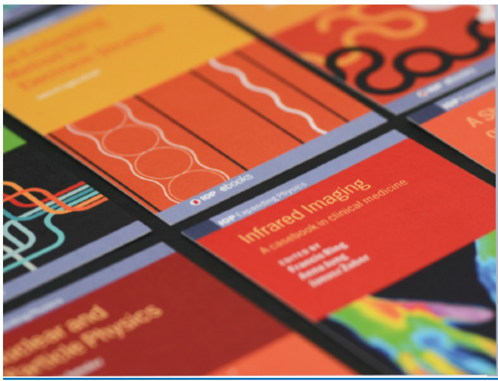
Trilateral South-American project: a reference system for measuring electric power up to 100 kHz – progress report II



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Trilateral South-American project: a reference system for measuring electric power up to 100 kHz – progress report II

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Abstract. Three countries in South America are jointly developing a reference system for measuring electric power up to 100 kHz. The objective is the construction of three similar measuring systems, one for each institute. This project will contribute to provide calibration services in measuring ranges still not covered by the three institutes. The status of its development by the end of 2017 is described here.

1. Introduction

As reported in [1], the Instituto Nacional de Metrologia, Qualidade e Tecnologia (Inmetro), in Brazil, the Instituto Nacional de Tecnología Industrial (INTI), in Argentina, and the Administración Nacional de Usinas y Transmisiones Eléctricas (UTE), in Uruguay, are jointly developing a reference system for measuring electric power up to 100 kHz. The objective is the construction of three similar measuring systems, one for each institute. The project is supported in part by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), in Brazil.

Apart from coordinating this project, Inmetro is also responsible for the development of the power amplifiers and the transconductance amplifiers. INTI is responsible for the development of the arbitrary waveform function generators, the dual-channel digitizers and the current shunts (and their calibration). UTE is responsible for the development of the resistive voltage dividers (and their calibration). The integration and testing of the measuring systems are to be performed by the three institutes.

The current status of this development is described in this article.

2. Measuring system

The reader should consult [1] for a description of the measuring system. It comprises: an arbitrary waveform function generator with two synchronized channels, a power amplifier, a transconductance amplifier, a resistive voltage divider, a current shunt and a digitizer with two synchronized channels.

2.1 Arbitrary waveform function generator

The design requirements for such generator were presented in [1]. A two-channel version of the design described in [2]-[4] will be implemented. The circuit changes are not significant. The input buffer and analog-to-digital converter (ADC) are doubled and two power supplies for the ADC modules need to be used.

The generator circuits and printed circuit boards (PCBs) layout were designed by INTI. The circuit components were purchased by Inmetro and the PCBs fabricated in Brazil, all being transported to INTI. The prototype integration and testing is now being carried out by INTI.

Electronic components and product enclosures, for assembling 3 (three) two-channel arbitrary waveform function generators, and PCBs for assembling the dual-channel digitizers, weighing 39.85 kg and amounting US$ 12,052.25 FOB embarked to INTI on August 29, 2017. The PCBs for the function generators amounting US$ 1,890.00 embarked to INTI on November 29, 2017.

2.2 Power amplifier

The design requirements for such amplifier were presented in [1]. The amplifier topology was selected by Inmetro. A total of 2 (two) amplifiers will be assembled: one using pin-through-hole (PTH) components based on [5] and another using surface-mount-device (SMD) technology based on a one-stage version of [6]. The National Institute of Standards and Technology (NIST) is collaborating with the development of the latter. The behavior of the two amplifiers will be compared. The circuit components were purchased by Inmetro and the PCBs of the PTH power amplifiers fabricated in Brazil. Four units of each amplifier were assembled at Inmetro and are now under test.

Inmetro purchased electronic components for assembling 4 (four) PTH power amplifiers weighing 2.80 kg and amounting US$ 1,744.91 FOB on September 03, 2016 and electronic components for assembling 4 (four) SMD power amplifiers weighing 8.55 kg and amounting US$ 4,321.78 FOB on March 21, 2017. They arrived at Inmetro only on June 27, 2017 as CNPq had problems with the renewal of her transportation security contract since January 2017. Inmetro also purchased on December 05, 2016, 12 units of 500-V and 6 units of +/−15-V linear power supplies for assembling the abovementioned amplifiers weighing 33 kg and amounting US$ 5,671.20 FOB (plus US$ 953.35 for transportation). They also arrived at Inmetro only on June 27, 2017. The PCBs for assembling the PTH power amplifiers were fabricated in Brazil for US$ 620.

