Improvements in AC-DC voltage transfer at Inmetro

Gean Marcos Geronymo
Instituto Nacional de Metrologia, Qualidade e Tecnologia, Inmetro, Rio de Janeiro, Brazil
E-mail: gmgeronymo@inmetro.gov.br

Abstract. In this paper we present the development of a second set of thermal converters, coaxial resistors and micropotentiometers, used as standard for AC-DC voltage transfer. The new set was fully characterized for AC-DC voltage transfer by step-up and step-down procedures, starting from one PTB calibrated thermal converter. An internal comparison was made between this new set of standards and the main set of standards and the results obtained are consistent.

Keywords: AC-DC Transfer, Step-up, PMJTC.

1. Introduction
For many years Inmetro’s AC voltage standards, for the 2 mV to 1000 V voltage range, 10 Hz to 1 MHz frequency range, were based on a commercial ac-dc thermal transfer standard that was traceable to the SI through the Physikalisch-Technische Bundesanstalt (PTB), the NMI of Germany. The traceability costs and the high uncertainties associated with this system were the main motivation for developing a new system based on Planar Multijunction Thermal Converters (PMJTCs) [1], coaxial resistors and micropotentiometers (µpots) [2]. With this new system we only need to send a single standard for calibration, and build the whole voltage scale using this standard as the starting point (step-up and step-down procedures). The new system was validated with an international comparison between Inmetro and LNE, at 1.5 V and 1000 V [3]. For the low voltage range (2 mV to 200 mV) a micropotentiometer-based system was developed, using disc resistors [4] and commercial current shunts (discrete micropotentiometer) [5, 6].

Recently, we have built a second set of PMJTCs and coaxial resistors. Using this second set, we can do an independent step-up procedure to build the ac voltage scale from 1 V to 1000 V, and validate it by a direct comparison with the first set. We also built a new µpot, replacing the damaged thermal element of a commercial µpot with a 400 Ω PMJTC. With this µpot we can do an independent step-down procedure to build down the voltage scale from 200 mV to 2 mV, and compare the results obtained with our discrete µpot by calibrating a commercial thermal transfer standard (TTS) in the mV-range.

2. Calibration setup
The ac-dc voltage difference quantity is defined as

$$\delta_{ac-dc} = \frac{V_{ac} - V_{dc}}{V_{dc}} \bigg|_{U_{ac}=U_{dc}}$$

where $V_{ac}$ is the root mean square (RMS) value of the AC signal, $V_{dc}$ is the average of direct and reverse DC input, $U_{ac}$ is the output response to AC input and $U_{dc}$ is the output response to DC input.
The measurement setup is presented in Figure 1. The measurement setup uses two voltage calibrators as sources, one as DC voltage source and the other as AC voltage source. The voltage sources are connected to a remote controlled AC-DC switch. The output of the switch is connected to a tee connector that connects the standards (the reference standard and the device under test) in parallel. Two nanovoltmeters are used to measure the output of the standards. The sources, the meters and the AC-DC switch are GPIB (IEEE-488) controlled by software developed in-house in the LabVIEW programming language. Currently we operate three independent measurement systems, for both voltage and current AC-DC transfer, using the same computer (but with one independent GPIB controller for each system). The measurement systems are connected to the computer using optical GPIB extenders / isolators.

3. Standards
The standards used for the ac-dc voltage transfer system are based on PMJTCs associated with coaxial resistors or \( \mu \) pots, depending on the voltage level. Each set of standards is characterized up to 1000 V (PMJTCs with coaxial resistors) and down to 2 mV (\( \Omega \) pots), starting from 1 V, with step-up and step-down procedures. The source of the traceability is two 90 \( \Omega \) heater resistance PMJTCs, rated for 1 V, both calibrated in PTB.

3.1. First coaxial set
The first coaxial set is used for the voltage range from 1 V to 1000 V. The 1 V standard is a 90 \( \Omega \) heater PMJTC, the 1.5 V standard is a 180 \( \Omega \) heater PMJTC and the 3 V standard is a 900 \( \Omega \) heater PMJTC. For the upper ranges, we use uncoated power film resistors assembled in coaxial cylinder housing as range resistors (10 V, 30 V, 100 V and 300 V ranges), associated with 90 \( \Omega \) heater PMJTCs. For 1000 V range we use a commercial range resistor associated with a 400 \( \Omega \) heater PMJTC. The step-up from 1 V reference to 1000 V follows the scheme of Figure 2.

3.2. Second coaxial set
The second coaxial set is very similar to the first coaxial set. The main difference is on the 3 V range, where we use a 400 \( \Omega \) heater PMJTC as standard. For the other ranges, we use PMJTCs and coaxial resistors of the same specification of the first coaxial set. The step-up from 1 V reference to 1000 V follows the same scheme of the first set (Figure 2).

