INDUCTIVE VOLTAGE DIVIDER CALIBRATION FOR A NASA FLIGHT EXPERIMENT

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Abstract: The inductive voltage dividers (IVDs) used in the thermostat of NASA's Zeno experiment were tested using an automatic IVD bridge developed at the National Institute of Standards and Technology (NIST). To achieve ±10 μK temperature control, the thermostat must be able to measure resistance ratios with a differential linearity of ±0.1 parts-per-million (ppm). The test results show that within a ratio range of 0.5 to 0.6 at frequencies between 200 Hz and 400 Hz, the thermostat IVDs were linear to ±0.07 ppm.

INTRODUCTION

Zeno is a critical fluid light scattering experiment in which photon correlation spectroscopy will be used to measure fluctuation decay rates on a sample of Xenon near its critical point in microgravity(1). The present status of temperature measurements in similar experiments approaches a resolution of 1 mK. Zeno will try to characterize the critical point, approaching it in 3μK steps. In order to achieve this goal, a 10 part-per-billion (ppb) resolution ac thermometry bridge was developed at the University of Maryland. The resolution of the Zeno bridge is based on the differential linearity of inductive voltage dividers used for the ratio measurents. A 3 μK step is equivalent to a ratio change of 30 ppb. To verify the linearity of the IVDs used in this bridge, a new automatic IVD bridge was developed at NIST(2).

The first test on the engineering model of the Zeno experiment was performed in June 1991. The results for a few selected test points showed satisfactory differential linearity and are given in reference 3. In October 1992 the second test was performed on the Zeno flight model. Results of this test are discussed in this paper.

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MEASUREMENT

A 30-bit Binary Inductive Voltage Divider (BIVD) developed at NIST was used to measure the differential linearity of the Zeno IVDs. The automatic IVD bridge used for this calibration is described in the reference 2. A simplified block diagram of the measurement circuit is shown in Fig.1.

A dual channel sine wave generator serves as the Voltage Source. This source produces two amplitude- and phase-adjustable signals. Channel A supplies the test voltage that is isolated through the Isolation Transformer. Channel B supplies a second voltage that is used to balance the voltage difference between the output of the Test and Standard IVD. The Reference output is a TTL signal that is in-phase with the Channel A signal and provides the reference signal for the detector. The detector is isolated from the measurement point (the tap of the test IVD) through the Balance Circuit. This allows both the detector input and the tap of the Test IVD to be grounded. The instrumentation in this bridge is controlled using the General Purpose Interface Bus (GPIB) .

