REFERENCE RESISTORS FOR CALIBRATION OF WIDEBAND LCR METERS

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Abstract: A set of resistance standards ranging from 100 Ω to 10 000 Ω and applicable to calibrations of wideband LCR meters has been prepared using surface mount metal foil resistors. Frequency dependences of these standards have been evaluated by comparing them with resistors having calculable frequency performance.

Keywords: surface mount resistor, calculable resistor, LCR meter.

1. INTRODUCTION

At present, many commercial LCR meters measure impedances at frequencies up to 1 MHz with uncertainties less than 0.1 %. These meters proved to be useful tools for component and material characterization and are extensively used in a range of fields (research and development, quality assurance, incoming inspection, etc.). It is necessary to have a number of reference resistance and capacitance standards for calibrations of these bridges and traceability to relevant national standards is required when these calibrations are made at accredited laboratories.

At the Department of Measurements, Faculty of Electrical Engineering, Czech Technical University coaxial transformer bridges are available which make it possible to calibrate resistance, capacitance and inductance standards at frequencies up to 5 kHz by linking them with AC quantized Hall resistance [1]. Of course, these standards, in turn, can be used as references in calibrating LCR meters at frequencies higher than 5 kHz if their frequency dependences are known, which enables calculation of their values for higher frequencies from the results of the quantum Hall effect based calibrations made in the low frequency range.

Miniturization being one possible way of reducing residual impedances and frequency dependences of impedance standards, various possibilities of making high-frequency standards from surface mount capacitors and resistors have been investigated recently [2-3]. Mainly surface mount capacitors made from NP0 ceramic materials are used in capacitance standards because of their small temperature and voltage coefficients and their acceptable dissipation factors. More capacitors are connected in parallel in standards of higher values. As an example, capacitance element of a 10 nF standard formed by ten 1 nF SMD 1206 capacitors is shown in Fig. 1. Fig. 2 shows frequency dependence of the series equivalent capacitance C_s of this
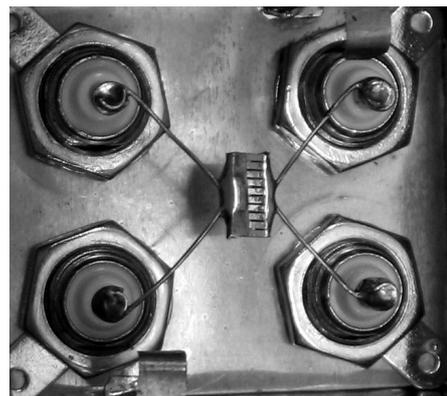
Fig. 1. Capacitance element of a 10 nF standard formed by ten 1 nF surface mount capacitors
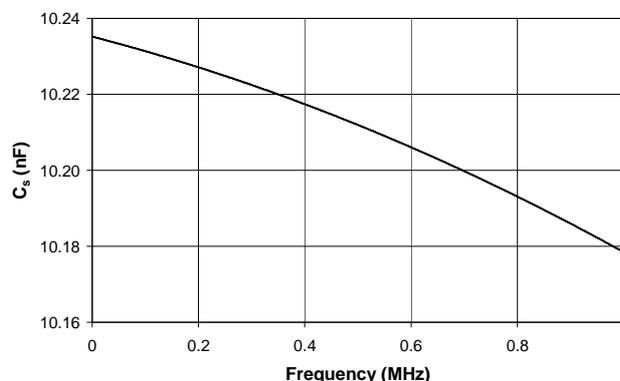
Fig. 2. Frequency depepndence of the series equivalent capacitance of the 10 nF standard of Fig. 1

standard, which has been obtained by direct measurement by means of an Agilent 4284A precision LCR meter.

In the high frequency resistance standards described in this paper surface mount metal foil resistors are used as resisitive elements.