2.3 Tranconductance amplifier

A total of 4 (four) transconductance amplifiers are being constructed each covering the following ranges: 20 mA, 200 mA, 5 A, and 20 A. The nominal output voltage of the shunts is always 0.8 V. Budget restrictions prevented the construction of the 100 A shunt as had been planned in [1].

The design requirements for such amplifiers were presented in [1]. The amplifiers contain only analog circuits to reduce electrical noise. Linear power supplies are utilized in all amplifiers except the 20 A module also to reduce electrical noise. Vishay Z-Foil resistors (VTA) with low TCR are employed in critical circuit locations to increase the output stability of the amplifier. For 20 A capability, the amplifier needs adequate means to dissipate power while having a small physical geometry to maintain a low inductance in the output current circuit.

The amplifier circuits and product integration were designed by Inmetro based on [7]-[9]. The prototype integration and testing is now being carried out by Inmetro.

Inmetro purchased on June 16, 2016, electronic components for assembling 12 transconductance amplifiers – 3 (three) units at each nominal range - weighing 15.55 kg and amounting US$ 9,936.77 FOB (plus US$ 227 for transportation). They arrived at Inmetro on November 14, 2016. Inmetro also purchased from May 11 to July 16, 2015, Vishay resistors for critical circuits of the abovementioned amplifiers amounting US$ 14,379.83 FOB. They arrived at Inmetro on January 15, 2016. Inmetro also purchased on July 29, 2015, 12 linear and 6 (six) switching-mode +/−12 V power supplies for assembling the abovementioned amplifiers weighing 51 kg and amounting US$ 7,659 FOB (plus US$ 953.35 for transportation). They arrived at Inmetro on January 20, 2016.

Inmetro developed a Brazilian supplier and purchased for US$ 174.86 a total of 24 units of 45-cm long flat flexible circuit material with 9-mm wide copper strips separated by a thin dielectric. Those cables have low impedance and are used as the output cables of the transconductance amplifiers. Inmetro also fabricated 11 cooling tunnel assemblies with 4 (four) black-anodized aluminum heat sinks each to dissipate up to 240 W from the amplifier output transistors. They are going to be used in the abovementioned 5 A and 20 A transconductance amplifiers (and in future ones). A total of 18 PCBs of the 5 A amplifier, 12 PCBs of the buffer amplifier and 12 PCBs of the +/–15 V linear power supply were fabricated in Brazil for US$ 1,300.

2.4 Resistive voltage divider

There are 9 (nine) resistive voltage dividers to be used one at a time whose (binary) nominal value (from 4 V to 1024 V) depends on the test voltage selected [10][11]. Each divider comprises two cascaded, independently shielded sections: a range resistor and a shunt resistor. The dividers have input resistances ranging from 1 kΩ @ 4 V to 256 kΩ @ 1024 V. Thus the power amplifier output current is always 0.004 A. A 200-Ω shunt resistor is used so that the nominal output voltage of the dividers is always 0.8 V. The two sections can be calibrated together as a voltage divider or separately as resistors. This provides flexibility in testing.

Vishay Z-Foil audio resistors (VAR) with low dissipation factor whose dissipated power in each resistor does not exceed 100 mW are employed. It was confirmed by UTE that nonlinear effects are reduced considerably by soldering such resistors on PTFE boards (see [1] and references therein). Such boards have a very low dissipation factor. Once nonlinear effects have been minimized, stray capacitances are the most relevant linear parasitic effect. A special shielding technique for nulling radial electric fields is employed in this work [12].

The voltage divider circuits, the special shielding and the product integration were all designed by UTE. The circuit components and PTFE boards were purchased by Inmetro and transported to UTE. The PCBs layout was carried out and a few prototypes were assembled and tested by UTE. Divider labels containing the project partners logos were fabricated in Brazil. All resistive voltage dividers are now being assembled by UTE. UTE is also developing a system [13] for comparing the divider ratio errors and phase displacements.

