Ac-dc transfer standard shunts for frequencies up to 1 MHz

U. Pogliano, C.G. Bosco, M. Lanzillotti, D Serazio

Istituto Nazionale di Ricerca Metrologica (I.N.RI.M.)
Strada delle Cacce 91 10135 Torino - Italy
tel. +39 011 3919.433, e-mail: pogliano@ien.it

Abstract - A new type of coaxial shunt for high frequency ac-dc current transfer standards has been designed. The structure of the shunts with nominal current from 100 mA to 5 A are made of a disk with two coaxial conductive layers in one side. SMD resistors are soldered in parallel between the two layers. Two conductive screens are applied in both side of the disk. In order to reduce stray effects, the structure has ideally no common magnetic interaction between the input current and the output voltage and practically a very low section where the magnetic field is confined, so allowing a flat response in a wide frequency range.

I. Introduction

The request for ac current calibration, which was previously limited to frequencies up to 10 kHz, has now evolved. New multifunction calibrators and transconductance amplifiers have been produced that require the calibration of frequencies up to 1 MHz. Consequently, there has been an increasing interest for the measurement of ac currents in an extended frequency range. This interest is confirmed by the decision of CCEM (Consultative Committee for Electricity and Magnetism) to organise an international key comparison (CCEM K 12) for current up to 5 A and frequency up to 100 KHz.

In primary metrological laboratories the reference for ac electrical current is obtained at the best level of accuracy by means of ac-dc thermal converters, even if, for currents that exceed 20 mA, the direct measurements by means of thermal converters is not possible. So, for these currents, shunts are generally used. The resulting ac voltage at the output of the shunt is then compared to the dc one by means of a thermal converter operating as voltage ac-dc transfer standard.

Shunts, connected with suitable single-junction or multijunction thermal converters at their output, act as current ac-dc transfer standards and can be compared between themselves in a step up procedure, which allows to extend the traceability from 10 mA, where the basic reference standard is maintained, to 20 A and more.

At I.N.RI.M. the traceability for current measurement was established many years ago, and it was based on a set of commercial shunts that are connected in parallel with single junction thermal converters. The standard was maintained for current up to 20 A up to 10 kHz and, in a more limited region (up to 2 A), the operating frequency was also extended up to 100 kHz [1], and particular devices were built for their measurements [2].

However, the models of shunts commercially available have been designed several years ago for operating in the frequency range lower than 20 kHz, and their contribution to the total ac-dc difference is not negligible at higher frequencies. In order to improve the ac-dc transfer standard of current a set of shunts to be used with multijunction thermal converters is now under development.

II. The proposed approach

The design of a set ac high frequency shunts to be used for the ac-dc transfer standard of current is based on the following considerations:

- The shunts have to be applied to thermal elements operating at a voltage level up to 1 V and, to have a sufficient sensitivity, at the nominal current the voltage must be at least 200 mV. Then, apart the 10 mA range directly measured with the thermal converters without shunts, the set of shunts must cover, in the best way, all the current range. The solution adopted is shown in table I. In particular, at least two shunts can be used for any given current (for example both shunts B and C can be used for currents from 50 mA to 100 mA).

- For currents higher than 200 mA, where the power is not negligible, the devices should dissipate, with a limited increment in internal temperature, the heat both by radiation from the container and by conduction through the connectors.
- For high frequency the stray reactive parameter should be reduced to a minimum.

Table I Characteristics of the shunts designed

	Nominal current	Shunt resistance	SMD resistors	Resistance of each resistor
A	5 - 20 mA	100 Ω	1	100 Ω
B	20 - 50 mA	20 Ω	1	20 Ω
C	20 - 100 mA	10 Ω	10	100 Ω
D	50-200 mA	5 Ω	10	50 Ω
E	100 - 500 mA	2 Ω	10	20 Ω
F	200 mA -1 A	1 Ω	10	10 Ω
G	500 mA - 2 A	0.5 Ω	10	5 Ω
H	1 - 5 A	0.2 Ω	25	5 Ω

In order to comply with the design requirements, different approaches can be undertaken as, for example those described in [3] and [4]. The power dissipated at higher currents requires not negligible dimensions of the shunts and a careful design of the thermal system. For the dimensions required, a particular attention has to be devoted to the reduction of the stray parameters. The resistance is generally low, so the predominant stray parameters for these shunts are the variation of the resistance as a frequency function, the capacitance between the resistors and the screens, the inductance in the voltmetric circuit and the mutual inductance between the amperometric and the voltmetric circuits. A simplified circuit for the evaluation of the influence of the stray parameters is represented in Fig. 1.

