during transfer E and again during transfer G. When examined after its final return to NIST, that questionable channel was definitely drifting uncharacteristically. To compensate, a second analysis for the later half of the data was tried, as shown in Figure 2. This data combines only three outputs, eliminating the questionable one. The alternate analysis did slightly affect the earlier data. The "3 Avg" column in Table 1 summarizes these results, which indicate much better agreement for the later transfers , except for transfer G. This unexpectedly large offset is not yet understood and warrants future investigation.

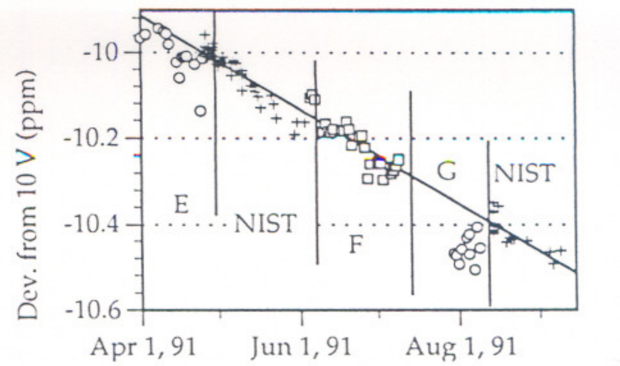

Figure 2. An expanded graph, showing the most recent data. The line is fitted to the average of the three best output channels, using these two sets of NIST data.

Conclusions

Interestingly, there were surprising values from some of the array systems, including two separate labs that reported initial measurements that were in error by 15 ppm, with a random uncertainty of 0.005 ppm! These were easily identified as incorrect step number determinations, but proved that high precision can cause overconfidence in array operation. Overall, the results indicate that Zener references have the potential for improving the uncertainty of volt transfers by at least a factor of five. There were problems with the reference, but the redundancy allowed an alternate analysis. Discounting a series of extraordinary coincidences of array errors compensating Zener reference shifts, the results show that all but one of the Josephson array systems are arguably as accurate as the national volt representation at NIST, to within an uncertainty of about 0.02 ppm.

References

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