INMETRO'S PRIMARY AC-DC CURRENT TRANSFER STANDARD BASED ON PMJTCS

R. Afonso [1], *M. Klonz* [2], *R. M. Souza* [3], *R. P. Landim* [4]

[1] Inmetro/Dimci/Diele, Duque de Caxias, Brasil, rajunior@inmetro.gov.br
[2] Retired from Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, manfred.klonz@ptb.de
[3] Inmetro/Dimci/Diele, Duque de Caxias, Brasil, rmsouza@inmetro.gov.br
[4] Inmetro/Dimci/Diele, Duque de Caxias, Brasil, rplandim@inmetro.gov.br

Abstract: This paper describes the new primary standard for the ac-dc current transfer at Inmetro, based on PMJTCs and the new shunts manufactured by Fluke for rated currents from 10 mA up to 20 A.

The build-up of the ac-dc current scale is described together with the uncertainty budgets which result in final uncertainties at 5 A of 6 µA/A to 12 µA/A in the frequency range from 10 Hz to 100 kHz. These are small compared to international standards.

Key words: ac-dc difference, PMJTC, comparison.

1. INTRODUCTION

Inmetro, the Brazilian National Metrology Institute, is responsible for developing new techniques and standards that will improve the capacity of providing a higher quality calibration service, specially to the Brazilian accredited laboratories. These laboratories, on the other hand, are responsible for providing calibration services to all other laboratories and industries in Brazil.

The Voltage and Current Laboratory – Latce, among its tasks, has to develop new techniques and methodologies, so Latce started to invest in standards worldwide known – PMJTCs (Planar Multijunction Thermal Converters), to replace SJTCs (Single Junction Thermal Converters) as primary standard at 10 mA current level. For higher currents the new TCCs (Thermal Current Converters) are based on PMJTCs together with high quality coaxial shunts, model A40B, manufactured by Fluke.

The thermal converters – TC, are capable of comparing the joule heating between ac and dc modes at 0.1 µV/V level, and are widely employed as the primary standard in most of the national metrology institutes .

Hermach's paper [1] launched the field of ac-dc thermal transfer metrology, which forms the basis for ac voltage and current measurement and calibration throughout the world [2]. In this case, he worked with a traditional SJTC, which uses one thermocouple at the midpoint of the heater and encloses both heater and thermocouple in a vacuum envelop to improve its sensitivity [1].

The fundamental limitations on the performance of an SJTC are thermoelectric errors (Thomson and Peltier effects) in the heater due to the rather large (about 200 ºC) temperature gradient along the heater. To reduce these thermoelectric errors, the MJTC uses as many as two hundred thermocouples spaced along a much longer heater wire [3]. However, MJTCs fabrication process is difficult and slow. The PMJTCs are suitable to mass-production; they also provide long-term stability together with high sensitivity and high dynamic range. They are well known for very small ac–dc current transfer differences at audio frequencies [4].

In order to validate the new system, an unofficial comparison was made between PTB (Physikalisch Technische Bundesanstalt, Germany) and Inmetro standards. The measurements were performed at 10 mA and 5 A, in the frequency range from 10 Hz to 100 kHz.

2. CALIBRATION SET-UP

The basic standard for ac-dc current transfer is the 10 mA PMJTC providing traceability to PTB. All standards for higher currents contain a shunt associated with a dedicated PMJTC which measures the voltage across the shunt. To build-up the current scale from 10 mA to 20 A, the different current ranges have to be calibrated against each other.

In this build-up method starting from 10 mA the next higher current standard for 20 mA is calibrated at the current of 10 mA. Under the assumption that it does not change its ac-dc current transfer differences, it is used then at 20 mA. This procedure continues step by step for all frequencies from 10 Hz to 100 kHz and currents up to 20 A.

The calibration set-up used is shown in detail in Fig. 1. Two separate calibrators deliver AC and DC voltages. An ac-dc switch connects the AC and DC voltages to the transconductance amplifier which converts the voltage to the necessary current. Both ac-dc current transfer standards are connected in series and therefore get the same current for this comparison. The two nanovoltmeters Keithley 182 measure the output voltage of the PMJTCs. The nanovoltmeters are modified because their input amplifiers should be driven at the potential of the ac-dc transfer standards.

