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An Improved Design of a Fully Automated Multiple Output Micropotentiometer

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Abstract

This paper describes in details a new design of a fully automated multiple output micropotentiometer (μpot). A prototype has been built at the National Institute for Standards (NIS), Egypt to establish this highly improved AC voltage source in the millivolt range. The new device offers three different outputs covering a wide frequency range from only one outlet. This valuably supports the precise sourcing ranges of low AC voltage at NIS. The design and the operation theory of this prototype have been discussed in details. An automatic calibration technique has been introduced through specially designed software using the LabVIEW program to enhance the calibration technique and to reduce the uncertainty contributions. Relative small AC-DC differences of our prototype in the three output ranges are fairly verified. The expanded uncertainties of the calibration results for the three output ranges have been faithfully estimated. However, further work is needed to achieve the optimum performance of this new device.

Keywords: Multiple Output μpot, AC-DC Transfer Standard, Single Junction Thermal Converter, Calibration, Uncertainty

1. Introduction

In recent years new types of AC instruments and high precision AC-DC voltage transfer devices for low voltages and high frequencies have been widely adopted in metrological and industrial laboratories. Therefore, new activities for developing systems operating at these levels have been undertaken [1,2].

The measurement of AC voltages and currents may involve several methods [3]. However, thermal converters are mostly used in national measurement institutes and other laboratories as the basis for deriving AC quantities (voltage, current, and power) referring to known DC quantities [4]. Normally, the measurement of AC quantities with thermal converters implies the transformation of the electrical energy into thermal energy by means of the Joule heat dissipated in the thermal converter heater resistor [5,6]. Evidently, these thermal converters are the most accurate AC-DC transfer standards for the transfer of alternating voltage and current to the equivalent DC quantities [7,8]. Commonly, there are two types of thermal converters: single-junction thermal converter (SJTC) and multi-junction thermal converter (MJTC) [6]. Although MJTCs in planar technique are used for voltages down to 100 mV [9], SJTC are mainly used as thermal current converters because they are simpler and easily available [8].

In national metrology institutes, the accurate AC instruments are mostly calibrated using micropotentiometers (μpots), which are basically voltage sources [10,11]. The μpots are developed for the generation of accurate low AC voltages at wide range of frequencies. In actual fact the SJTC μpots are still highly admitted specially those designed with thin-film radial resistors, because radial resistors so far ensure optimum frequency response [12].

As accurate calibration of low AC voltages presents several challenges, we implemented the design of a new simple versatile accurate multiple output μpot in order to enhance the capabilities of NIS by extending its precise output sourcing ranges of low AC voltage.

The traceability for the precision sourcing of AC voltages in the ranges of 10 mV, 25 mV, 50 mV, 100 mV, 200 mV, and 500 mV at frequencies from 10 Hz to 20

KHz had been derived at NIS from a set of SJTC μpots which had been previously fabricated and calibrated [13]. Nevertheless, each μpot of that set produces only one output AC voltage range.

In this work we aimed to build a fully automated prototype of a multiple range μpot offering three different output millivolt ranges from only one outlet through two disc resistors. These three output ranges are 300 mV, 400 mV, and the parallel resistances combination equivalent value (171.4 mV) at frequencies from 10 Hz to 10 KHz. Furthermore, the automatic calibrations of the new device, the AC-DC differences (δ), and the expanded uncertainties for the results had been fully investigated in this work.

2. Construction of the New Developed Multiple Output μPot

Figure 1 demonstrates the block diagram of the multiple output μpot which consists of a N type male coaxial input connector, an ultra high frequency (UHF) type SJTC with nominal rated current of 5 mA, and a microcontroller (AT89C2051). The microcontroller is used to control two mechanical relays through four-push button switches. The first switch actuates the PC to automatically control all the circuit, while the other three can be manually activated to change between two radial resistors with nominal values of 60Ω, and 80Ω. Each one of the two resistors consists of ten parallel equal resistors and is securely soldered into the output female N-type coaxial connector for producing the output voltage.

