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The cover design depicts the microwave planar near-field scanner being developed at NPL.

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Experimental study of the noise properties of electronic voltage references

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1. Introduction

There is a gradual move away from the traditional Weston standard cell towards DC Zener diode-based electronic voltage references in many national laboratories as short-term transfer standards and in secondary standards laboratories as travelling standards. This is despite the fact that the electronic standards have long-term drifts and noise levels larger than the standard cells they are replacing. The advantages of electronic standards over standard cells are that they are less sensitive to temperature changes, mechanical shock and electrical trauma. They are also easier to handle and maintain, and are available with 10 V and 1 V outputs in addition to the more usual 1.018 V output available from standard cells.

Therefore, the performance of such solid state references has been extensively investigated over the last decade. Their voltage noise is one of the main contributions to the measurement uncertainty in the calibration of secondary voltage standards. The noise performance of Zener diode-based standard has been investigated in other laboratories through the measurement of their voltage output against Josephson array standards using a detector with a bandwidth of about 0.1 Hz [1],[2].

Zener diode-based standards use either conventional resistive dividers or, more rarely, time-based division to produce outputs around 1 V and 1.018 V with output impedances similar to that of standard cells (500 - 1000 Ω). The 10 V outputs of these devices have lower output impedance and are directly amplified from the Zener diode voltage. Thus the voltage noise of the 10 V output more closely represents the intrinsic device noise without the addition of Johnson noise from the divider circuit.

The level of noise voltage of the 10 V outputs of four different, and arbitrarily selected, commercial Zener diode-based standards has been measured and the noise power spectrum up to 5 Hz has been calculated for each standard. This paper will report the results obtained by comparing each standard with a low noise voltage source designed for this purpose based on a mercury cell.

2. The 10 V low noise voltage source

The 10 V low noise voltage source (LNVS) uses a mercury battery as a voltage reference.

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The battery has a nominal output voltage of 1.35 V and this is scaled to 10 V using an amplifier and a potential divider, as shown in figure 1. The input signal to the amplifier chain is the difference between the mercury cell voltage and the voltage across the 200 Ω in the potential divider. A negative feedback loop is completed by connecting the output of the amplifier chain to the high of the potential divider. The first stage in the amplifier chain is an EM A10 nanovolt amplifier with a gain of 1000. Its high input impedance prevents current drain from the mercury cell. The second stage is an inverting amplifier with a gain inversely proportional to frequency to ensure stability of the negative feedback loop.

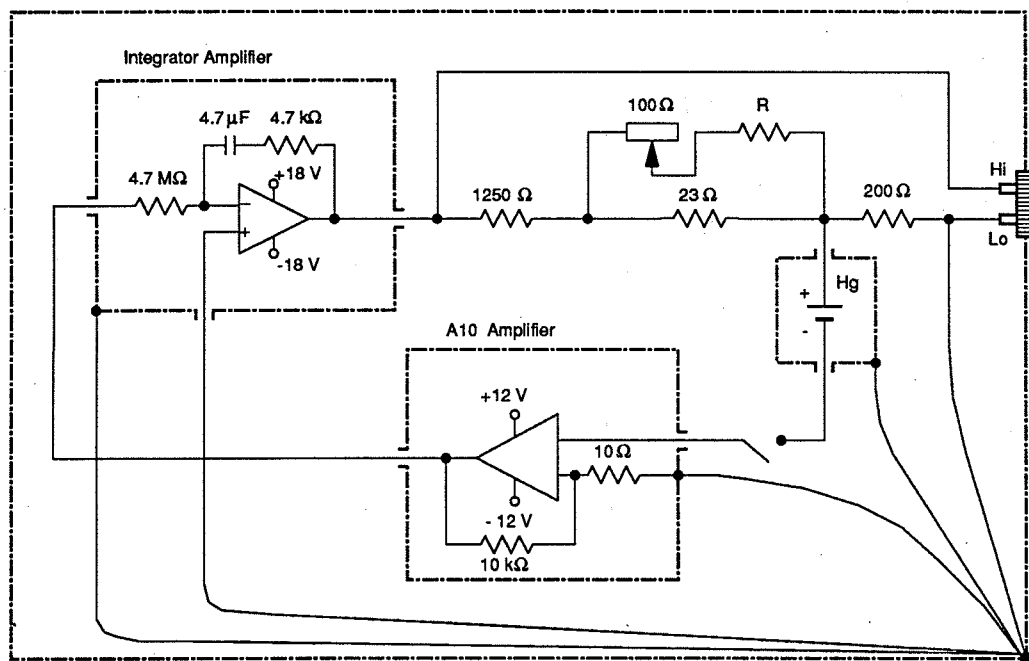


Figure 1 The 10 V DC low noise voltage source (LNVS) circuit based on a mercury cell. Dashed lines represent the enclosure boxes.

The nominal ratio of the potential divider is 10:1.35 and is adjusted by R and a 100 Ω potentiometer, to generate the required voltage at the 10 V level. The output impedance of the device is determined by that of the second amplifier stage and is therefore low. The noise of the output is dominated by the Johnson noise in the potential divider. The mercury cell is mounted in a small aluminium box insulated with polystyrene to reduce changes in the ambient temperature causing changes of cell voltage[3],[4]. The LNVS showed a short-term linear drift of less than 2.5 nV/min measured during 410 seconds after a warm-up period, which is in good agreement with [4].

