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PRECISION DC VOLTAGE REFERENCE

Metrology Laboratory Report

G. E. Kater, Project Leader

Project Team:
D. D. Kort

Published February 1978

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PRECISION DC VOLTAGE REFERENCE

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A precision dc voltage reference has been constructed to serve as a driver for a regulated direct current source used in the calibration of ammeters, resistors, and shunts. Two ranges of voltages are generated: 0 to 0.16 V and 0 to 1.6 V. The resolution is 0.625 ppm of full scale, and the estimated output uncertainty is ± 50 ppm of the setting or $\pm 10 \mu\text{V}$, whichever is greater. The voltage reference has improved measurement accuracy, and it is easy to operate.

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CONTENTS

Section	Page
SUMMARY.	5
DISCUSSION	6
SCOPE AND PURPOSE.	6
PRIOR WORK	6
ACTIVITY	6
<u>Description.</u>	6
<u>Test Results</u>	10
ACCOMPLISHMENTS.	10
FUTURE WORK.	12
REFERENCES	17
DISTRIBUTION	18

ILLUSTRATIONS

Figure		Page
1	Schematic of Precision DC Voltage Reference. .	8
2	Precision DC Voltage Reference Mounted Above the Regulated Direct Current Supply (P-96635).	9
3	Bottom View of Precision DC Voltage Reference Chassis With Cover Removed (P-96636)	11
4	Precision DC Voltage Reference Showing Holes in Top Cover of Chassis Enclosed to Increase Thermal Stability (P-96637).	12

TABLES

Number		Page
1	Voltage-Reference Output Measurements.	13
2	Current-Source Output Measurements	15

SUMMARY

A precision dc voltage reference has been constructed to serve as a driver for a regulated direct current source used in the calibration of ammeters, resistors, and shunts.

Variable output voltages are generated by dividing the output of a 10-V supply (CODI Semiconductor Inc. Model PVS10CA) to a nominal 0.16 and 1.6 V, selected by range switching. These voltages are applied to the input of a 320-k Ω , six-decade, Kelvin-Varley divider, the output of which is used to drive the regulated direct current source. Provision has been made for precision adjustment of the input voltages to the Kelvin-Varley divider.

The resolution of the output voltage is 0.625 ppm of full scale, with an estimated uncertainty of ± 50 ppm of the setting or ± 10 μ V, whichever is greater. The voltage reference is easy to use, and it has improved measurement accuracy.

DISCUSSION

SCOPE AND PURPOSE

A regulated direct current source is used to calibrate ammeters, resistors, and shunts. In these applications, it is required to generate precision currents ranging from less than 1 μA to 15 A. The generated currents are determined by the range-setting of and the driving-voltage input to the current source.

This project was initiated to develop and construct a highly reliable, variable, solid-state, precision dc voltage driver for the current source (replacing a commercially-available potentiometer) which would improve accuracy and stability, and which would be easy to operate. The following specific design goals were established:

- Floating output voltages in two ranges--from 0 to 0.16 V and from 0 to 1.6 V;
- Resolution of at least 10 ppm at a setting of one-tenth full scale; and
- Accuracy, including stability, of ± 50 ppm of setting or ± 10 μV , whichever is greater.

PRIOR WORK

A regulated direct current calibration source has been designed and constructed in the Bendix Kansas City Metrology Laboratory.¹ Output currents of this source are generated in six full-scale ranges from 0 to 150 μA and 15 A. The output currents within each range-setting are controlled by an external voltage reference of 0 to 1.5 V.

ACTIVITY

Description

The regulated direct current source which has been developed and constructed in the Bendix Kansas City Metrology Laboratory¹ is capable of generating constant-current outputs in the following ranges: 0 to 150 μA ; 0 to 1.5 mA; 0 to 15 mA; 0 to 150 mA; 0 to 1.5 A, and 0 to 15 A. Current outputs within each of these range-settings are determined by the driving-voltage input (0 to 1.5 V) to the current source. Until now, the driving voltage has been obtained from a somewhat difficult to operate potentiometer.

A schematic of the precision dc voltage reference which has been developed is shown in Figure 1. This voltage reference, shown in Figure 2 mounted in a cabinet with the regulated direct current source, consists of the following components:

- A 28-Vdc power supply (Acopian Model 28X10);²
- A precision 10-Vdc source (CODI Semiconductor Inc. Model PVS10CA);³
- A voltage-divider network to provide range switching and trimming capabilities; and
- A six-decade Kelvin-Varley divider.

Because variable voltages up to at least 1.5 V were required to drive the current source, the decision was made to step down some voltage greater than 1.5 V while, at the same time, providing a means for adjusting the required voltages to exact values. The CODI Semiconductor Model PVS10CA, with a manufacturer's rated output of 10 V $\pm$ 10 ppm, a stability of 7 ppm per month, and an output-current capacity of 10 mA, was chosen as the voltage source around which to build the voltage reference.

The output of the precision 10-V source is fed into a voltage-dropping, variable-resistance circuit which consists of a 100-k Ω , 40-turn potentiometer in parallel with a 100- Ω resistor, both in series with a 3.6- Ω resistor. This combination provides the capability for varying the input to the range-divider circuits (Point D in Figure 1) about a nominal voltage of 9.66666 V.