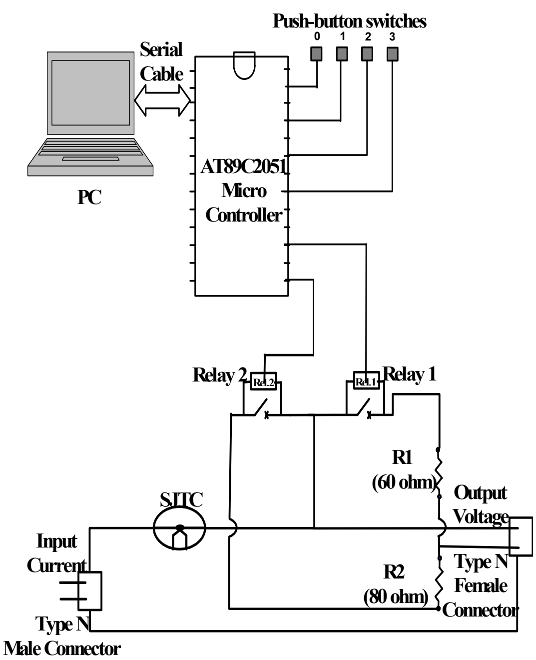

Figure 1. Block diagram of the multiple output μpot.

In this technique, each one of the two resistors can be easily chosen when the corresponding push button switch is pressed while; the third button introduces their parallel combination (34.29Ω) by activating the two relays at the same time.

The AT89C2051 microcontroller is a low voltage, high performance and powerful microcomputer which provides a highly flexible and cost effective solution to many embedded control applications. In addition, the AT89C205 microcontroller is designed with static logic (binary code) which is stored in the microcontroller ROM through a C-language program [14].

The μpot is normally designed to provide a precisely determined voltage at its output terminal when it is excited with an external source. The input current flows through the heater of the SJTC to the radial resistor and the voltage drop across the radial resistor induces a low-impedance source of AC voltage. The output voltage is nominally the product of the heater current and the resistance of the radial resistor [15].

The measurement principle of the SJTC is based on converting the electrical signal to a heat power [16]. In such a converter, energy dissipated by an AC current flowing through a heater resistor, raises its temperature above the ambient. It is then compared to an equal energy dissipated by a DC current flowing through the same heater. The increase in the temperature of the heater resistor by the rms of the AC signal and the equivalent DC signal is proportional to the dissipated energy and it is then measured using the thermocouple. A relative difference between the response of the converter to AC and DC inputs, called AC-DC transfer difference, is determined from these two measurements [17]. The AC-DC transfer difference is the main objective of the metrological characterization of each AC-DC standard [18].

In our adopted design, the normal radial resistors are replaced by two radial resistors producing three output values as explained before which gaining benefit of getting three output voltages of 300 mV, 400 mV, and 171.4 mV by a very simple circuit. In this design, more advanced variable resistors were used instead of the resistors used in the single range μpot. This type of resistors are called multi-turn presets resistor. It is mostly used where very precise adjustments must be made through its screw. Its screw is turned to give very fine adjustment control of the resistor required value. The multi-turn presets resistors are miniature versions of the standard variable resistor. They are designed to be mounted directly onto the circuit board and adjusted only when the circuit is built.

Moreover a new software using LabVIEW program is prepared to measure δ of the μpot and calculate the uncertainties of the results.

3. Setup of the Whole Automated System

In metrological and industrial laboratories, programmable instruments are now widely employed and increasingly included in measurement systems, because they can perform automatically the time consuming operations required in the calibration activity. Accordingly, there is an effective request for software able to calibrate such instruments [19]. However, building automatic systems for calibration is not straightforward, especially for application in metrological laboratories that operate at high level of accuracy. For this reason, a special programmable measurement system has been built.

As shown in **Figure 2** the automated calibration system of the multiple output µpot consists of a highly accurate (FLUKE 5720), programmable calibrator, used as a precise source for both alternating and direct currents, SJTC multiple output µpot with three output ranges, highly sensitive digital multimeter (DMM) with a very high input resistance (10 GΩ) and 10 nV DC resolution (HP 3458A) to measure the output emf of the multiple output µpot at each range of the three ranges. Moreover, the (HP 3458A) DMM implements a reasonable digital method for the measurement of DC and AC voltages [20]. Finally, a personal computer (PC) is used to drive the calibrator and to record the DMM readings by using the specially designed LabVIEW program.

