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AC Resistance Measurement System at CEM

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Abstract **– This paper describes the ac resistance measurement system developed at CEM. It consists on a four terminal-pair coaxial bridge that allows the measurement of ac resistance with traceability to dc resistance by means of a calculable resistor with a nominal value of 10 kΩ. This coaxial bridge enables the determination of ac resistance standards between 1 Ω and 100 kΩ, in a range of frequencies from 40 Hz to 5 kHz, with an expanded uncertainty between 1 µΩ/Ω and 5 µΩ/Ω, depending on the nominal value of the resistor and the measurement frequency.**

Keywords **–ac resistance, calculable resistor, four terminal-pair, coaxial bridge**

I. INTRODUCTION

Ac resistance measurements are required in many industrial applications and the development of this four terminal-pair coaxial bridge to measure like-impedance (two resistors or two capacitors) establishes the Spanish measurement capacity in this field.

A quadrifilar resistor of nominal value of 10 kΩ was used as reference standard in an ac resistance ratio bridge to determine the resistance value of an unknown resistor. The calculable resistor was used to enhance frequency range from dc to 5 kHz and, according to Gibbing's theory [1], its ac-dc difference is small and can be computed on the basis of its dimensions and the properties of materials employed.

For a ratio 1:1 measurement, the deviation δ of the ratio transformer from the nominal 1:1 ratio can be eliminated by a reversal measurement but for a 10:1 ratio the transformer calibration is necessary. At CEM the transformer was calibrated by means of a straddling method [2].

In this paper, the four terminal-pair coaxial bridge and the calculable resistor employed as reference are described in detail. Results and uncertainties are also presented.

II. RELATED RESULTS IN THE LITERATURE

In most National Metrology Institutes (NMIs) the ac resistance is linked to dc resistance unit by special resistors having calculable ac–dc differences [3, 4]. There are also a number of papers on construction and characterization of these calculable resistors [5-7], paying special attention to frequency dependence.

As national industry require, NMIs establish ac resistance bridges to obtain ac resistance from dc resistance. Despite of the complexity of the system, the four terminal-pair coaxial bridge is the most employed system thanks to its good stability, very low uncertainty, and isolation from external noise sources. These properties have led CEM to the development of a four terminal-pair coaxial bridge for the ac resistance measurement.

III. DESCRIPTION OF THE METHOD

A. Calculable Resistor

In the ac resistance system the reference standard is a 10 kΩ quadrifilar coaxial resistor manufactured by N.L. Engineering. This resistor is constructed in such a way that their frequency can be accurately calculated from the knowledge of its geometry and material properties. The calculable resistor ac value can be expressed as:

$$R_{ac} = R_{dc}(1 + \Delta(f)) \qquad (1)$$

being R_{dc} the calculable resistor value measured with dc energisation and traceable to Quantum Hall Resistance and $\Delta(f)$ the resistance frequency dependence [8]. The frequency dependence of the quadrifilar resistor was evaluated at CEM from a uniform-transmission-line

model based on Gibbing's theory [1] and the results obtained are shown in Fig.1.

This calculable resistor is used as reference standard in the four terminal-pair coaxial ratio bridge that allows the determination of an unknown ac resistor value.
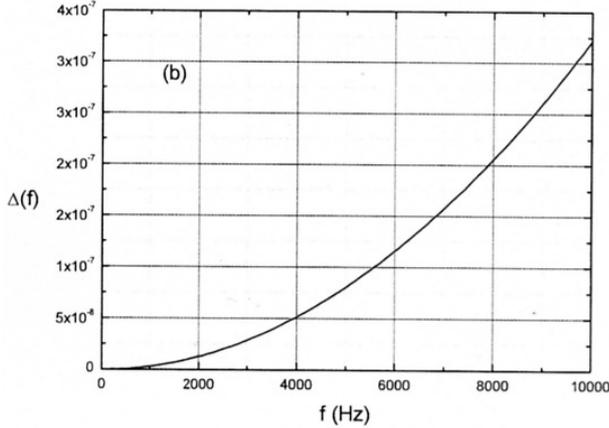

Fig. 1. Frequency characteristic of the quadrifilar calculable resistor.