3.3. Discrete micropotentiometers
Since 2013 we use discrete \( \mu \) pots as standards for the mV range [6], following the design of the circuit presented in Figure 5. The 100 mV to 20 mV range uses a commercial 100 mA current shunt, with 8 \( \Omega \) nominal resistance, as output resistor. The 20 mV to 6 mV range uses a commercial 500 mA current
shunt, 1.6 Ω nominal resistance. The 6 mV to 2 mV range uses a 2 A current shunt (0.4 Ω nominal resistance). The step-down from 1 V reference to 2 mV follows the scheme of Figure 3.

3.4. Modified commercial micropotentiometer

Figure 6 shows the circuit schematic of a modified commercial multi-range μpot. The thermal element was replaced by a 400 Ω heater PMJTC. Table 1 shows the measured input and output resistance of the μpot for each range and the $V_{in} / V_{out}$ ratio, needed to calculate the input voltage required to obtain the desired output voltage. The step-down from 1 V reference to 2 mV, for the modified commercial μpot, is done according to the scheme of Figure 4.
Table 1. $V_{in} / V_{out}$ ratio for modified μpot ranges.

| Range [mV] | $R_{in}$ [kΩ] | $R_{out}$ [kΩ] | $V_{in} / V_{out}$ |
|-----------|---------------|----------------|-------------------|
| 200       | 2.26282       | 39.8394        | 56.80             |
| 100       | 2.26282       | 19.9091        | 113.66            |
| 50        | 2.26282       | 9.93084        | 227.86            |
| 20        | 2.26282       | 3.96420        | 570.81            |
| 10        | 2.26282       | 1.98301        | 1141.10           |
| 5         | 2.26282       | 0.99125        | 2282.79           |
| 2         | 2.26282       | 0.39902        | 5670.95           |

Table 2. Comparison results, in μV/V, for 1 V level.

| Frequency [kHz] | 0.01 | 0.06 | 1 | 10 | 100 | 1000 |
|----------------|------|------|---|----|-----|------|
| Step-up δ U (k=2) | 3.3  | -0.2 | 0.3 | 0.7 | 10.9 | 45   |
| 2nd set as standard δ U (k=2) | 3.2  | 0.6  | 0.4 | 0.7 | 11.9 | 49   |
| | 0.03 | 0.25 | 0.02 | 0.01 | 0.13 | 0.16 |

4. Comparison Results

4.1. Coaxial sets

To compare the coaxial sets, two independent step-up procedures were performed, following the scheme of Figure 2. Then, we did a direct comparison between the standards at the voltage levels of 1 V, 10 V, 100 V and 1000 V. We are comparing the results obtained for the first coaxial set by the step-up procedure with the results obtained using the second coaxial set as reference standard in a direct calibration. The results are presented in Table 2, Table 3, Table 4 and Table 5 for 1 V, 10 V, 100 V and 1000 V, respectively. The normalized error $E_n$ was computed for each measurement in order to evaluate the agreement of the results.

The results presented in Table 2, Table 3, Table 4 and Table 5 are consistent, showing a normalized error much smaller than 1.

4.2. Micropotentiometers

Two independent step-down procedures were performed, following the scheme of Figure 3 and Figure 4, to calibrate the discrete μpot and the modified commercial μpot down to 2 mV.

Due to the nature of the μpot topology (Figure 5 and Figure 6), similar to a voltage divider, it is impossible to do a direct comparison between them. So, we did the comparison by calibrating a commercial thermal transfer standard (TTS) using the discrete μpot and the modified commercial μpot. The results are presented in Table 6, Table 7, Table 8 and Table 9, for 60 mV, 20 mV, 10 mV and 2 mV, respectively. The normalized error $E_n$ was computed for each measurement in order to evaluate the agreement of the results.

The results presented in Table 6, Table 7, Table 8 and Table 9 are consistent, showing a normalized error much smaller than 1.
Table 3. Comparison results, in $\mu$V/V, for 10 V level.

| Frequency [kHz] | 0.01 | 0.06 | 1   | 10  | 100 | 1000 |
|----------------|------|------|-----|-----|-----|------|
| Step-up $\delta$ | 6.4  | 0.3  | 1.1 | -0.1| 9.9 | 106  |
| U (k=2)         | 4.0  | 3.7  | 3.3 | 3.5 | 6.7 | 22   |
| 2nd set as standard $\delta$ | 6.2  | 1.0  | 0.5 | 0.7 | 7.7 | 115  |
| U (k=2)         | 4.9  | 3.9  | 4.0 | 4.1 | 7.7 | 23   |
| En              | 0.02 | 0.13 | 0.11| 0.15| 0.19| 0.30 |

Table 4. Comparison results, in $\mu$V/V, for 100 V level.

| Frequency [kHz] | 0.01 | 0.06 | 1   | 10  | 100 |
|----------------|------|------|-----|-----|-----|
| Step-up $\delta$ | 3.1  | 0.5  | 1.7 | -0.7| 1   |
| U (k=2)         | 7.4  | 6.4  | 6.6 | 6.8 | 11  |
| 2nd set as standard $\delta$ | 1.9  | 0.8  | 0.6 | 0.0 | 4   |
| U (k=2)         | 7.7  | 6.7  | 6.9 | 7.2 | 12  |
| En              | 0.12 | 0.03 | 0.12| 0.07| 0.16|