This basic design of the measurement set-up for 10 mA is given in Fig. 1. For higher current, coaxial shunts, model A40B, manufactured by Fluke, are associated to them.

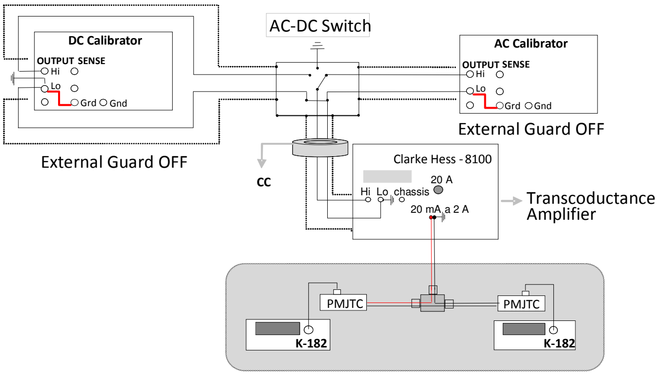

Fig. 1 Measurement set-up for AC–DC current transfer difference measurements

The different earth connections are chosen in a specific way to avoid any earth loops which may change the measured values in an unknown way. A coaxial choke (CC) has been introduced to suppress earth currents causing common mode voltages at the input of the transconductance amplifier.

The introduction of potential driven guards (Fig.2) in the comparison circuit of the two ac-dc transfer standards avoids systematic changes of the ac-dc transfer difference of the standard which is at the higher potential in the series connection of the two standards especially at higher frequencies. This is necessary because the standard is calibrated at low potential and used at high potential. Photos in Fig. 3 and Fig. 4 show the calibration set-up.

With this calibration set-up, all the current ranges have been built-up with a standard deviation of the measurement smaller than 1 μA/A.

In Fig. 5 the different steps in the step-up procedure are shown. All PMJTCs called 90 have heater resistances of 90 Ω, whereas the 400 has a heater resistance of 400 Ω and the 900 has 900 Ω. The second name is the shunt for the different currents.

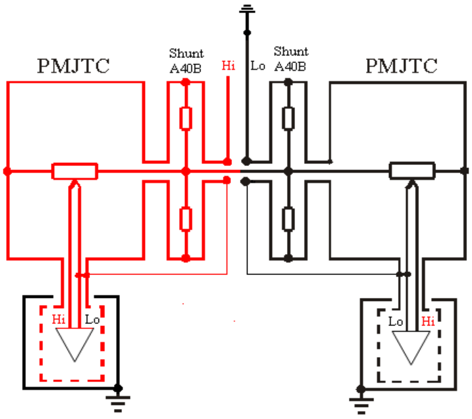

Fig. 2 AC-DC current transfer with potential driven guards (PMJTCs with shunts for current ranges above 10 mA)