B. Four terminal-pair coaxial ratio bridge.

The measurement system is a four terminal-pair coaxial ratio bridge to measure like impedances. It is very stable and allows very low uncertainties. The basic principle of the ratio bridge to measure the ratio of two like impedances is shown in Fig. 2. The resistance ratio is obtained comparing the voltage dropped in each resistor (Z_{+1} and Z_{-1}) when a common current flows through them, with the output voltages (V_{+1} and V_{-1}) of an ac voltage ratio transformer. To balance the bridge, in-phase and quadrature currents must be injected. These injections are generated by means of inductive voltage dividers. In-phase injection is performed through a two-stage coil (ΔV_1 and ΔV_2) with a 1:100 ratio, which is part of the standard transformer (T_R), and the quadrature current is generated by using an auxiliary capacitor C_{injec}.
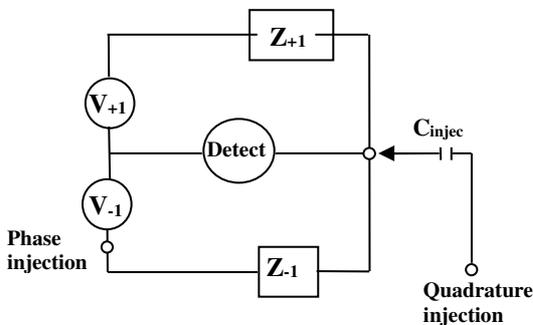

Fig. 2. Basic principle of the ratio bridge.

The circuit scheme of the coaxial ratio bridge can be seen in Fig. 3. In the diagram, the standard transformer

(T_R) and the current equalizers are shown.

For two resistors having the same nominal value (ratio 1:1 measurement), the deviation δ of the ratio transformer from the nominal 1:1 ratio can be eliminated by a reversal measurement, interchanging both resistor positions in the measurement bridge. However, for a 10:1 ratio the transformer calibration is necessary to assure traceability. At CEM the transformer was calibrated by means of a straddling method (see Fig.4) [9]. This system, based on the straddling method with triaxial guards, compares the constant output voltage V_0 of a standard divider, constant in normal and reversed position, with the two unknown voltages of the divider under test, V_{+1} and V_{-1}. This setup allows the calibration of the transformer standard employed in the ac resistance ratio bridge for all the frequency range with an expanded uncertainty of 0.07 µV/V.

IV. NOVELTIES IN THE PAPER

In order to validate the coaxial bridge two calculable resistors of the same nominal value were compared in 1:1 ratio at several frequencies. The 10 kΩ quadrifilar calculable resistor by N.L. Engineering was the reference and a 10 kΩ bifilar calculable resistor by Semenov [10] was the resistance to be determined. To minimize uncertainty related to resistance temperature changes the quadrifilar resistor has a thermostable enclosure to regulate temperature and the bifilar resistor is placed inside an oil bath during the measurement.

The resistance of the bifilar resistor was obtained and the time constant was measured on the basis of the calculated time constant of the quadrifilar calculable resistor in the range of frequencies from 40 Hz to 5 kHz. The maximum frequency is principally due to the limitations of the bridge measurement system, and it could be improved up to 10 kHz. Results agree with the ac value of the bifilar resistor within the uncertainty interval. Expanded uncertainties depend on the frequency and range from 1 µΩ/Ω at 40 Hz to 5 µΩ/Ω at 5 kHz. The main contribution to the final expanded uncertainty is type A contribution, specially at lowest and highest frequencies, where it is more difficult to achieve a good accuracy with the measurement system. Other meaningful uncertainty contributions are the type B contributions arising from the ac-dc difference of the calculable resistors and from the deviation δ of the ratio transformer for a 10:1 ratio.