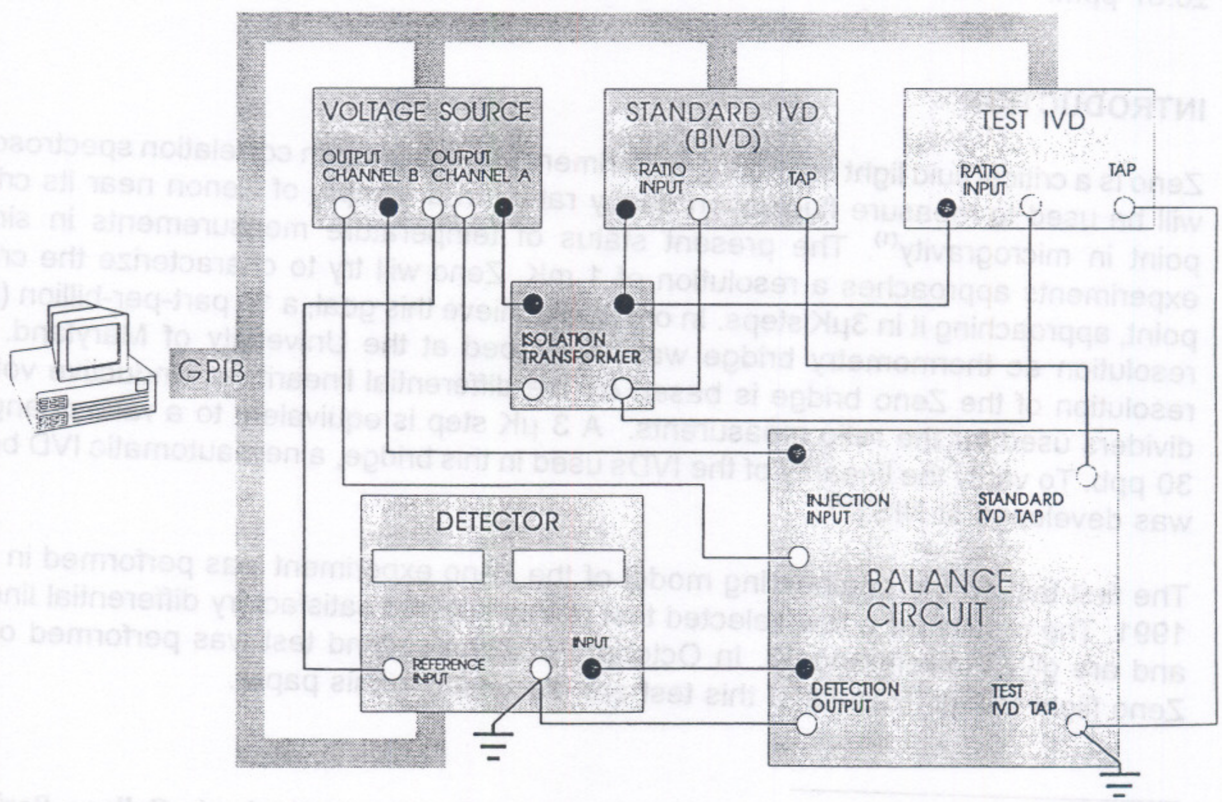

Figure 1. IVD calibration bridge.

The measurement procedure initially aligns the detector reference input with the IVD bridge input. Then both the BIVD and the Zeno IVD are set to the nominal ratio, R_n, and the voltage difference between their outputs is measured. From these two measurements the true ratio, R_t, is obtained.

Differential nonlinearity is defined as the maximum difference between the nominal ratio, R_n, and the true ratio, R_t, over the range of the ratios measured.

TEST RESULTS

The Zeno bridge measures the ratio between a temperature sensing resistor and a fixed value resistor. Both resistors have the same nominal values so that the ratios are around 0.5. Due to various influences, the actual operating ratio range for the Zeno IVDs is expected to be between 0.55 and 0.56.

There are two IVDs in the Zeno bridge: an 8-decade IVD used to set the operating point and a 6-decade IVD used to measure the temperature. Operating frequencies for the 8- and 6-decade IVDs are 351 Hz and 266 Hz, respectively.