Vishay resistors, special connectors and PTFE boards, for assembling 27 resistive voltage dividers – 3 (three) units at each nominal value –, weighing 5.23 kg and amounting US$ 10.045.42 FOB (plus US$ 660 for transportation) embarked to UTE on April 08, 2016. Additional Vishay resistors and connectors weighing 2.80 kg and amounting US$ 2,602.60 FOB (plus US$ 460 for transportation) embarked to UTE on September 28, 2017. Further special connectors amounting US$ 1,161.12 (plus US$ 460 for transportation) to finalize the assembly of the dividers embarked to UTE on October 20, 2017.

2.5 Current shunt

There are 12 current shunts to be used one at a time whose nominal value (20 mA, 50 mA, 100 mA, 200 mA, 0.5 A, 1 A, 2 A, 5 A, 10 A, 20 A, 50 A and 100 A) depends on the test current selected [14]. Their input resistances range from 40 Ω @ 20 mA to 0.008 ohm @ 100 A. Thus the nominal output voltage of the shunts is always 0.8 V. Vishay Z-Foil resistors (Z201) with low TCR whose power dissipated in each resistor does not exceed 0.33 W are employed to satisfy stability requirements (see [1] and references therein).

The current shunt circuits and PCBs layout were designed by INTI and Inmetro based on [15]. The circuit components were purchased by Inmetro and the PCBs fabricated in Brazil, all being transported to INTI. All current shunts are now being assembled by INTI [16].

Special connectors and Vishay resistors for assembling 48 shunts – 4 (four) units at each nominal value – weighing 11.25 kg and amounting US$ 47,232.04 FOB, embarked to INTI on September 20, 2016. The PCBs were ready in July, 2016. The PCBs, weighing 26.70 kg and amounting US$ 4,080.88 FOB, embarked to INTI on September 12, 2016.

Two additional units of each nominal value were independently constructed by Inmetro for ac-dc transfer measurements and instrument calibration purposes. Inmetro already tested the 0.5 A, 1 A, 2 A, 5 A, 10 A and 20 A shunts [17]. Inmetro elaborated software to model the current shunts behavior and estimate their ac-dc transfers and phase displacements [18]. An M. Sc. dissertation will be produced under Inmetro´s metrology postgraduate program to document the modeling and experimental results obtained.

Inmetro purchased (May 22, 2015) special connectors, (May 11, 2015) Vishay resistors, and (April 26, 2016) PCBs for assembling 24 current shunts – 2 (two) units at each nominal value – amounting US$ 24,759.40 FOB (plus US$ 4,015.46 for transportation).The special connectors arrived at Inmetro on December 11, 2015 and the Vishay resistors on January 15, 2016.

A total of 24 units of 70x70x1.5-mm, 48 units of 130x130x1.5-mm, 24 units of 250x250x1.5-mm and 48 units of 46x18x0.5-mm metallic panels for assembling 72 current shunts – 6 (six) units at each nominal value – were fabricated in Brazil. All aluminum panels are anodized, matted (with small porous diameter for aesthetic purposes) and contains the colored logos of the project partners. Such service cost US$ 2,850. Two-thirds of these panels were transported to INTI and the remaining will stay at Inmetro.

2.6 Dual-channel digitizer

A high-resolution, digital sampling system based on a Sigma-Delta analog-to-digital converter (Σ–Δ ADC) has been developed and characterized [19]. The system has been modified to accommodate two synchronized channels.

The design requirements for such digitizer were presented in [1]. The digitizer circuits and PCBs layout were designed by INTI. The circuit components were purchased by Inmetro and the PCBs fabricated in Brazil, all being transported to INTI. The prototype integration and testing is now being carried out by INTI.

Electronic components and product enclosures for assembling 3 (three) dual-channel digitizers, weighing 68.53 kg and amounting US$ 16,609.47 FOB (plus US$ 1,000 for transportation) embarked to INTI on May 18, 2016. Information on the PCBs for the digitizers was given in section 2.1.

3. Project management

The project is coordinated by Inmetro, who is responsible for the purchase and transportation of the components and parts needed to the construction of the modules, and for the transportation of the modules needed to the assembly of the measuring systems, in each partner country.

The project activities include the design, layout and documentation of the PCBs, the design and documentation of the electronic packaging of the modules, the calibration certificates of resistive voltage dividers and current shunts, the design and documentation of the software and firmware, and the measuring system integration, testing and documentation.

Additional small scattered spending is not reported here. Nearly 95% of the funding allocated for this project has already been spent by December 2017. The project is a little delayed due to customs problems.

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