This system allows the measurement of ac resistors with nominal values between 1 Ω and 100 kΩ, departing from the 10 kΩ quadrifilar calculable resistor, in a 10:1 ratio. The ac resistance can be measured in a frequency range from 40 Hz to 5 kHz, with an expanded uncertainty ranging from 1 µΩ/Ω to 5 µΩ/Ω, depending on the resistor value and the measurement frequency.
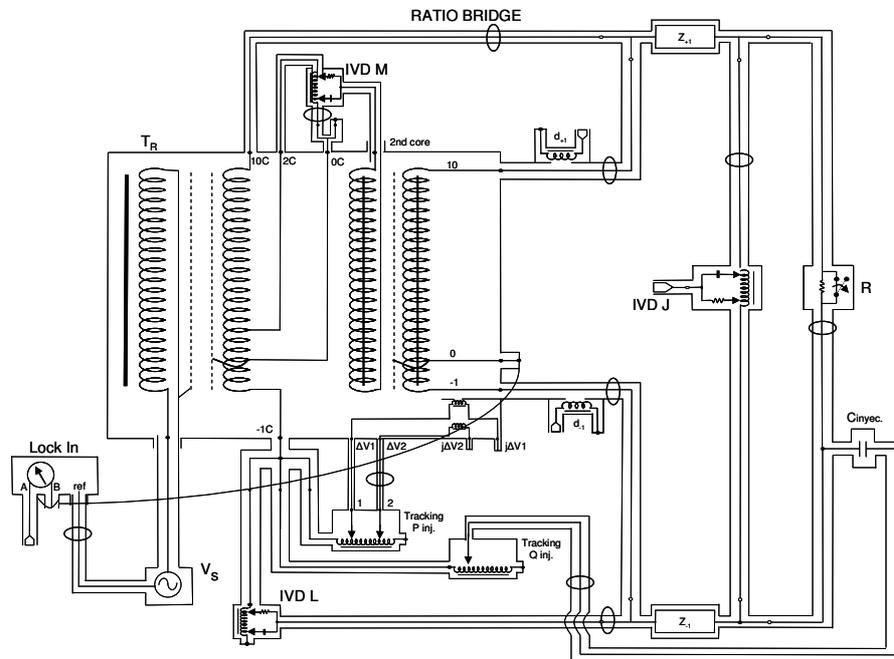
Fig. 3. Scheme of the four terminal-pair coaxial resistance ratio bridge
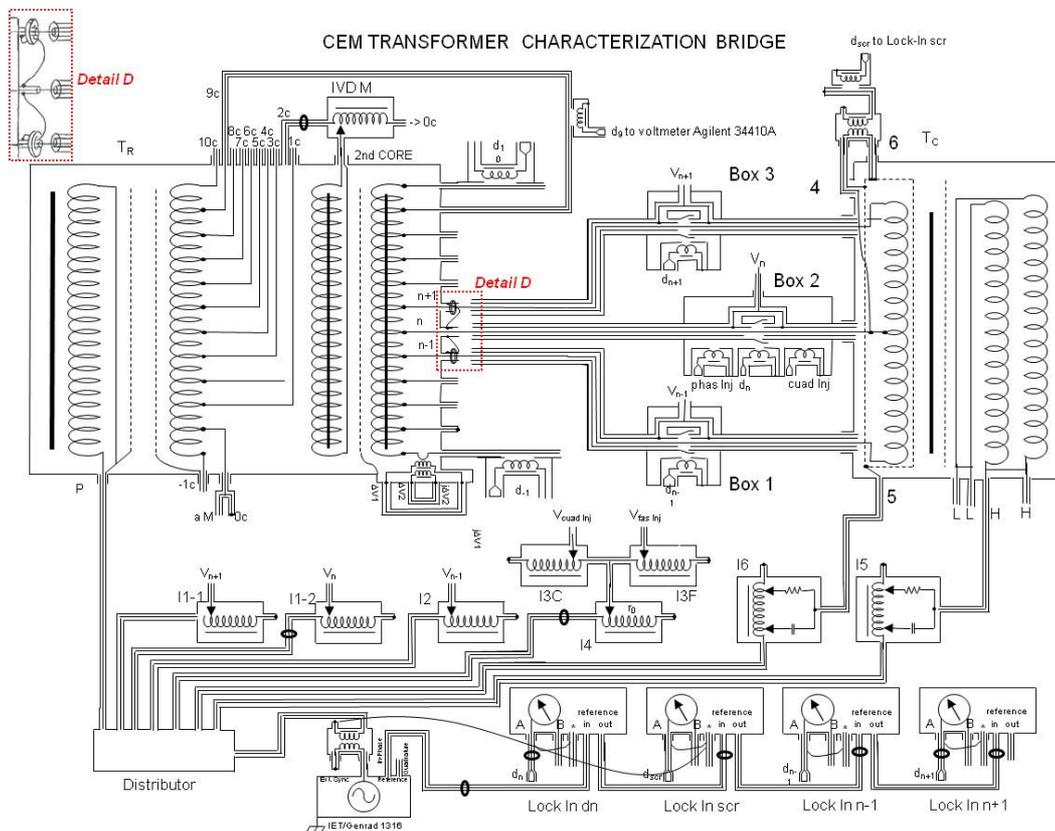

Fig.4. Scheme of the ac voltage ratio bridge for transformer characterization based on straddling method.

V. CONCLUSIONS

A four terminal-pair coaxial bridge has been developed for the measurement of ac resistance with traceability to dc resistance by means of a calculable resistor with a nominal value of 10 kΩ. This coaxial bridge allows the determination of ac resistance standards between 1 Ω and 100 kΩ, in a range of frequencies from 40 Hz to 5 kHz, with an expanded uncertainty between 1 μΩ/Ω and 5 μΩ/Ω, depending on the nominal value of the resistor and the measurement frequency.

The measurement system was validated by comparing to calculable resistors of the same nominal value and with known ac value in a 1:1 ratio. The results obtained agree within the uncertainty interval.

Further improvement of the ac resistance bridge will be the extension of frequency range to 10 kHz and the reduction of expanded uncertainty.

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