

CALIBRATION OF AC-DC VOLTAGE TRANSFER STANDARDS AT INMETRO

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Abstract: The aim of this work is to present the AC-DC transfer calibration system of Voltage and Current Laboratory (Latce) of Brazilian's Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro). Latce is responsible for the realizations of both the volt and the ampère in accordance to SI, and for its dissemination through the network of accredited laboratories in Brazil, so as to assure traceability of the national standards.

Key words: AC-DC, Inmetro, Latce, transfer, voltage.

1. INTRODUCTION

From the physical standpoint, two AC and DC functions are considered identical when dissipate identical power on a perfect resistor. In practice, however, such a resistor does not exist, and electrothermal devices are employed to compare, through indirect measurements of dissipated heat, an unknown electrical function to a reference standard.

The experimental technique of comparison of AC and DC functions is known as AC-DC transfer. The AC-DC transfer allows to overcome the inexistence of definition of time-dependent electrical quantities in terms of DC SI units, and it is the main foundation of AC metrology [1].

To assign the characteristics of an AC-DC transfer standard means to measure, with the smallest possible uncertainty, its non-Joule heat conversion errors, combined in what is conventioned to call transfer error, or AC-DC difference, denoted by the greek letter δ . The AC-DC difference is defined in such a way that $\delta > 0$ when more AC is required to dissipate the same RMS power that a DC reference signal [1,2].

From the metrological standpoint, therefore, two AC and DC functions are considered identical when, after corrected for the transfer error, dissipate heat with the same power on a standard. The power dissipated by Joule effect is measured through a thermal converter (TC). TCs may be applied to voltage (thermal voltage converter, or TVC) or current (thermal current converter, or TCC) measurements, through the proper application of voltage and current dividers to the circuit [1-3]. A TVC with defined AC-DC difference in a parameter space point (voltage and frequency) constitutes the AC-DC transfer standard to that RMS function.

2. TRACEABILITY

Seeking to develop a primary calibration system, Latce has recently acquired a set of planar multijunction thermal converters (PMJTC), and assembled the necessary set of resistors to build the standards and to stabilize the voltage scale from 200 mV to 1000 V [8,9].

Currently, Latce uses commercial electronic transfer standards Fluke model 792A [4,5], that operate from 2 mV to 1000 V and from 10 Hz to 1 MHz. One of the standards, assigned primary, has its AC-DC differences traced to Physikalisch Technische Bundesanstalt – Germany (PTB). Development of primary PMJTC voltage system shall bring traceability of the volt to Latce, and avoid the shipment of the electronic standards (which must then operate only as working standards) to foreign countries.

3. CALIBRATION OF TRANSFER STANDARDS

AC-DC difference is disseminated to our clients through the electronic standards as described in Ref [6]. This AC-DC transfer calibration is briefly discussed in the next paragraphs. Consider the basic scheme of Fig. 1, which refers to an AC-DC voltage transfer calibration.

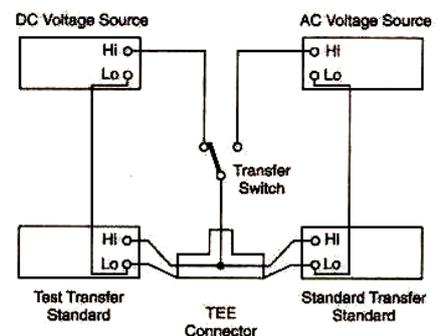


Fig. 1. Calibration of a voltage transfer standard. After Ref. [2]

The switch (Transfer Switch) alternates between the application of sine-alternating voltage (VA), direct DC voltage (VP) and reversed DC voltage (VM) to Test Transfer Standard (or just "test", for the sake of simplicity) and Standard Transfer Standard (or just "reference"), following the cycle sequence VA, VP, VA, VM, VA. After each switch (and proper stabilization times), the average readings EA, ED, UA, UD are registered from the test and reference standards outputs', where:

- 1- UA (alternatively, EA) is the average reading on the reference standard (test) when VA is applied to the circuit;
- 2- UD (alternatively, ED) is the average reading on the reference standard (test) when VP and VM are applied to the circuit

The AC-DC difference δ_i of each cycle is determined by:

$$\delta_i = \frac{\frac{UA}{UD} - 1 - \frac{EA}{ED} - 1}{\frac{NP}{NO} - \frac{EA}{ED} - 1} \quad (1)$$

where NO and NP are linearity coefficients of test and reference standards, respectively. A measurement is made of N repetitions of a cycle, and the measured AC-DC difference δ is finally determined by:

$$\delta = \delta_N + \delta_S + \delta_D + \delta_C + \delta_T \quad (2)$$

where δ_N is the average of the δ_i in N repeated cycles; δ_S is the AC-DC difference of the reference standard; δ_D is the contribution to δ due to the reference standard's drift; δ_C is the contribution to δ due to cabling and connectors; δ_T is the contribution to δ due to temperature fluctuations. Differences δ_D , δ_C e δ_T contribute only to the combined uncertainty, and $\delta_D = \delta_C = \delta_T = 0$.