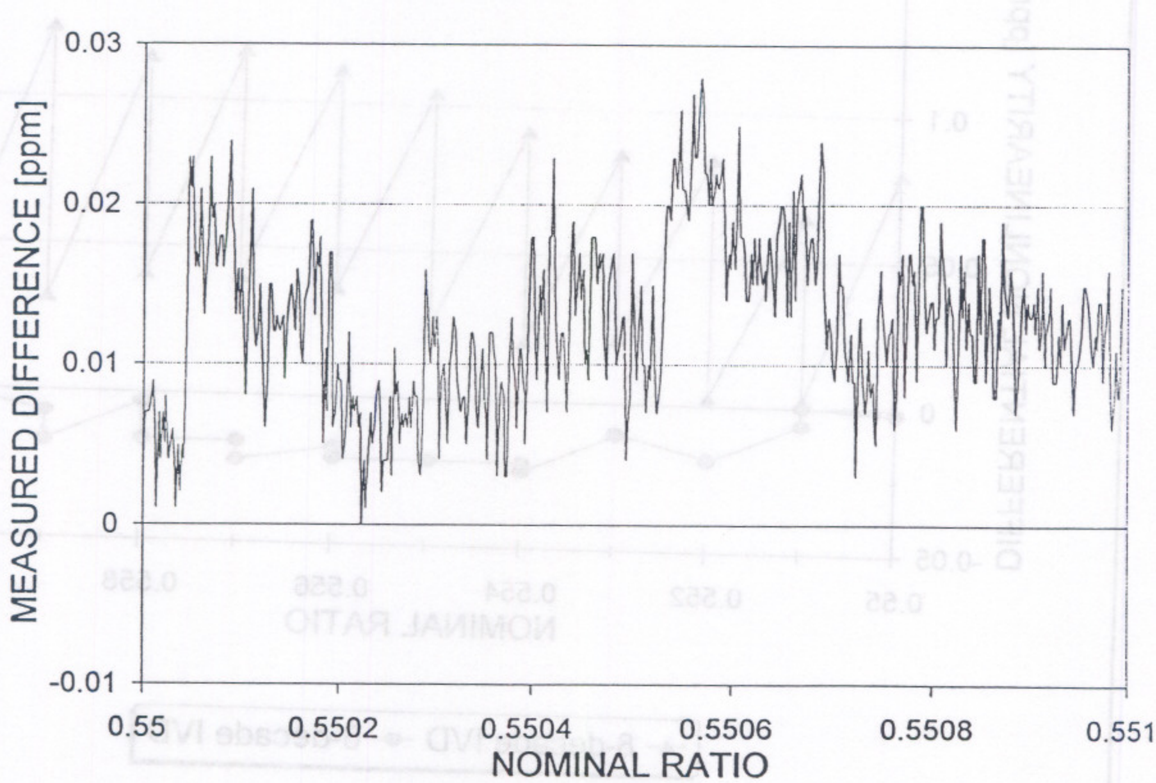

Figure 2. Measured difference between the BIVD and the 6-decade Zeno IVD.

To measure the temperature approaching, and at, the critical point, the Zeno procedure interpolates the 1 ppm steps of the 6-decade IVD to a resolution of 30 ppb. The differential linearity of the 6-decade IVD is crucial to the experiment, and a special test was performed to verify its linearity. Ratios between 0.55 and 0.551 were changed in increments of 2 ppm. The measured differences between the BIVD and the Zeno 6-decade IVD are plotted in Fig. 2. This data is further analyzed in the next part of the paper.

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. To get close to this point it is essential to approach in small equidistant steps. The 8-decade IVD can divide the input signal with the resolution of 10 ppb, so it can provide 100 fine steps around the point where the 6-decade IVD is set. Special attention is needed to characterize points where the largest deviations are expected, for example, when the ratio switches from 0.550 999 to 0.551 000 or from 0.5539 9999 to 0.5540 0000. In Fig. 3 the measured differences are plotted between the BIVD and the Zeno 8- and 6-decade IVDs for those specific points.