Table 5. Comparison results, in $\mu$V/V, for 1000 V level.

| Frequency [kHz] | 0.01 | 0.06 | 1   | 10  | 100 |
|----------------|------|------|-----|-----|-----|
| Step-up $\delta$ | 9    | 1    | 2   | -4  | -168|
| U (k=2)         | 16   | 15   | 15  | 15  | 28  |
| 2nd set as standard $\delta$ | 8    | 0    | 0   | -5  | -169|
| U (k=2)         | 16   | 15   | 15  | 15  | 29  |
| En              | 0.06 | 0.05 | 0.11| 0.05| 0.02|

Table 6. Comparison results, in $\mu$V/V, for 60 mV level (220 mV range of the TTS).

| Frequency [kHz] | 0.01 | 0.06 | 1   | 10  | 100 | 1000 |
|----------------|------|------|-----|-----|-----|------|
| Discrete $\mu$pot $\delta$ | -194 | 4    | 2   | -19 | 20  | 1481 |
| U (k=2)         | 13   | 13   | 12  | 13  | 19  | 84   |
| Modified $\mu$pot $\delta$ | -191 | 6    | 0   | -22 | 17  | 1474 |
| U (k=2)         | 14   | 12   | 12  | 13  | 19  | 84   |
| En              | 0.16 | 0.12 | 0.12| 0.16| 0.11| 0.06 |
Table 7. Comparison results, in $\mu$V/V, for 20 mV level (220 mV range of the TTS).

| Frequency [kHz] | 0.01 | 0.06 | 1   | 10  | 100 | 1000 |
|----------------|------|------|-----|-----|-----|------|
| Discrete $\mu$pot $\delta$ U (k=2) | -154 | 3    | 2   | -21 | 20  | 1499 |
| Modified $\mu$pot $\delta$ U (k=2) | -153 | 0    | -1  | -24 | 16  | 1480 |
| En                        | 0.04 | 0.18 | 0.17| 0.14| 0.14| 0.16 |

Table 8. Comparison results, in $\mu$V/V, for 10 mV level (22 mV range of the TTS).

| Frequency [kHz] | 0.01 | 0.06 | 1   | 10  | 100 | 1000 |
|----------------|------|------|-----|-----|-----|------|
| Discrete $\mu$pot $\delta$ U (k=2) | -345 | 36   | 17  | -7  | -31 | 682  |
| Modified $\mu$pot $\delta$ U (k=2) | -344 | 39   | 21  | -4  | -36 | 657  |
| En                        | 0.16 | 0.03 | 0.12| 0.14| 0.10| 0.13 |

Table 9. Comparison results, in $\mu$V/V, for 2 mV level (22 mV range of the TTS).

| Frequency [kHz] | 0.01 | 0.06 | 1   | 10  | 100 | 1000 |
|----------------|------|------|-----|-----|-----|------|
| Discrete $\mu$pot $\delta$ U (k=2) | -410 | -55  | -75 | -93 | -115| 654  |
| Modified $\mu$pot $\delta$ U (k=2) | -397 | -31  | -60 | -89 | -116| 637  |
| En                        | 0.16 | 0.21 | 0.46| 0.24| 0.05| 0.01 |

5. Conclusions
The results of the comparison between the different coaxial sets and micropotentiometers are consistent, indicating that the system works reliably. The use of two independent sets of standards adds reliability and flexibility to our system.

References
[1] M. Klonz, H. Laiz and E. Kessler, “Development of thin-film multijunction thermal converters at PTB/IPHT,” IEEE Trans. Instrum. Meas., vol. 50, no. 6, pp. 1490-1498, 2001.
[2] M. Klonz and T. Funck, “Micropotentiometers providing low output impedance for milivolt ac-dc transfer”, IEEE Trans. Instrum. Meas., vol. 56, no. 2, pp. 468-471, 2007.
[3] R. Afonso Jr., G. M. Geronymo, R. Barros e Vasconcellos, A. Polleaff, “New Generation of AC-DC Voltage Transfer Standards at Inmetro”, NCSLI Measure, June 2014, Volume 9, Number 2, 66-73.
[4] 7º Congresso Brasileiro de Metrologia, “Sistema de padronização primária de transferência térmica ac-dc de baixa tensão no Inmetro”, November 24-27, 2013.

[5] G. M. Geronymo, C. I. Ribeiro-Silva, R. M. Souza and M. Klonz, “AC-DC transfer measurements in the mV-range using discrete micropotentiometers”, 29th Conference on Precision Electromagnetic Measurements (CPEM 2014), Rio de Janeiro, 2014, pp. 514-515. doi: 10.1109/CPEM.2014.6898485

[6] G. M. Geronymo, “Comparison of two different methods to build micropotentiometers for low-voltage AC-DC transfer”, Journal of Physics: Conference Series, vol. 733, p. 12066, jul. 2016.