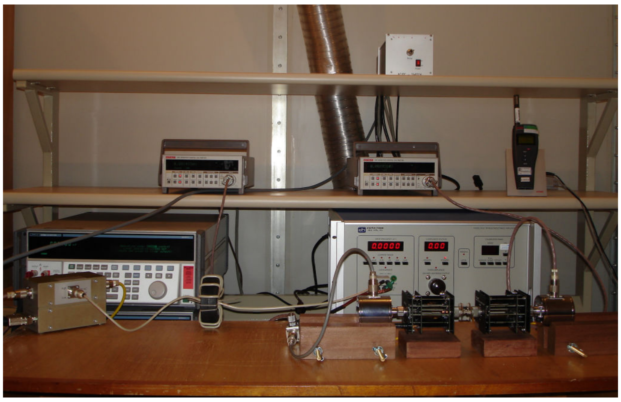

Fig. 3 AC-DC current transfer set-up

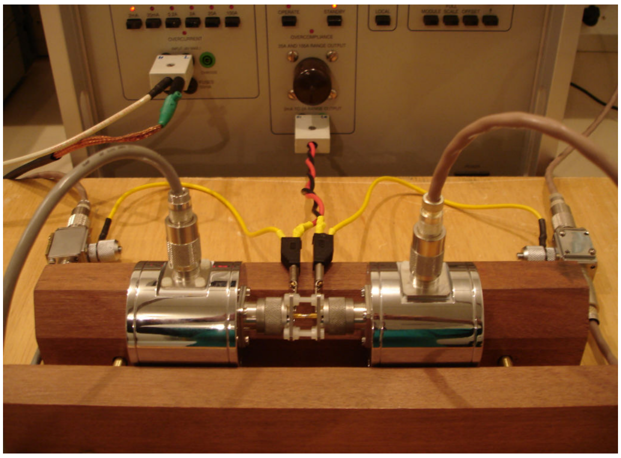

Fig. 4 Connection of the AC-DC current transfer standards in series

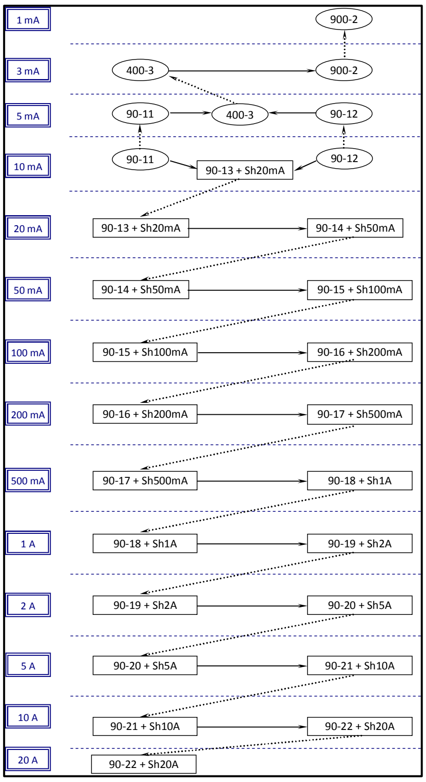

Fig. 5 Schematics of the step-up procedure

3. UNCERTAINTY ANALYSIS

Model equation :

$$\delta_{\text{stepi}} = \delta_{\text{stepi-1}} + \delta_{\text{C}} + \delta_{\text{com. mode}} + \delta_{\text{Lev}} + \delta_{\text{LF}} + \delta_{\text{A}}$$

with

$\delta_{\text{stepi-1}}$	Transfer difference of standard at the step i-1
δ_{C}	Measured transfer difference in the step-up measurements
$\delta_{\text{com. mode}}$	Transfer difference from the common mode effect in the transconductance amplifier
δ_{Lev}	Transfer difference due to level dependence of shunts
δ_{LF}	Transfer difference due to low frequency behavior of PMJTC
δ_{A}	Correction of the mean of twelve measurements

The sum of the variances of the different contributions results in the variance of the result:

$$u^2(\delta_{\text{stepi}}) = u^2(\delta_{\text{Stepi-1}}) + u^2(\delta_{\text{C}}) + u^2(\delta_{\text{com. mode}}) + u^2(\delta_{\text{Lev}}) + u^2(\delta_{\text{LF}}) + u^2(\delta_{\text{A}})$$

with

$u^2(\delta_{\text{Stepi-1}})$	Variance of the transfer difference of the standard at the step i-1
$u^2(\delta_{\text{C}})$	Variance of the measured transfer difference in step-up
$u^2(\delta_{\text{com. mode}})$	Variance of the transfer difference from the common mode effect in the transconductance amplifier
$u^2(\delta_{\text{Lev}})$	Variance of the transfer difference due to level dependence of shunts
$u^2(\delta_{\text{LF}})$	Variance of the transfer difference due to low frequency behavior of the PMJTC
$u^2(\delta_{\text{A}})$	Variance of the mean of twelve measurements

The uncertainty budgets of the different current steps are given in Tables I to IV.

Table I. Uncertainty analysis for the step-up at 10 mA

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0,01	**0,02**	**0,03**	**0,04**	**0,055**	**0,12**	**0,5**	**1**	**5**	**10**	**20**	**50**	**70**	**100**
$u(\delta_{10\text{ mA}})$	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
$u(\delta_{\text{A}})$	0,5	0,4	0,3	0,5	0,6	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,4	0,6
$u(\delta_{\text{C}})$	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
$u(\delta_{\text{Com. mode}})$	1,0	1,0	1,0	1,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
u_{level}	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
u_{LF}	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
$u(\delta_{10\text{ mA}})$	1,9	1,8	1,8	1,9	1,9	1,8	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,6
$U(\delta_{10\text{ mA}})$ k=2	3,8	3,6	3,6	3,8	3,8	3,6	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,2