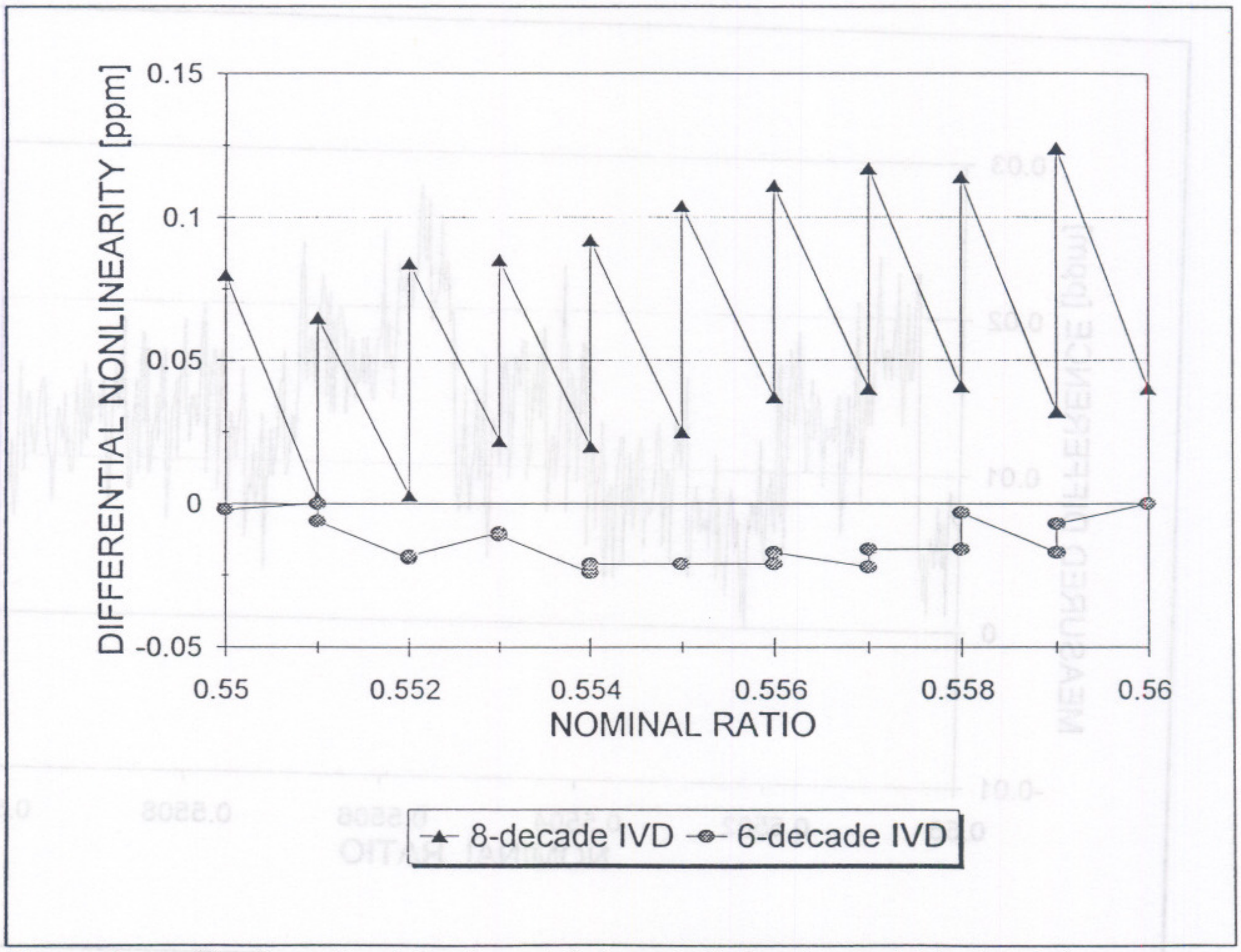

Figure 3. Nonlinearity of the 6- and 8-decade IVDs at special test points.

To establish more confidence about the behavior of the 8-decade IVD, 10 random nominal ratios in the range of interest were tested. A nonlinearity of ±65 ppb was observed. The data is plotted in Fig. 4.

To measure the repeatability of the collected data, 10 measurements were taken for one chosen ratio for both the 6- and 8-decade IVDs. The difference between the maximum and minimum reading is 6 ppb for the 8-decade IVD, and 4 ppb for the 6-decade IVD.

Based on tests that were performed on the 6- and 8-decade IVDs, differential nonlinearities are ±15 ppb and ±65 ppb, respectively. The measurement uncertainty was ±10 ppb for this specific ratio and frequency range.

