Automatic calibration of inductive voltage dividers for the NASA Zeno experiment

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Two inductive voltage dividers (IVDs) used for temperature measurements in NASA's Zeno experiment were tested. In order to obtain the required resolution of 10 parts-per-billion, a 30-bit binary inductive voltage divider developed at the National Institute of Standards and Technology was used to measure the differential linearity of the Zeno IVDs. Automatic measurements were performed on the dividers in the Zeno engineering model at frequencies of 266 and 351 Hz over a ratio range of 0.55–0.56. The measured differential linearity limits the temperature resolution to 5 μK.

I. INTRODUCTION

The NASA Critical Fluid Light Scattering experiment (Zeno) will measure the properties of a sample of xenon near its critical point in microgravity.[1] The critical point is a special point on the thermodynamic surface of the pressure, temperature, and density where thermodynamic properties and transport coefficients all diverge. One way to find this point is to maintain a constant volume of a critical density sample and increment the temperature in small equidistant steps. The resolution of temperature measurements in similar experiments has approached a mK. For thermometry and temperature control in Zeno, a 10-ppb resolution ac bridge was constructed at the University of Maryland. This bridge uses decade inductive voltage dividers (IVDs) to obtain the needed linearity to achieve μK temperature control.

There are two programmable IVDs in the Zeno bridge: an eight-decade IVD used to set the operating point and a six-decade IVD used to measure temperature. Differential linearity on the order of 10 ppb is essential for the experiment, because Zeno will try to approach the critical point in 3-μK steps. A linearity error of 10 ppb will result in a temperature error of about 1 μK.

To measure the temperature, the Zeno bridge finds the ratio between a temperature sensing resistor and a fixed value resistor. It interpolates the 1-ppm steps of the six-decade IVD to a resolution of 30 ppb. The eight-decade IVD is used to divide the input signal with the resolution of 10 ppb around the point when the six-decade IVD is set. Since the resistors are the same nominal value the IVD ratios are around 0.5. The actual operating ratio range will be somewhere between 0.55 and 0.56. The bridge operates at the selected frequencies of 266 and 351 Hz for six- and eight-decade IVDs, respectively. Binary inductive voltage dividers have been used in other applications at NIST.[2,3] For this project a high-resolution 30-bit BIVD was developed to verify the linearity of the Zeno dividers. (A detailed description of the BIVD is given in Ref. 4.) This article presents the first application of an automatic bridge based on this BIVD.

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II. MEASUREMENTS

The test on the engineering model of the Zeno experiment was performed in June 1991. It had two phases: the first was to verify the linearity of the BIVD used as the standard IVD in the automatic bridge, and the second was to test the Zeno IVDs.

A. BIVD linearity test

To test the linearity of the BIVD, a one-decade divider (Gr10) was built. A commercial seven-decade IVD was connected between two taps of the Gr10 to obtain eight-decade resolution. In this way it is possible to set ratios between 0.5 and 0.6 with a resolution of 10 ppb. The simplified scheme of the circuit is shown in Fig. 1. Measured differences between the 30-bit BIVD and this limited eight-decade IVD are plotted in Fig. 2. The good agreement of 11 ppb is significant because the structures of decade and binary dividers are quite different and they would not be expected to track each other.

B. Measurement circuit

The automatic BIVD-based bridge used for Zeno calibration is described in Ref. 4. A simplified block diagram of the measurement circuit is shown in Fig. 3 and a brief description of its operation is given below.

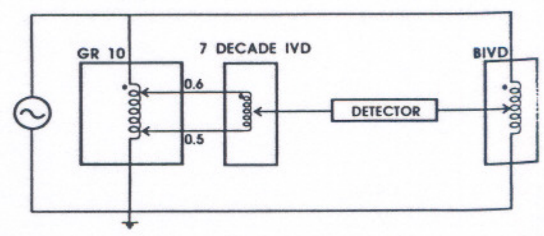

FIG. 1. Measurement circuit for the BIVD linearity test. Gr10 is a specially built IVD to cover the ratio range of 0.5–0.6. The seven-decade IVD is a commercial divider which, in combination with Gr10, provides a resolution of 10 ppb.

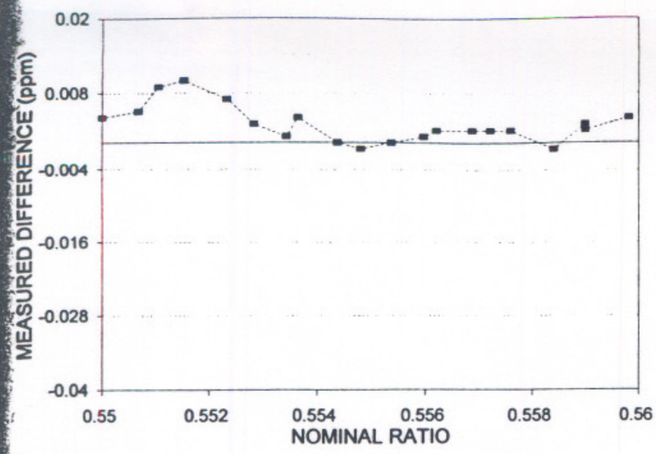

FIG. 2. Measured difference between the BIVD and the specially constructed decade IVD.

A voltage source produces two amplitude and phase adjustable signals. Channel A supplies the bridge drive voltage that is isolated through the isolation transformer. Channel B supplies a voltage used to balance the orthogonal component of the voltage difference between the outputs of the test and standard IVD (BIVD). The reference signal for the detector is a TTL output of channel A. The measurement point (the tap of the test IVD) is isolated from the detector through the detection transformer. This allows both the detector input and the tap of the test IVD to be grounded. The bridge is automatically controlled via the general purpose interface bus (GPIB).