The range circuits consist of two voltage dividers in parallel. The X1-range circuit is a 6:1 divider that produces a nominal 1.611110-V input to the Kelvin-Varley divider, corresponding to the full-scale setting of the Kelvin-Varley divider. The X0.1-range circuit is a 60:1 divider that produces a nominal 0.1611110-V input to the Kelvin-Varley divider. Both circuits have provisions for trimming the output voltage to an exact value.

The Kelvin-Varley voltage divider that is used in the voltage reference was derived by modifying an ESI Model CA1408/1403 Kelvin-Varley divider. The modification consisted of adding four steps to the first dial to provide a total of 15 steps, and selecting or trimming resistors in the first-dial circuit to obtain a linearity error no greater than 10 ppm of the input. The total input impedance of the modified Kelvin-Varley divider is 320 k Ω .

The output of the Kelvin-Varley divider is used to drive the regulated direct current source. Because the control amplifier in the current source is in a potentiometric-feedback configuration, there is no appreciable loading of the Kelvin-Varley output.

Figure 1. Schematic of Precision DC Voltage Reference

Figure 2. Precision DC Voltage Reference Mounted Above the Regulated Direct Current Supply

As previously stated, the output of the regulated direct current source is from 0 to 15 A, in six ranges. At each range-setting, the output is driven full-scale by an input of 1.5 V. With a full-scale reading on the 150- μ A range, the X0.1 multiplier of the voltage reference is used to obtain the 0-to-15- μ A range.

Components of the dc voltage reference were mounted in a standard rack-type chassis supplied by the Zero Manufacturing Company (Figures 3 and 4). Some of the standard openings in the top and bottom covers and the side framework of the chassis were enclosed to increase the thermal stability of the unit (Figure 4).

Test Results

After fabrication had been completed, the dc voltage reference was turned on and allowed to stabilize for approximately 24 hours. Output voltages were measured and adjusted to nominal at settings of 1.000000 V on the X1 range and 0.1000000 V on the X0.1 range, using a Leeds and Northrup Model 7556 potentiometer. Approximately 24 hours later, measurements of the output voltage were made at various settings. The results that were obtained are shown in Table 1.

The dc voltage reference then was connected to the direct current source, and current outputs were measured at various settings by monitoring the voltage drop across precision standard resistors. Results of these tests are presented in Table 2.

The test results indicate that the design-goal maximum output-voltage deviation of ± 50 ppm of the setting or ± 10 μ V, whichever is greater, has been achieved. The output uncertainty of the system is now stated as ± 0.02 percent of the reading or ± 1 nA, whichever is greater. Results indicate that the current outputs are well within these limits.

Subsequent calibration of the system will consist of checking the current outputs, as shown in Table 2. Range adjustments of the voltage reference, if necessary, will be made at current outputs of 10 μ A for the X0.1 range and 10 mA for the X1 range.

ACCOMPLISHMENTS

A precision dc voltage reference which has been constructed to replace a commercially-available potentiometer as the driving voltage for a regulated direct current source provides the following advantages.

- Output voltages are available in two ranges: 0 to 0.16 V and 0 to 1.6 V.

Figure 3. Bottom View of Precision DC Voltage Reference Chassis
With Cover Removed

- The resolution is 10 ppm at a setting of one-tenth full scale.
- The accuracy, including stability, is ± 50 ppm of the setting or $\pm 10 \mu\text{V}$, whichever is greater.
- The precision dc voltage reference is much easier to operate.

Figure 4. Precision DC Voltage Reference Showing Holes in Top Cover of Chassis Enclosed to Increase Thermal Stability

Considerable insight has been gained into the resistance-measurement accuracy and the assembly techniques that are required to achieve the desired linearity in the Kelvin-Varley divider output.

FUTURE WORK

Future work will include further investigation of possible causes for the relatively large deviations in the output voltages and currents at low settings of the X0.1 range. The following areas will be examined:

Table 1. Voltage-Reference Output Measurements

Range	Reference Setting (V)	Measured Output (V)	Deviation 9	
			μV	PPM
X1	0.100000	0.0999994	-0.6	-6
	0.200000	0.2000005	+0.5	+3
	0.300000	0.3000009	+0.9	+3
	0.400000	0.4000008	+0.8	+2
	0.500000	0.5000009	+0.9	+2
	0.600000	0.6000005	+0.5	+1
	0.700000	0.7000006	+0.6	+1
	0.800000	0.8000012	+1.2	+2
	0.900000	0.9000007	+0.7	+1
	1.000000	1.0000010	+1.0	+1
	1.100000	1.1000018	+1.8	+2
	1.200000	1.2000010	+1.0	+1
	1.300000	1.3000009	+0.9	+1
	1.400000	1.4000006	+0.6	0
	1.500000	1.5000009	+0.9	+1
	0.011111	0.0111105	-0.5	-45
	0.022222	0.0222216	-0.4	-18
	0.033333	0.0333329	-0.1	-3
	0.044444	0.0444442	-0.2	-5
	0.055555	0.0555555	+0.5	+9
	0.066666	0.0666667	+0.7	+11
	0.077777	0.0777778	+0.8	+10
	0.088888	0.0888888	+0.8	+9
	0.099999	0.1000000	+1.0	+10
	0.0XXXXX	0.1111107	+0.7	+6
	0.09999X	0.1000004	+0.4	+4
	0.19999X	0.2000005	+0.5	+3
	0.29999X	0.3000019	+1.9	+6
	0.39999X	0.4000018	+1.8	+5