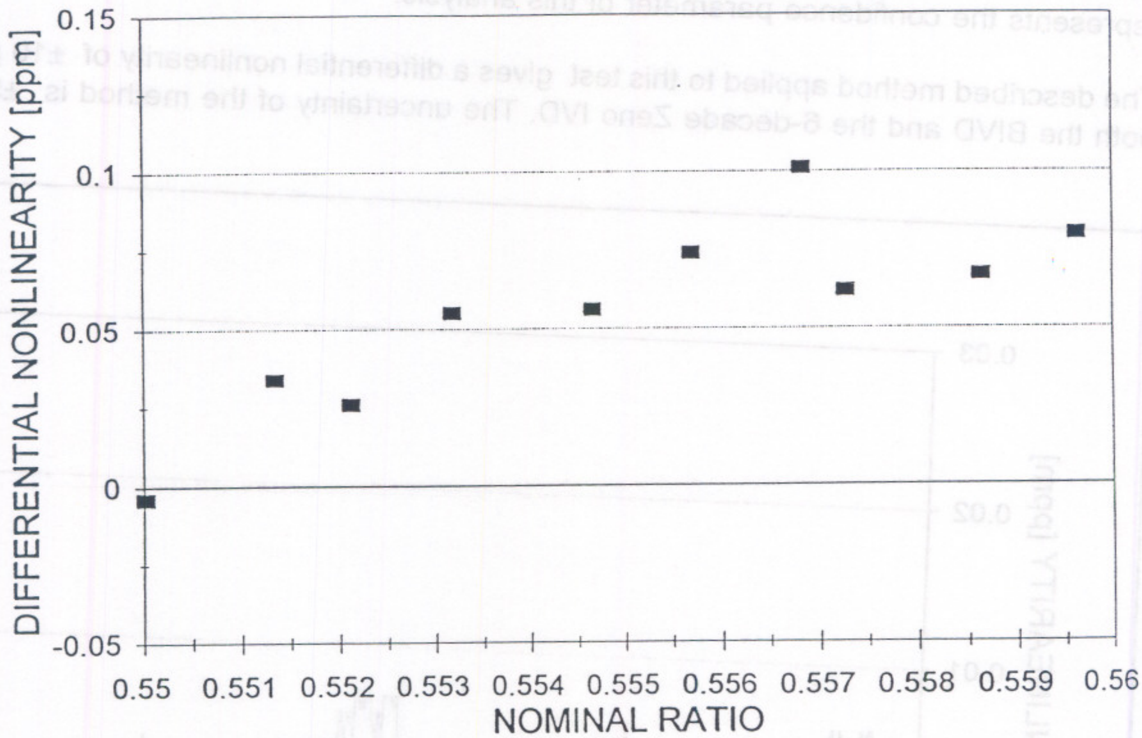

Figure 4. Nonlinearity of the 8-decade Zeno IVD at random points.

ERROR DECOMPOSITION

A data processing technique has been developed to extract the differential nonlinearities for both the BIVD and the Zeno 6-decade IVD from their differences.

Using a linear error model, it is possible to decompose any error pattern into a suitable set of basis functions[4]. In this test we have compared a decade structured device to a binary one. A model was developed that consists of decade and binary representations that are orthogonal. The representations reflect the actual construction of each device. The test data was then fit to the model using a mathematics software package. The errors associated with the binary model are plotted in Fig. 5.

The decade errors are ploted in Fig. 6. If the sum of these error components is subtracted from the actual measured error, the residual is obtained (see Fig. 7). The residual represents the confidence parameter of this analysis.

The described method applied to this test gives a differential nonlinearity of ±10 ppb for both the BIVD and the 6-decade Zeno IVD. The uncertainty of the method is ±5 ppb.