All the necessary precautions were accomplished in order to attain the optimum performance of the measuring circuit. Technical considerations were also given to fulfill correct grounding connections in this type of measurement and to avoid any interference from high field strength [15,16].

4. Experimental Work

Throughout the experimental work, the DC and AC currents had been applied to the µpot. The DMM then precisely recorded the output emf of the µpot through a specific LabVIEW command. The software was controlled to send the gathering results to the computer to be saved in a prepared excel worksheet. Indeed, the selected current combined with the appropriate frequency for each range was software processed.

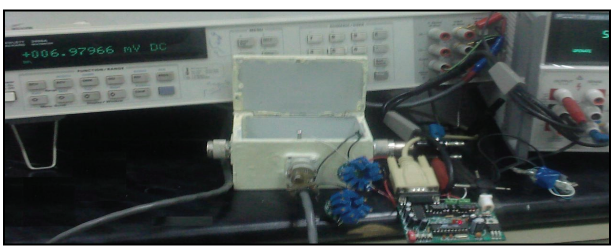

Figure 2. Automated system of the multiple output µpot.

The nominal current (5 mA) was applied to each range of the multiple output µpot in the sequence (AC, DC^+, DC^-, AC) at approximately equal time intervals to readily eliminate the DC reversal error [21].

Sufficient time had been allowed after each current change for the SJTC to reach its final emf value [22]. After completing these four steps, the AC-DC difference (δ) was evaluated at each frequency from the following relation [15]:

$$\delta = \frac{E_{AC} - E_{DC}}{n \cdot E_{DC}} \tag{1}$$

where, E_{AC} is the average output emf due to the AC current. While, E_{DC} is the mean emf value due to the forward (DC^+) and the reverse (DC^-) currents and n is a dimensionless characteristics [21]. In fact, n is a necessary factor in the equation due to the square law response of the thermal converters. It approximately equals "2" (≈ 1.6 to 2) at rated heater current [22].

At the beginning of the test the value of n must firstly be determined. It was measured using the change in the output emf, ΔE, when the nominal input current is varied by ΔI according to the following relation [23]:

$$n = \frac{\Delta E / E}{\Delta I / I} \tag{2}$$

where,

I, is the nominal rated DC current (5 mA).

E, is the output emf corresponding to the nominal rated DC current.

ΔE, is the change in the output emf due to small changes in the applied current, ΔI.

Noting that, ΔI, had been programmed to be ± 0.5 percent of the nominal rated current, and the final AC-DC difference resulted at each frequency was the average of 30 determinations of AC-DC difference under the same measurement conditions.

The determined values of δ at different frequencies were then added to the calibrated value of the applied DC current with 5 mA nominal value to calculate the actual values of the input AC current by using the following equation:

$$I_{ac} = I_{dc}(1+\delta) \tag{3}$$

Afterwards, by applying the actual values of the AC current the actual values of the AC output voltage of each range of the multiple output µpot at each frequency could be obtained.

Furthermore, to get convincing evidence that the multiple output µpot performs as expected, the uncertainty budget was thoroughly estimated. The uncertainty is defined as the range of error of a measurement within which the true value of the measurand is estimated to lie within a stated level of confidence [16]. Type A and Type B evaluations are the two approaches to estimate the uncertainty sources.

For AC-DC measurements, the Type B uncertainties are generally dominating [23]. Type A evaluations of standard uncertainty components are founded on normal distributions, while type B evaluations are founded on a suitable chosen distributions.

The combined standard uncertainty equals to the Root Sum Square (RSS), of all the uncertainty contributions [16,24]. All components of the combined standard uncertainty (Type A, Type B) were taken into consideration. The expanded uncertainties of the multiple output μpot were calculated with confidence level of 95% (coverage factor K = 2).

5. Results and Discussion

The results obtained at the rated current for *n* of each voltage range were 1.69, 1.72, and 1.73 for the 300 mV, the 400 mV and the 171.4 mV output AC voltage respectively. Also, the AC-DC differences for the three ranges of the μpot had been fully investigated. They are presented in **Table 1** and **Figure 3**. The plots illustrate the AC-DC differences of the 300 mV, 400 mV, and 171.4 mV ranges at frequencies from 10 Hz to 10 KHz in part per million (ppm).