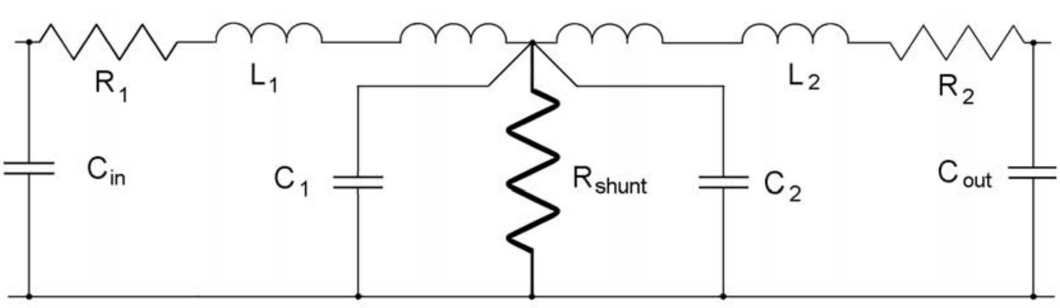

Fig. 1 Simplified circuit of the shunts

Applying the simplified circuit with stray parameters evaluated by the geometrical dimensions of the elements the following results can be derived.
In all cases the variation of the ac-dc transfer difference is related to the variation of the resistance of the shunt (R_{shunt}) in ac with respect to the dc. Furthermore, for low current shunts (less than 100 mA) the more critical parameters that limits the operating frequency are the stray capacitances, while for shunts for higher currents critical parameters are the mutual inductance between the amperometric and the voltmetric circuit.

So, in order to reduce these effects the resistors have been specifically selected for their low variation with the frequency.
Then, for the resistors A and B a very simple structure has been employed: a resistor is simply connected between the central conductor and a returning wire at the potential of the external coaxial screen and, in order to reduce all the stray capacitances, the connection between the input and the output is as short as possible.

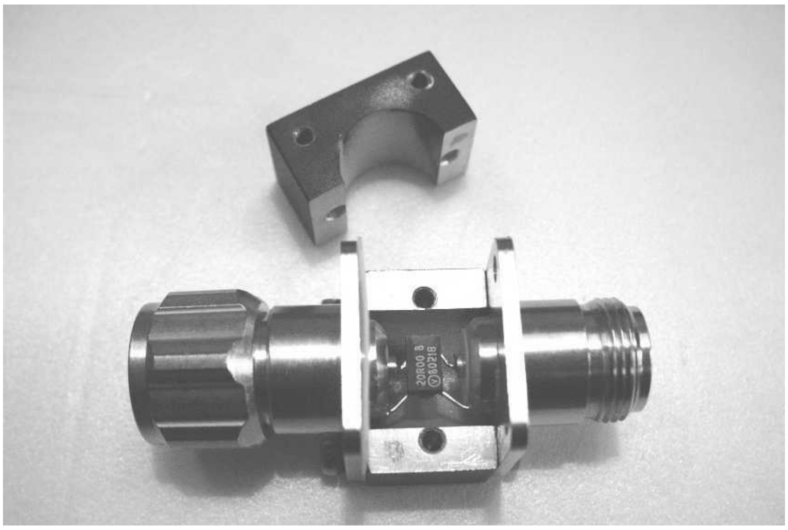

Fig. 2 Photograph of a shunt for 50 mA.

In the shunts for higher currents, the inductance of the amperometric circuit and the mutual inductance between the amperometric and the voltmetric circuit are reduced by the geometrical design similar to a disk resistor.
The basic structure of the shunts is quasi-coaxial, as is represented in Fig. 3.

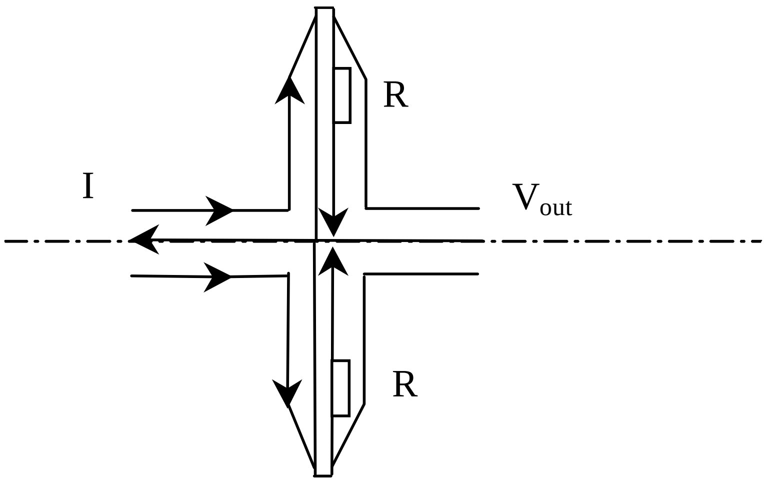

Fig. 3 Basic scheme of the shunt with the current path.

Ideally, the resistor is a coaxial disk and the amperometric circuit has a minimum transversal space where the magnetic field is confined.

The mechanical construction of a shunt consists of a disk of insulating material with two coaxial conductive layers. In one side the conductive layer is removed apart from the external border and, in the other, a ring is removed by a proper machining. The conductive parts and the external edges connecting the two sides are coated with gold and SMD resistors are soldered across to the insulating ring (Fig. 4).
Then, two circular covers for the voltmetric and the amperometric circuit are built (Fig. 5) and finally all the assembly is mounted with the two connectors in a suitable container with thermal dissipator. The space between the covers and the dissipator is filled with thermally conductive epoxy resin.