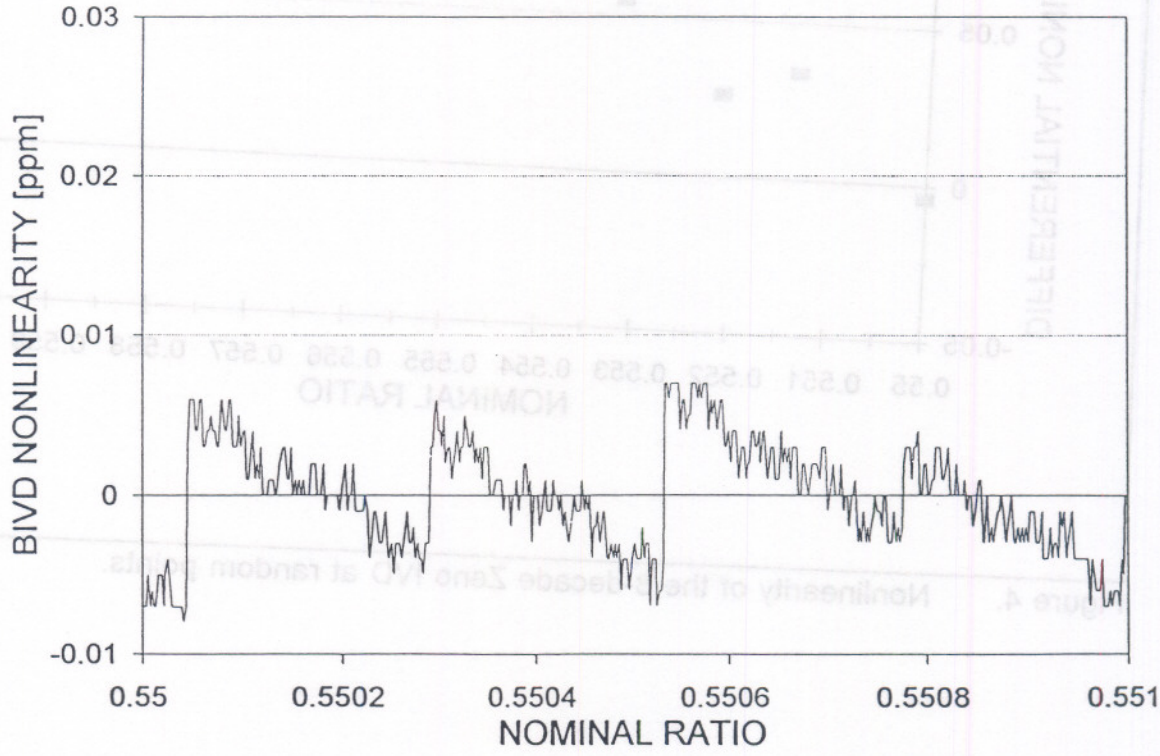

Figure 5. Nonlinearity of the BIVD between ratios of 0.550 and 0.551.

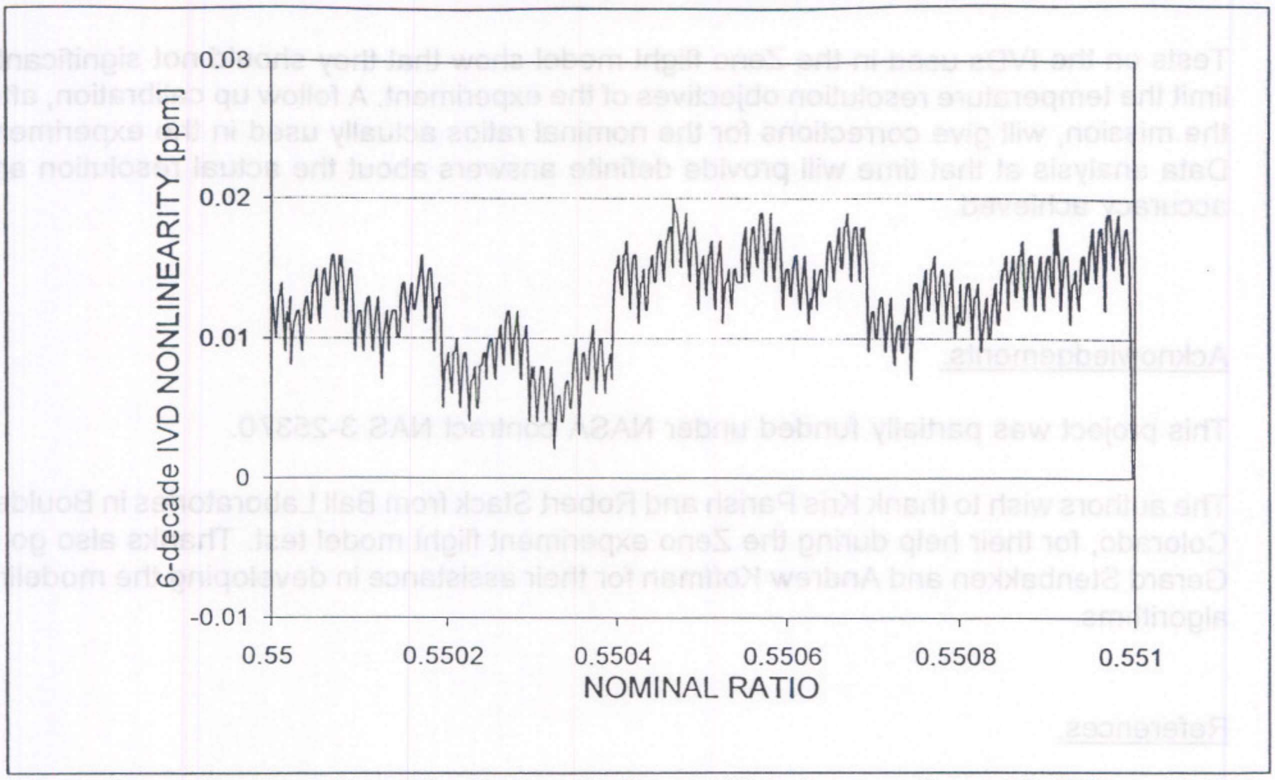

Figure 6. Nonlinearity of the 6-decade Zeno IVD between ratios of 0.550 and 0.551.