Table II. Uncertainty analysis for the step-up at 100 mA

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0,01	**0,02**	**0,03**	**0,04**	**0,055**	**0,12**	**0,5**	**1**	**5**	**10**	**20**	**50**	**70**	**100**
$u(\delta_{50\text{ mA}})$	3,0	2,6	2,5	2,5	2,5	2,4	1,7	1,8	1,7	1,7	1,7	1,7	1,7	1,9
$u(\delta_{\text{A}})$	0,5	0,3	0,5	0,4	0,3	0,5	0,4	0,4	0,4	0,2	0,4	0,4	0,4	0,5
$u(\delta_{\text{C}})$	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
$u(\delta_{\text{Com. mode}})$	1,0	1,0	1,0	1,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
u_{level}	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,4
u_{LF}	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
$u(\delta_{100\text{ mA}})$	3,2	2,9	2,8	2,7	2,7	2,6	1,8	1,9	1,8	1,7	1,8	1,8	1,8	2,0
$U(\delta_{100\text{ mA}})$ k=2	6,4	5,8	5,6	5,4	5,4	5,2	3,6	3,8	3,6	3,4	3,6	3,6	3,6	4,0

Table III. Uncertainty analysis for the step-up at 1 A

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0,01	**0,02**	**0,03**	**0,04**	**0,055**	**0,12**	**0,5**	**1**	**5**	**10**	**20**	**50**	**70**	**100**
$u(\delta_{500\text{ mA}})$	3,8	3,5	3,4	3,3	3,3	3,3	2,0	2,0	2,0	1,9	2,0	2,0	2,1	2,4
$u(\delta_{\text{A}})$	0,4	0,3	0,3	0,3	0,3	0,4	0,3	0,3	0,2	0,2	0,2	0,2	0,3	0,3
$u(\delta_{\text{C}})$	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
$u(\delta_{\text{Com. mode}})$	1,0	1,0	1,0	1,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
u_{level}	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,5
u_{LF}	0,4	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
$u(\delta_{1\text{ A}})$	4,1	3,8	3,7	3,6	3,7	3,6	2,3	2,3	2,3	2,2	2,3	2,3	2,3	2,9
$U(\delta_{1\text{ A}})$ k=2	8,3	7,6	7,5	7,3	7,3	7,2	4,6	4,5	4,5	4,4	4,6	4,6	4,6	5,8

Table IV. Uncertainty analysis for the step-up at 5 A

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0,01	**0,02**	**0,03**	**0,04**	**0,055**	**0,12**	**0,5**	**1**	**5**	**10**	**20**	**50**	**70**	**100**
$u(\delta_{2\,A})$	4,4	4,1	4,0	3,9	3,9	3,9	2,6	2,6	2,5	2,7	3,1	3,8	3,9	4,6
$u(\delta_A)$	0,3	0,4	0,3	0,2	0,4	0,4	0,3	0,5	0,4	0,2	0,2	0,4	0,6	0,4
$u(\delta_C)$	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
$u(\delta_{\text{Com. mode}})$	1,0	1,0	1,0	1,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
u_{level}	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,5	2,0	3,0	3,0	3,5
u_{LF}	0,4	0,3	0,1	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
$u(\delta_{5\,A})$	4,7	4,3	4,3	4,2	4,2	4,2	2,8	2,8	2,7	3,1	3,7	4,9	5,0	5,8
$U(\delta_{5\,A})$ k=2	9,4	8,6	8,6	8,4	8,4	8,4	5,6	5,6	5,4	6,2	7,4	9,8	10,0	11,6

4. COMPARISON RESULTS

An unofficial interlaboratory comparison of ac-dc current transfer standards between PTB and Inmetro was performed at Inmetro's laboratory. The current points chosen were 10 mA and 5 A, in the frequency range from 10 Hz and 100 kHz. Each current point is measured in twelve cycles at all frequencies, and the mean is calculated using the results of the sequence which gives the ac-dc transfer difference, usually represented by δ. Tables V and VI show the results obtained.

PTB uses a similar calibration set-up and similar standards. The shunts are manufactured by the Norwegian Metrology Institute Justervesenet with a different design [6].