According to the range and point to be calibrated, and after proper stabilization times, measurements of four to six cycles are performed to calculate δ . Four measurements are made to determine NP and NO at the beginning of each measurement.

The quantities NP, NO, δ_N , δ_D and δ_C (assigned respectively x_1 to x_5) contribute to the combined uncertainty with standard deviations. The quantities δ_S , δ_T , UA, UD, EA and ED (assigned respectively x_6 to x_{11}) contribute to the combined uncertainty with type B, rectangular-distributed, uncertainties. The quantities x_8 to x_{11} are not independent, but rather correlated through the correlation coefficients $r_{8,9}$ and $r_{10,11}$. The calculation of the combined uncertainty then proceeds as:

$$u_c^2(\delta) = \sum_i c_i^2 u(x_i)^2 + 2r_{8,9}c_8c_9u(x_8)u(x_9) + 2r_{10,11}c_{10}c_{11}u(x_{10})u(x_{11}) \quad (3)$$

where the c_i are sensitivity coefficients, calculated as described in Ref. [7].

Fig. 2 shows a frequency dispersion of AC-DC differences at 6 mV, on the 22 mV range of the standard. These are results from a calibration of one of our clients' transfers, made in april of 2009; frequency is denoted by the letter f , and is measured in hertz, and AC-DC differences are given in $\mu\text{V}/\text{V}$. The errorbars shown are expanded uncertainties; these are given in further detail in Table 1, which shows 18 different points on the 22 mV range, between 40 Hz and 1 MHz. The straight lines at $\delta = 0$ and $\delta = 100 \mu\text{V}/\text{V}$ are meant to aid the visual inspection.

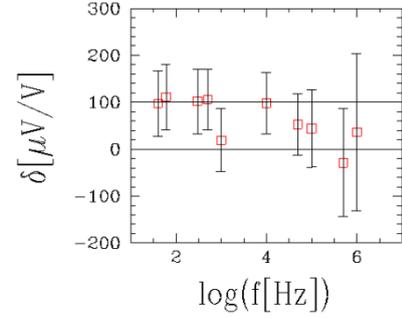


Fig. 2. Frequency dispersion of δ at 6 mV

The uncertainties reported in Table 1 are declared as standard uncertainties, multiplied by a coverage factor $k=2$, which, for a normal distribution, corresponds to a probability of approximately 95%. Fig 3 shows the uncertainty budget at 20 mV, on the 22 mV range of the standards, and Table 2 gives their precise figures.

Table 1. Uncertainties in the 22 mV range.

Range	Voltage	Expanded Uncertainties [$\mu\text{V}/\text{V}$]				
		40 [Hz]	300 [Hz]	1 [kHz]	50 [kHz]	1 [MHz]
22 mV	2 mV	96	94	92	90	204
	6 mV	70	69	67	65	167
	10 mV	60	60	55	51	151
	20 mV	43	43	43	47	137

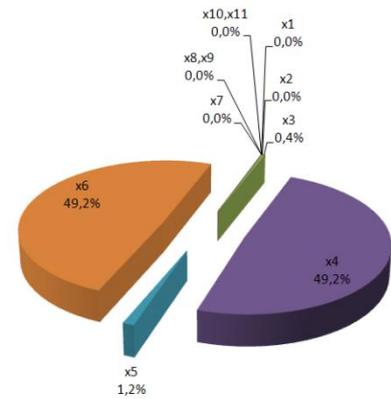


Fig. 3. Uncertainty budget at 20 mV and 300 Hz

The AC-DC differences in Fig. 2 show a dispersion profile that is consistent with the expected frequency

behaviour of such electronic standards [2,4], with differences smaller than 20 $\mu\text{V}/\text{V}$ at 1 kHz (and smaller than 200 $\mu\text{V}/\text{V}$ at 1 MHz), in an active range of the devices.

Table 2. Uncertainty budget at 20 mV and 300 Hz

Quantity [refer to text]	$u_i(\delta)$ [ppm]
x_1	0,43
x_2	0,04
x_3	1,34
x_4	15,00
x_5	2,31
x_6	15,00
x_7	0,29
x_8 and x_9	8,9E-06
x_{10} and x_{11}	1,3E-04
u_C	21,39

Fig. 4 shows a frequency dispersion of AC-DC differences at 2 mV, on the 22 mV range of the standard. These results are extracted from the same calibration service referred to above; frequency is denoted by the letter f , and is measured in hertz, and AC-DC differences are given in $\mu\text{V}/\text{V}$. The errorbars shown are expanded uncertainties; these are also given in in Table 1. The straight lines at $\delta = 0$ and $\delta = 100 \mu\text{V}/\text{V}$ are meant to support the visual inspection.