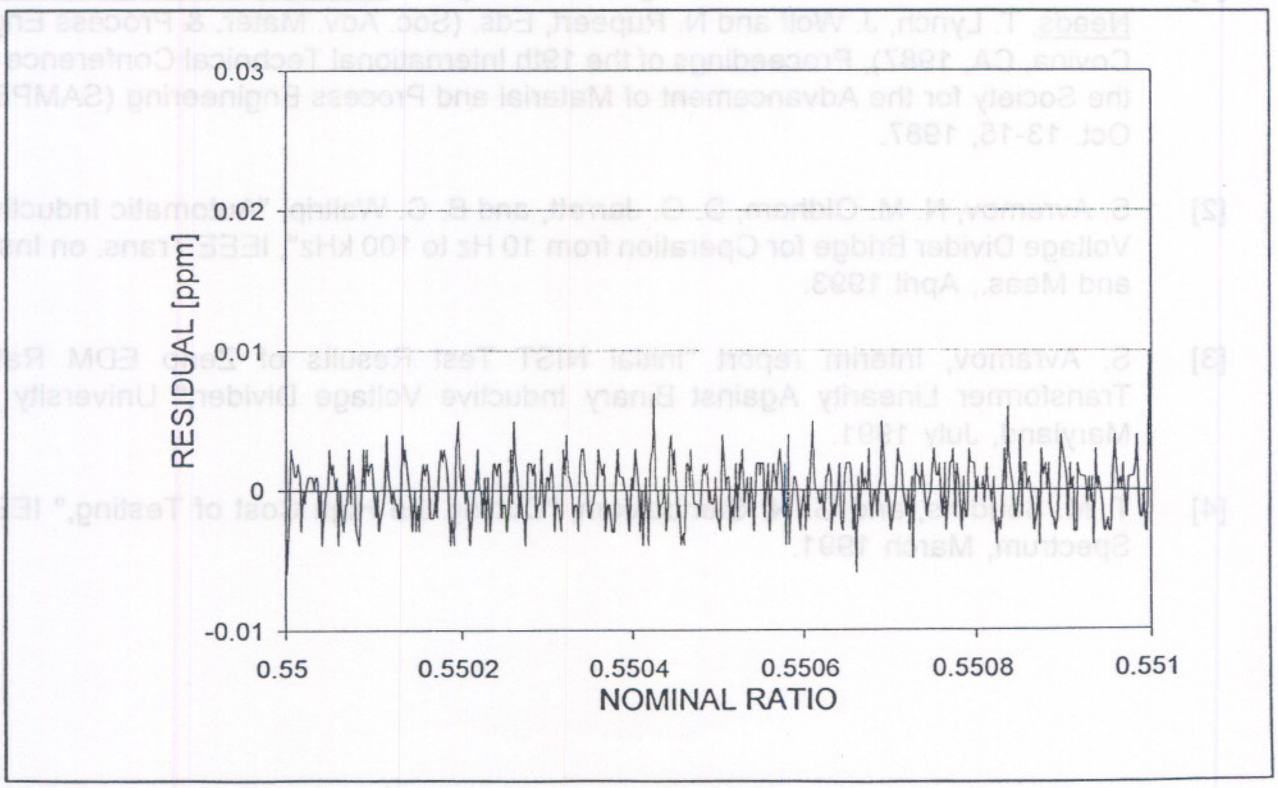

Figure 7. Linear model residual.

CONCLUSION

Tests on the IVDs used in the Zeno flight model show that they should not significantly limit the temperature resolution objectives of the experiment. A follow up calibration, after the mission, will give corrections for the nominal ratios actually used in the experiment. Data analysis at that time will provide definite answers about the actual resolution and accuracy achieved.

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