C. Comparison procedure

The comparison procedure used in the test, first aligned the detector reference input with the IVD bridge input. The IVD under test was set to the ratio R_m, in the middle of the range of interest. The BIVD was set to the ratio 1.005 R_m. The phase of the detector reference was changed to obtain a maximum in-phase reading.

The next step in the procedure was to set both the IVD under test and the BIVD to the nominal ratio and measure the voltage difference between the taps. Since the objective is to perform a calibration at the 10-ppb level, the quadrature component (typically 3 ppm) was suppressed so that it was less than 0.7 ppm using the injection circuit. This gives adequate detector sensitivity to balance the bridge to better than 10 ppb. The channel B output was divided with the resistor pair R1 and R2 and the step down injection transformer, to obtain the appropriate voltage to balance the quadrature component. Also, an iterative procedure was applied to assure that the injection signal was orthogonal to IVD bridge input signal.

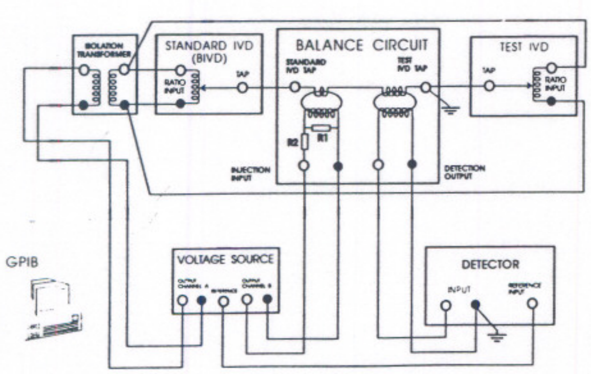

FIG. 3. Simplified scheme of the automatic BIVD bridge for the Zeno IVDs test.

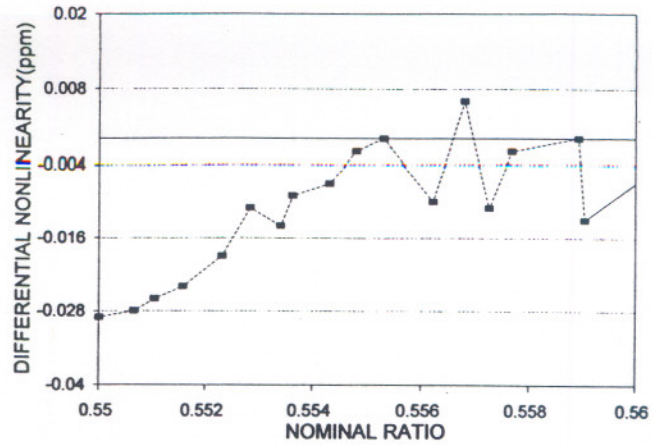

FIG. 4. Nonlinearity of the six-decade Zeno IVD as measured using the BIVD bridge.

Once the quadrature component was balanced, the BIVD ratio was changed to balance the in-phase component of the error. Knowing the bridge parameters and the voltage difference between the taps, ΔU, made it possible to predict the BIVD setting that would bring the bridge close to balance. After the BIVD was set to the predicted value, the residual difference ΔU_B was measured. The true IVD ratio R_t was related to the nominal ratio R_n by

$$R_t = R_n + c,$$

where $c = d + b$, $d = (\Delta U / U_{\text{in}})$, $b = (\Delta U_B / U_{\text{in}})$, ΔU is the voltage difference between the taps of the IVD under test and the BIVD when both dividers are set to the nominal ratio R_n, ΔU_B is the voltage difference between taps on the IVD under test set to the nominal ratio R_n, and the

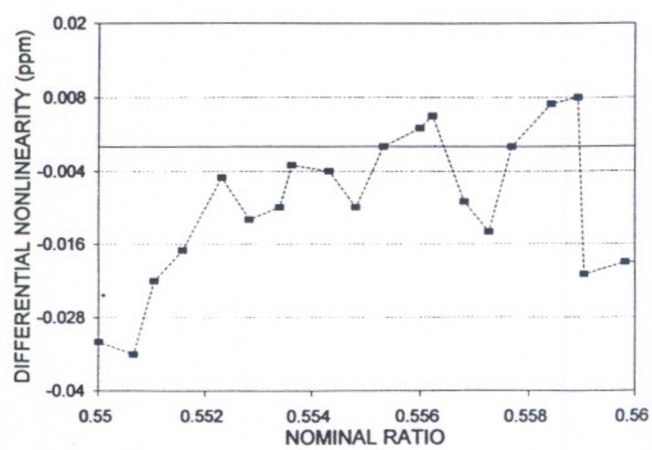

FIG. 5. Nonlinearity of the eight-decade Zeno IVD as measured using the BIVD bridge.

BIVD set to the ratio R_n+d, and U_{in} is the voltage applied to both dividers. For the Zeno tests differential nonlinearity was defined as the maximum deviation of c in the ratio range of 0.55 and 0.56.

III. RESULTS

The observed nonlinearities for the six- and eight-decade IVDs are plotted in Figs. 4 and 5, respectively. From these data, the differential nonlinearity is 35 ppb for the six-decade IVD and 42 ppb for the eight-decade IVD. Measurement uncertainty was 10 ppb. These tests show that the uncorrected nonlinearity of the dividers may limit the temperature resolution to 5 μK. After applying the corrections for the selected ratios, the Zeno experiment objective of 3 μK may be attainable.

ACKNOWLEDGMENTS

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