Table 1 Continued. Voltage-Reference Output Measurements

Range	Reference Setting (V)	Measured Output (V)	Deviation 9	
			μV	PPM
X1	0.49999X	0.5000019	+1.9	+4
	0.59999X	0.6000015	+1.5	+3
	0.69999X	0.7000016	+1.6	+2
	0.79999X	0.8000022	+2.2	+3
	0.89999X	0.9000017	+1.7	+2
	0.99999X	1.0000010	+1.0	+1
	1.09999X	1.1000018	+1.8	+2
	1.19999X	1.2000020	+2.0	+2
	1.29999X	1.3000019	+1.9	+1
	1.39999X	1.4000016	+1.6	+1
	1.49999X	1.5000019	+1.9	+1
	1.59999X	1.6000018	+1.8	+1
X0.1	0.09999X	0.01000050	+0.5	+50
	0.100000	0.00999950	-0.5	-50
	0.500000	0.05000002	+0.02	0
	0.99999X	0.10000136	+1.36	+14
	1.000000	0.10000045	+0.45	+5
	1.500000	0.14999999	-0.01	0
	1.5XXXXX	0.1611107	-0.3	-2

- Output error in the voltage reference at the zero setting;
- Output error in the current source at the zero setting; and
- Ground loops between the current source and the measuring equipment used.

Table 2. Current-Source Output Measurements

Voltage Reference Setting	Current Supply Range Setting	Measured Current Output	Deviation	Percent
0.09999X X0.1	0.15 mA	1.000099 μ A	+0.000099 μ A	+0.010
0.100000 X0.1	0.15 mA	1.000099 μ A	+0.000099 μ A	+0.010
0.500000 X0.1	0.15 mA	5.000059 μ A	+0.000059 μ A	+0.001
0.99999X X0.1	0.15 mA	10.000125 μ A	+0.000125 μ A	+0.001
1.000000 X0.1	0.15 mA	9.999985 μ A	-0.000015 μ A	0
1.500000 X0.1	0.15 mA	15.000389 μ A	+0.000389 μ A	+0.003
0.100000	0.15 mA	10.00072 μ A	+0.00072 μ A	+0.007
0.500000	0.15 mA	50.00109 μ A	+0.00109 μ A	+0.002
1.000000	0.15 mA	100.00170 μ A	+0.00170 μ A	+0.002
1.500000	0.15 mA	150.00299 μ A	+0.00299 μ A	+0.002
0.100000	1.5 mA	0.1000043 mA	+0.0000043 mA	+0.004
0.500000	1.5 mA	0.5000084 mA	+0.0000084 mA	+0.002
1.000000	1.5 mA	1.0000139 mA	+0.0000139 mA	+0.001
1.500000	1.5 mA	1.5000263 mA	+0.0000263 mA	+0.002
0.100000	15 mA	1.000009 mA	+0.000009 mA	+0.001
0.500000	15 mA	4.999992 mA	-0.000008 mA	0
1.000000	15 mA	9.999965 mA	-0.000035 mA	0
1.500000	15 mA	15.000015 mA	+0.000015 mA	0
0.100000	0.15 A	0.01000030 A	+0.00000030 A	+0.003
0.500000	0.15 A	0.05000194 A	+0.00000194 A	+0.004

Table 2 Continued. Current-Source Output Measurements

Voltage Reference Setting	Current Supply Range Setting	Measured Current Output	Deviation	Percent
1.000000	0.15 A	0.10000399 A	+0.00000399 A	+0.004
1.500000	0.15 A	0.15000673 A	+0.00000673 A	+0.004
0.100000	1.5 A	0.0999985 A	-0.0000015 A	-0.002
0.500000	1.5 A	0.4999909 A	-0.0000091 A	-0.002
1.000000	1.5 A	0.999983 A	-0.000017 A	-0.002
1.500000	1.5 A	1.499981 A	-0.000019 A	-0.001
0.100000	15 A	0.999943 A	-0.000057 A	-0.006
0.500000	15 A	4.999691 A	-0.000309 A	-0.006
1.000000	15 A	9.999665 A	-0.000335 A	-0.003
1.500000	15 A	14.999665 A	-0.000335 A	-0.002

REFERENCES

¹Deleted.

²*Operating and Instruction Manual, Regulated Power Supplies.* Easton, Pennsylvania: Acopian Corporation, 1969.

³*Specification Notes for PVS10G.* Fair Lawn, New Jersey: CODI Semiconductor Division of Computer Diode Corporation.

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