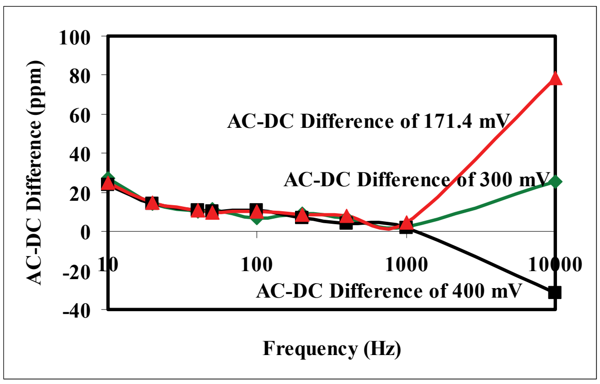

Figure 3. AC-DC difference of the 300 mV, 400 mV, 171.4 mV ranges (ppm).

It is cleared that, the AC-DC differences for the three output ranges of the multiple output μpot are fairly small at frequencies from 10 Hz to 10 KHz, as it is known that μpots can be used to generate AC voltage signals in millivolt ranges from 10 Hz to 1 MHz with AC-DC differences ranging from 20 ppm to 1000 ppm [25].

The gained results show that from 20 Hz to 1 KHz the multiple output μpot has a very stable output where the AC-DC differences are much smaller than the lower limit of the admitted AC-DC differences range.

Although, at 10 Hz and 10 KHz the AC-DC differences are relatively high, they are still very near to the lower limit. However, rather different but not highly effective behavior appeared at the 10 KHz for the 400 mV output where it shows a negative sign with its δ. This is most probably due to some dielectric losses inherent in the resistors.

Also, the δ of the 171.4 mV output at 10 KHz is relatively high due to factors contribute to frequency and voltage dependant errors. In fact this needs more careful investigation to reach the optimum design performance.

Nevertheless, the AC-DC differences of our developed multiple output μpot faithfully prove to be highly successful.

Tables 2-4 illustrate all the components of the uncertainty budget for the multiple output μpot three ranges respectively.

The AC input currents, and AC output voltages for the three voltage ranges at 10 Hz to 10 KHz combined with the corresponding expanded uncertainties are listed in **Tables 5-7**.

It is clearly shown from the tables that, the expanded uncertainties of the multiple output μpot proved to be less than 5 ppm for all values. This presents that the output voltages of the multiple output μpot are very satisfactory.

6. Conclusions

It is fairly demonstrated that our new design provides a

Table 1. Results of the AC-DC differences of the 300 mV, 400 mV, and 171.4 mV ranges at different frequencies.

Frequency (Hz)	δ (300 mV Range) (ppm)	δ (400 mV Range) (ppm)	δ (171.4 mV Range) (ppm)
10	27	24	25
20	14.2	14	14.6
40	10.2	11	11
50	11.3	10	9.7
100	6.6	11	10
200	9.3	7	8.8
400	6.8	4	7.8
1000	2.2	2	4.4
10000	25.6	–31.5	78.7

Table 2. Uncertainty budget of the 300 mV range calibration in (ppm).

Sources of Uncertainty	Type of Uncertainty	Uncertainty Value (ppm)	
Repeatability of o/p DC current	(Type A)	0.2	
U-Calibrator calibration certificate	(Type B)	1.3	
U-DMM calibration certificate	(Type B)	3.0	
U-Cables thermal emf	(Type B)	2.9	
Repeatability of δ	(Type A)	Freq. (Hz)	Value (ppm)
		10	0.4
		20	0.5
		40	0.5
		50	0.6
		100	0.6
		200	0.6
		400	0.6
		1000	0.6
		10000	0.5
Repeatability of AC Output Voltage	(Type A)	Freq. (Hz)	Value (ppm)
		10	2
		20	2.2
		40	1.2
		50	1.4
		100	1.3
		200	1.1
		400	1.2
		1000	1.4
		10000	0.8

Table 3. Uncertainty budget of the 400 mV range calibration in (ppm).