In Fig. 5, we show a sketch of the calibration system used in practice. This circuit has presented the most well-behaved AC-DC differences and the smallest uncertainties, compared to other few possible grounding and guarding configurations available. The tests performed on the AC-DC voltage transfer system at Inmetro are reported in Ref. [10]. In its simplest possible configuration, the measurement system is composed of two nanovoltmeters Keithley model 182A (DMM1 and DMM2), two electronic transfer standards Fluke model 792A (TVC1 and TVC2), one micropotentiometer Holt model 12 (HOLT) and one multifunction calibrator Fluke model 5720A (SRC). SRC operates as a voltage source in mode EXT GRD ON at all frequencies.

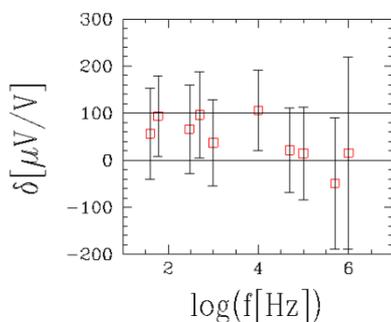


Fig. 4. Frequency dispersion of δ at 2 mV

The AC-DC differences in Figs. 2 and 4 show a dispersion profile that is consistent with the expected frequency behaviour of such electronic standards [2,4], with

differences smaller than 20 $\mu\text{V}/\text{V}$ at 6 mV and 1 kHz (approximately 200 $\mu\text{V}/\text{V}$ at 1 MHz) and smaller than 40 $\mu\text{V}/\text{V}$ at 2 mV and 1 kHz (smaller than 170 $\mu\text{V}/\text{V}$ at 1 MHz), in an active range of the devices.

4. CONCLUSION

In this work we have presented a brief description of the mathematical model and uncertainty budget for the calibration of AC-DC voltage transfer standards. This means to determine, through voltage measurements, the intrinsic error of Joule heat conversion on the test standard from voltage measurements in AC and DC regimes, performed simultaneously at the test and the reference standard, according to Fig. 1.

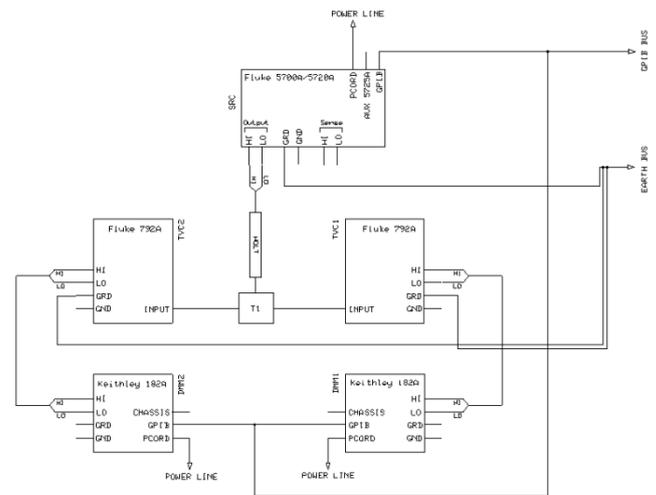


Fig. 5. Floating Lo circuit for AC-DC transfers at 22 mV range

Good results were obtained in all ranges of the test instrument, and some of the results for the active range were presented in both Figs. 2-4 and Table 1.

REFERÊNCIAS

- [1] Inglis, B. D., "Standards for AC-DC Transfer", Metrologia 29, pp. 191, 1992
- [2] Fluke Corp., "Calibration: Philosophy in Practice", Fluke Corp., 1994
- [3] Hermach, F.L., "Thermal Converters as AC-DC Transfer Standards for Current and Coltage Measurements at Audio Frequencies", J. Res. Nat. Bur. Std. 48, pp. 163, 1952
- [4] Fluke Corp., "Design and Evaluation of 792A AC-DC Transfer Standard", Fluke Application Note 1268781 A-ENG-N Rev. B, 2000
- [5] Fluke Corp., "792A Transfer Standard Instruction Manual", PN 871723 Rev. 1, 1990
- [6] Norma Inmetro Técnica NIT-Latce-001 Rev 07, 2010
- [7] Guide to the Expression of Uncertainty in Measurement, ISO, 1993
- [8] M. Klonz, H. Laiz, "New ac-dc transfer step-up calibration and uncertainty calculation in PTB and INTI", Precision Electromagnetic Measurements

Digest, 2000 Conference on 14-19 May 2000 pp. 490-491

- [9] R. Afonso Jr., G. Borghi, R. P. Landim, E. Afonso and F. A. Silveira, "O Sistema de Padronização Primária de Tensão AC do Inmetro", Proc. of VII Semetro, N 52010, June 2009
- [10] Silveira, F. A., "Minimização de Erros em Circuitos de Transferência AC-DC em Tensão", Proc. of IX Semetro, accepted for publishing and presentation, September 2011