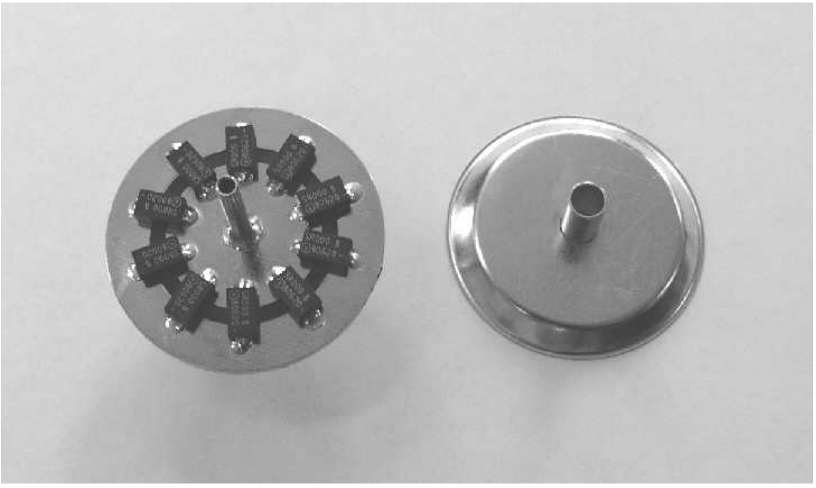

Fig. 4 Internal disk and cover of the shunts for currents from 100 mA to 2 A.

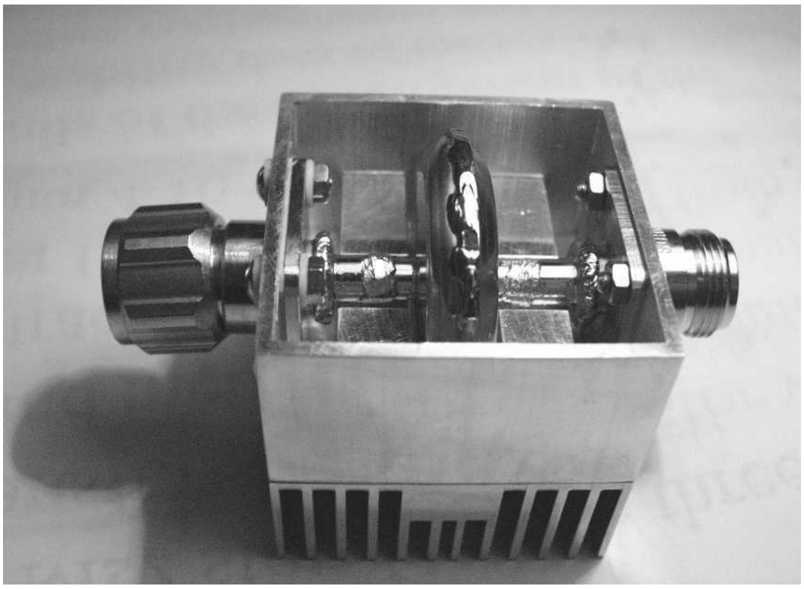

Fig. 5 Photograph of a shunt for 2 A.

III. Results

A complete characterization of the whole set has not been completed yet. However, some test have been performed on the shunt for nominal current of 2 A, built with ten 5 Ω resistors in parallel on a disk of 42 mm of diameter, which is the most critical one as ratio between the power and the surface.
At nominal current, the temperature raise on the disk is less than 20 K and the resistance variation between the zero and nominal current is less than 5 part in 10^5. This variation does not normally influence a lot the ac-dc transfer difference, if the thermal equilibrium is reached and the switching between ac and dc are sufficiently fast.
The inductive stray parameters were evaluated at reduced current (200 mA) by connecting this shunt in series with another coaxial shunt for lower currents. The phase difference between the two output voltages, with respect to the reference, measured at 1 MHz by means of a high frequency look-in, was lower than 50 mrad.
The comparison with the ac-dc transfer standards shows that the ac-dc transfer differences up to 100 kHz are within the limit of present accuracy of the standard (40 parts in 10^6).

IV. Conclusions

A set of coaxial shunts for the ac-dc transfer standard of current has been built at I.N.RI.M. for improving the level of the uncertainties in the current measurement for an extended frequency range (up to 1 MHz). This new set, built by means of SMD resistors, approximate the magnetic field produced by a disk resistor.
Preliminary tests show the possibility of high stability of the ac-dc transfer standard using these shunts and a very low stay parameters, which indicate a flat frequency response.
Measurements of whole set in a step-up procedure starting from 10 mA will allow to characterize each shunt of the set with high accuracy, so improving the ac-dc transfer standard of current.

V. Acknowledges

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