Sources of Uncertainty	Type of Uncertainty	Uncertainty Value (ppm)	
Repeatability of o/p DC current	(Type A)	0.2	
U-Calibrator calibration certificate	(Type B)	1.3	
U-DMM calibration certificate	(Type B)	3.0	
U-Cables thermal emf	(Type B)	2.9	
Repeatability of δ	(Type A)	Freq. (Hz)	Value (ppm)
		10	0.8
		20	0.4
		40	0.4
		50	0.5
		100	0.4
		200	0.3
		400	0.4
		1000	0.6
		10000	0.5
Repeatability of AC Output Voltage	(Type A)	Freq. (Hz)	Value (ppm)
		10	1.7
		20	1.4
		40	1.2
		50	1.6
		100	1.1
		200	0.6
		400	1.3
		1000	1.6
		10000	0.9

Table 4. Uncertainty budget of the 171.4 mV range calibration in (ppm).

Sources of Uncertainty	Type of Uncertainty	Uncertainty Value (ppm)	
Repeatability of o/p DC current	(Type A)	0.2	
U-Calibrator calibration certificate	(Type B)	1.3	
U-DMM calibration certificate	(Type B)	3.0	
U-Cables thermal emf	(Type B)	2.9	
Repeatability of δ	(Type A)	Freq. (Hz)	Value (ppm)
		10	0.8
		20	0.4
		40	0.4
		50	0.4
		100	0.4
		200	0.3
		400	0.4
		1000	0.4
		10000	0.7
Repeatability of AC Output Voltage	(Type A)	Freq. (Hz)	Value (ppm)
		10	0.9
		20	0.6
		40	0.6
		50	2.1
		100	0.6
		200	0.8
		400	0.9
		1000	0.5
		10000	0.4

Table 5. AC input currents and AC output voltages combined with the expanded uncertainties of the 300 mV µpot.

Freq. (Hz)	I_{AC} (mA)	V_{AC} (mV)	± Expanded Uncertainty (ppm)
10	5.0006822	299.85727	4.8
20	5.0003622	299.64441	4.9
40	5.0002622	299.85719	4.6
50	5.0002897	299.82553	4.6
100	5.0001722	299.85764	4.6
200	5.0002397	299.82329	4.5
400	5.0001772	299.81784	4.6
1000	5.0000622	299.81959	4.6
10000	5.0006472	299.87278	4.5

Table 6. AC input currents and AC output voltages combined with the expanded uncertainties of the 400 mV µpot.

Freq. (Hz)	I_{AC} (mA)	V_{AC} (mV)	± Expanded Uncertainty (ppm)
10	5.0006072	399.63049	4.8
20	5.0003572	399.79723	4.6
40	5.0002822	399.78593	4.6
50	5.0002572	399.78323	4.7
100	5.0002822	399.82343	4.5
200	5.0001822	399.78184	4.4
400	5.0001072	399.78409	4.6
1000	5.0000572	399.63214	4.7
10000	4.9992197	399.53989	4.5

Table 7. AC input currents and AC output voltages combined with the expanded uncertainties of the 171.4 mV μpot.

Freq. (Hz)	I_{AC} (mA)	V_{AC} (mV)	± Expanded Uncertainty (ppm)
10	5.0006322	171.38202	4.8
20	5.0003722	171.51913	4.6
40	5.0002822	171.58246	4.6
50	5.0002497	171.56305	4.7
100	5.0002572	171.58934	4.5
200	5.0002272	171.59201	4.4
400	5.0002022	171.56805	4.6
1000	5.0001172	171.56316	4.7
10000	5.0019747	171.61028	4.5

significantly stable AC voltage source in millivolt ranges. The combination of the microcontroller and the radial resistors with the SJTC offers three highly stable output AC voltages, 300 mV, 400 mV, and their parallel combination, 171.4 mV, from the same outlet. Experiments with the prototype indicate that its AC-DC differences for the three output AC voltage ranges are faithfully small.

In actual fact, it is expected that the adopted circuit will be a very good supplement or even may replace other commercial standards AC voltage sources due to its extreme simplicity, its very low cost and its excellent portability besides its admirable accuracy. In addition, this device is readily suitable for many other applications. However, further improvement can be achieved in the final product in the near future.

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