Table V. Result of the comparison between Inmetro and PTB at 10 mA

Institutes	AC-DC current transfer differences together with their uncertainties in µA/A at the frequencies in kHz													
	0,01	**0,02**	**0,03**	**0,04**	**0,055**	**0,12**	**0,5**	**1**	**5**	**10**	**20**	**50**	**70**	**100**
δ**INMETRO**	5,5	1,3	1,0	0,7	0,3	-0,1	-0,5	0,1	0,4	0,6	2,2	17,6	34,8	70,9
U_{INMETRO}	4	4	4	4	4	4	3	3	3	3	3	3	3	4
δ**PTB**	5,3	1,8	0,7	0,7	-0,3	-0,4	-0,1	-0,2	0,5	1,5	3,2	18,9	36,4	72,2
U_{PTB}	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Difference INMETRO-PTB	0,2	-0,5	0,3	0,0	0,5	0,3	-0,4	0,3	-0,1	-0,9	-1,0	-1,3	-1,6	-1,3
E_n	0,0	-0,1	0,1	0,0	0,1	0,1	-0,1	0,1	0,0	-0,2	-0,2	-0,3	-0,4	-0,3

Table VI. Result of the comparison between Inmetro and PTB at 5 A

Institutes	AC-DC current transfer differences together with their uncertainties in µA/A at the frequencies in kHz													
	0,01	**0,02**	**0,03**	**0,04**	**0,055**	**0,12**	**0,5**	**1**	**5**	**10**	**20**	**50**	**70**	**100**
δ**INMETRO**	0,0	0,4	0,2	0,1	0,0	-0,3	0,0	0,1	2,7	11,6	13,2	-88,1	-187,0	-353,9
U_{INMETRO}	9	9	9	9	9	9	6	6	6	6	8	10	10	12
δ**PTB**	-0,9	-0,2	0,4	0,2	-0,4	0,5	0,5	0,4	3,0	10,6	10,5	-89,9	-187,2	-349,4
U_{PTB}	5	4	4	4	4	4	4	4	4	5	7	9	10	11
Difference INMETRO-PTB	0,9	0,6	-0,2	0,0	0,4	-0,8	-0,5	-0,3	-0,3	1,0	2,7	1,9	0,2	-4,5
E_n	0,1	0,1	0,0	0,0	0,0	-0,1	-0,1	0,0	0,0	0,1	0,2	0,1	0,0	-0,3

5. CONCLUSION

In the first step a new step-up procedure was developed to build-up the ac-dc current tranfer standard for 10 mA up to 20 A and to perform an uncertainty analysis for the whole build-up.

The second step towards operacionalizing the new primary system of Latce was performing a comparison between Inmetro and PTB, which proved that Inmetro's new calibration set-up works as expected.

The results for both institutes' standards were within 2 µA/A for 10 mA and 5 µA/A for 5 A between 10 Hz and 100 kHz. That means this new system is reliable and it is ready for use in the next international comparison of ac-dc current transfer standards (SIM.EM-K12) [5].

REFERENCES

[1] Francis L. Hermach, "Thermal Converters as AC-DC Transfer Standards for Current and Voltage Measurements at Audio Frequencies", J. Res. Natl. Bur. Stand. 48, 121-138, 1952.

[2] R. E. Elmquist, M. E. Cage, Y-H. Tang, A-M. Jeffery, J. R. Kinard, R. F. Dziuba, N. M. Oldham, and E. R. Williams, "The Ampere and Electrical Units", J. Res. Natl. Inst. Stand. Technol., January-February, 2001.

[3] M. Klonz, "AC-DC Transfer Difference of the PTB Multijunction Thermal Converter in the Frequency Range from 10 Hz to 100 kHz," IEEE Trans. Instrum Meas., vol 36, No. 2, pp. 320-329, June 1987.

[4] M. Klonz, H. Laiz, T. Spiegel, P. Bittel, "AC-DC Current Transfer Step-up and Step-down Calibration and Uncertainty Calculation", IEEE Trans. Instrum Meas., vol. 51, No. 5, pp. 1027-1034, 2002.

[5] L. D. Lillo, "SIM.EM-K12 Comparison Protocol – AC-DC Current Transfer Difference", 2010

[6] T. Funck, and M. Klonz: Improved AC-DC current transfer step-up with new current shunts and potential driven guarding. IEEE Trans. Instrum. Meas.,Vol. 56, pp 361-364, April 2007.