Construction and evaluation of a low-cost AC-DC current shunt

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Abstract. The process of construction and evaluation of a shunt prototype for AC-DC transfer produced by Inmetro, built with low-cost materials and using commercially available thin film chip resistors will be presented. The main objective of this work is fully achieved, obtaining an equipment with characteristics that allow its use as standard in the calibration of AC current sources of high accuracy, in a wide frequency range.

Keywords: current, AC-DC transfer, coaxial shunt.

1. Introduction

AC-DC transfer measurement is based on the use of planar multijunction thermal converters [1] along with AC-DC shunts. To do this, according to P. S. Filipski [2], these shunts must to comply with a series of requirements, mainly stability and flat response of the AC-DC difference in the frequencies of interest. In addition to the technical parameters, we also aim at the requirement of low cost in construction.

2. Project and specifications

Different topologies of AC-DC shunts were evaluated [3] [4], and the design presented in "Design, modeling, and verification of high performance ac-dc current shunts from inexpensive components" [5] was chosen, due to the feasibility in terms of low cost, availability of materials and ease of assembly. The chosen model was based on the design shown in figure 1.

Figure 1 - Shunt design template. [5]
Due to the better material availability, resistors with a nominal value of 15 $\Omega$, with 250 mW of maximum power, and phenolite double-layer and single-layer printed circuit boards were used. For the design and build of the prototype, it was considered, in addition to the ohmic value of the resistors, the effects of load on the current generators subjected to it, culminating in a shunt for a rated current of 1 A. The assembly was done manually by the technicians of the Laboratory of Calibration in Electrical Metrology (Lacel) and the result can be observed in figure 2.

Figure 2 - Result of the shunt assembly process

Table 1 shows the costs of the inputs used in the construction of the prototype.

| Quantity | Description                                           | Total(U$) |
|----------|-------------------------------------------------------|-----------|
| 20       | Resistors                                             | $0.65     |
| 1        | Voltage Connector                                     | $3.75     |
| 1        | Current Connector                                     | $5.13     |
| 2        | Phenolite Double-layer Printed Circuit Board 100x100mm | $2.20     |
| 4        | Phenolite Single-layer Printed Circuit Board 100x100mm | $2.05     |
| 1        | Wire Soldering Tube                                   | $1.50     |
| Total    | ---                                                   | $15.28    |

Source: The author.

For a more coherent cost quantification, even the prototype being assembled by the technicians of the laboratory, we also considered the expenses involved in the construction and with the measurements for characterization of the shunt. Table 2 shows the values for personnel costs and calibration.

| Quantity | Description  | Total(U$) |
|----------|--------------|-----------|
| 20       | MH estimate  | $335.00   |
| 1        | Calibration  | $350.00   |
| Total    | ---          | $685.00   |

Source: The author.

With a total cost of $700.28, it is verified that around 50% refers to the calibration of the shunt, another 48% referring to personnel expenses. Remaining approximately 2% of the total cost related to the inputs needed to build the shunt. Given the low-cost requirements of the prototype, attention is focused on meeting the main technical parameters.

Our objective was the shunt to have an AC-DC difference with a flat response in frequencies from 10 Hz to 100 kHz, considering, as ideal, values smaller than 10 $\mu$A/A for frequencies up to 10 kHz and...
15 μA/A at frequencies above 10 kHz. This frequency range is relevant due to the calibration needs of instruments that generate currents that can reach up to 100 A in 100 kHz [6].

3. Results
For evaluation of the developed prototype, a series of tests was performed. Among them, we highlight the analysis of the AC-DC difference, obtained through the shunt calibration, the long-term stability evaluation, through a series of calibrations performed in the Laboratory of Metrology in Electrical Standardization (Lampe) in the period of approximately one year, short-term stability analysis and calibration analysis of a current source using the FDQ-01 prototype developed in comparison with the reference system. The results obtained are shown below.

3.1. AC-DC difference analysis
For this analysis, four (4) calibrations were performed, with frequencies between 10 Hz and 100 kHz. The nominal shunt current, 1 A, was applied and the AC-DC difference compared to the standard was measured. The results obtained were compared to the limits specified in the project and demonstrate that the flat response requirement across the frequency range of interest was fully achieved.