3. Voltage noise measurement system and results

The measurement system used to measure the voltage noise of the four available DC Zener diode-based references is shown in figure 2. The EM A7 DC nanovolt amplifier is a low-noise amplifier used here with a gain of 10^5 . It has a time constant of 22 ms (with no filter selected) giving an approximate calculated bandwidth of 7 Hz. A DVM connected to the output of the amplifier records the voltage difference between the LNVS and the 10 V output

of the Zener diode-based reference under test. A sample rate of 10 readings per second is used, giving a measurement bandwidth, without aliasing errors, of 5 Hz. Three sets of 4096 readings (3 observations of 410 seconds duration each) were recorded from each reference. The total measurement time of 410 seconds in each observation gives a minimum frequency being measured of 0.003 Hz.

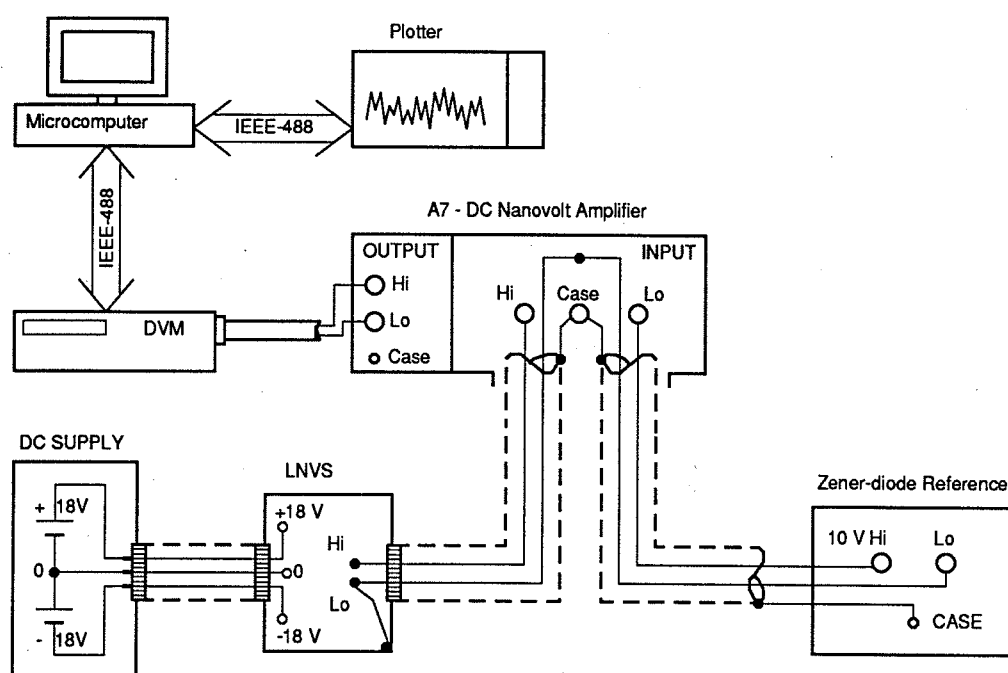


Figure 2 Schematic diagram of the system used to measure the voltage noise of Zener diode-based references. Dashed lines represent the cable screen.

Preliminary measurements were made to test the circuit noise performance including the LNVS and detectors. For this purpose the cell in the LNVS was replaced by a short circuit giving an output of zero volts. The voltage noise of the Zener diode-based references was measured with each unit powered by battery allowing adequate warm-up time where the unit operates only on battery power. The raw data was processed to remove linear drift which could result from temperature effects in the external circuit. The ASYSTANT™ data analysis software package was used to generate power spectra from the data (squared magnitude of the fast Fourier transform) for each reference.

Table 1 summarises the results for the LNVS and the four references, called A, B, C and D, and quotes, in column 2, the manufacturers' noise specification for each commercial reference for comparison. Column 3 gives an average RMS voltage noise for the five references. Using the superposition principle for independent random noise sources, the effect of the LNVS removed from the measurements on the other four. Therefore column 4 gives an adjusted RMS voltage noise for the four commercial references. Columns 5 and 6 give calculated results from the power spectra for the references. Column 5 is the noise power generated by each reference over the measurement bandwidth, related to the noise power generated by the LNVS. Column 6 gives a frequency below which 90% of the noise power measured in the 0.003 to 5 Hz band occurs and therefore gives some indication of the noise power bandwidth (usually defined at 50% level) for each reference.

Table 1 Summary of results for Zener diode-based references

Voltage reference	Manufacturers' noise specification	RMS noise 7 Hz bandwidth μV	RMS noise without LNVS μV	Relative noise power 0.003 to 5 Hz	90% frequency Hz
LNVS		0.06		1.0	0.59
A	0.1 to 10 Hz $\leq 1 \mu\text{V}$ RMS	0.16	0.15	6.4	0.94
B	0.01 to 10 Hz $1 \mu\text{V}$ peak max	0.24	0.23	14.6	0.39
C	$8 \mu\text{V}$ peak to peak	0.27	0.26	18.6	0.18
D	0.01 to 2 Hz $0.2 \mu\text{V}$	0.15	0.14	6.0	0.74

4. Conclusions

It is clear from the results that the LNVS designed for this work had sufficiently low noise for examination of the commercial references. However, its design was as a short-term source where linear drift could be tolerated and later removed mathematically from the data. Thus its purpose is different from the commercial Zener diode-based references.

It is interesting to observe the variation in the ways in which manufacturers' quote the noise performance of their references. The specifications in the table do not make it clear which reference would be expected to give the best performance, although, as far as it is possible to tell, all the references do meet their specifications. The results indicate that references A and D show similar voltage noise levels and are significantly better than references B and C. This conclusion is supported by longer-term experience of these references.

It must be noted that the study reported here is not considered to be an exhaustive study of all the available commercial references.

5. References

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