3.2. Temporal stability analysis
To analyze the temporal stability, four calibrations were performed within one year. The initial calibration, the second calibration after two months, the third after four months and the fourth about eleven months after the initial calibration. The results of the calibrations can be observed in figure 4, where the overlap of the dots shows that the measurements are stable and repetitive, with their variation much smaller than the uncertainty of the calibration itself at the measured point (error bars).
Table 3 shown the calculated stability values per year from the calibration results and numerically indicates the uncertainty of the AC-DC difference measurement for each applied frequency. The calculated stability for one year is less than a half of the uncertainty, being up to 15 times lower in the 1 kHz frequency.

**Table 3 – Temporal stability of shunt prototype FDQ-01**

| Frequency | Uncertainty (µA/A) | Stability (µA/A/year) |
|-----------|--------------------|-----------------------|
| 10 Hz     | 8.5                | 1.7                   |
| 20 Hz     | 8.1                | 0.6                   |
| 30 Hz     | 8.1                | 0.9                   |
| 40 Hz     | 8.1                | 0.9                   |
| 55 Hz     | 8.1                | 2.0                   |
| 62 Hz     | 8.1                | 1.4                   |
| 65 Hz     | 8.1                | 1.2                   |
| 120 Hz    | 8.1                | 1.3                   |
| 500 Hz    | 6.5                | 1.2                   |
| 1000 Hz   | 7.4                | 0.5                   |
| 5000 Hz   | 7.7                | 2.1                   |
| 10000 Hz  | 8.7                | 2.1                   |
| 20000 Hz  | 11                 | 1.1                   |
| 50000 Hz  | 12                 | 4.2                   |
| 70000 Hz  | 16                 | 4.4                   |
| 100000 Hz | 18                 | 7.5                   |

Source: The author.
3.3. Thermal stability analysis
For this analysis, the current difference between two successive measurements at 1 second intervals were measured by comparing a commercial Fluke A40-1A shunt to the prototype shunt FDQ-01, during the time interval typically used during a calibration. It is observed that from 100 seconds the difference drops to approximately zero. Considering that during the calibration the heating time is at least two minutes, it is noticed that both shunts reach the thermal stability before the beginning of the measurements and demonstrate a similar behavior.

![Figure 5 - Stability comparison of shunt Fluke A40-1A vs. shunt prototype FDQ-01](image)

3.4. Comparison with calibration performed using the reference system
To validate its use as standard, measurements were made of a digital calibrator of high accuracy in the 1 A current at the frequencies of 1, 5 and 10 kHz, using the reference system, composed of a Fluke 792A AC-DC converter and a set of Fluke A40 shunts and later using the prototype developed in conjunction with the same AC-DC converter. Table 4 shows the values obtained at each frequency and the normalized error of the comparison calculated for each point.

| Frequency (kHz) | Shunt Fluke A40-1A (A) | Uncertainty shunt Fluke A40-1A (A) | Shunt FDQ-01 (A) | Uncertainty shunt FDQ-01 (A) | Normalized error (En) |
|----------------|------------------------|-----------------------------------|------------------|----------------------------|----------------------|
| 1              | 0.999984               | 0.000020                          | 0.999981         | 0.000019                   | 0.11                 |
| 5              | 0.999676               | 0.000020                          | 0.999663         | 0.000019                   | 0.46                 |
| 10             | 0.999376               | 0.000021                          | 0.999373         | 0.000019                   | 0.12                 |

Source: The author.
4. Conclusions

The objective of this work was fully achieved, since a low-cost current shunt and adequate metrological performance was constructed and characterized, fully meeting the design requirements. The use of the FDQ-01 prototype shunt as standard was shown to be feasible. The materials needed and the way of assembly are simple and allow your design to be explored at a low cost. The components necessary for its assembly are easy to obtain, even in the national market. This work also allows the construction of a set of shunts for others current values, based on design and evaluations performed on the FDQ-01 prototype.

References

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