2. RESISTANCE STANDARDS MADE FROM SURFACE MOUNT RESISTORS

Vishay SMR1D metal foil resistors have been used to realize standards of four terminal-pair design having nominal values of 100 Ω, 1 000 Ω and 10 000 Ω. Main advantages of these resistors are high adjustment accuracy (0.02 % for 100 Ω resistors and 0.01 % for 1 000 Ω and
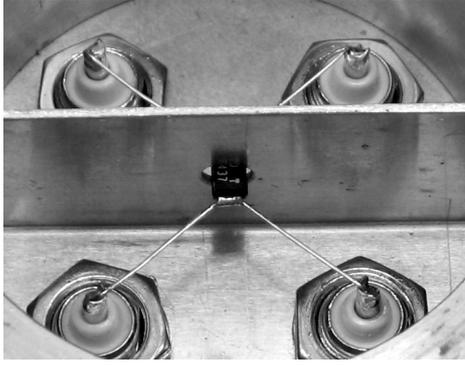
Fig. 3. 10 000 Ω resistive element formed by a SMR1D resistor

10 000 Ω resistors) and small temperature dependence of the value (temperature coefficient of +0.06 ppm/°C for temperatures from 0 °C to 25 °C and -0.06 ppm/°C for temperatures from 25 °C to 60 °C. The small physical size of the resistors ensures minimal self-inductance and the capacitance between the high and low ports and leads is minimized by inserting a shield (Fig. 3).

3. EVALUATION OF FREQUENCY DEPENDENCES OF THE REALIZED STANDARDS

Calculable resistors (resistors with calculable frequency dependence) of quadrifilar design [4] have been used as reference standards in measurements of frequency dependences of the 100 Ω and the 1 000 Ω resistor.

As can be seen from Fig. 4, resistive element of a quadrifilar resistor takes the form of a double loop arranged so that the current flows in opposite directions in its two halves. With such an arrangement, magnetic fluxes produced by the two halves of the loop tend to cancel.

In calculating frequency performance of a quadrifilar resistor, changes in resistance arising from parasitic inductances and capacitances, as well as from eddy currents induced both in the resistive element itself and in the conducting shield, have to be evaluated. A uniform transmission line model is used in the calculation of the effect of parasitic inductances and capacitances. Whilst inductances and capacitances of the cables interconnecting the ports PL, CL, CH and PH with the ends of the resistive

PL CL CH PH
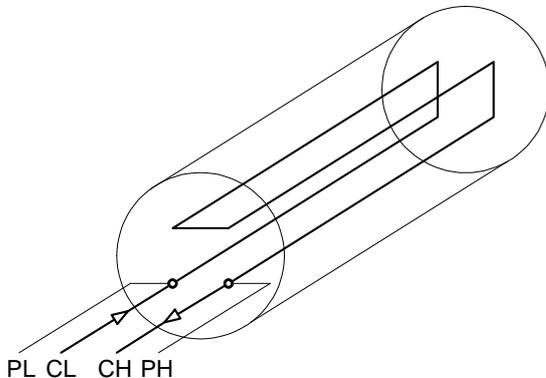
Fig. 4. Schematic of a quadrifilar resistor

element are measured by means of an LCR meter, all remaining parasitic inductances and capacitances are calculated from dimensions of the element and the shield.

Measurements of frequency dependences of the 100 Ω and the 1 000 Ω resistor (VR 100 and VR 1000) have been made by 1:1 comparisons with quadrifilar resistors of the same nominal value (QR 100 and QR 1000). Resistive elements of these resistors are surrounded by copper cylindrical shields and are made from bare resistive wires (Zeranin wire in case of QR 100, Nikrothal wire in case of QR 1000). In Tables 1 and 2 constructional parameters are given, from which frequency dependences of QR 100 and QR 1000 have been calculated. Graphs of these dependences are in Figs. 5 and 6.

Table 1. Constructional parameters of QR 100

Wire diameter (mm)	0.052
Wire resistivity (Ωm)	4.57×10^{-7}
Distance between adjacent wire elements (mm)	10
Distance between wire elements and axis of the shield (mm)	7.07
Folded length of resistive element (mm)	116
Inside shield diameter (mm)	116
Shield thickness (mm)	4

Table 2. Constructional parameters of QR 1000

Wire diameter (mm)	0.032
Wire resistivity (Ωm)	1.32×10^{-6}
Distance between adjacent wire elements (mm)	10
Distance between wire elements and axis of the shield (mm)	7.07
Folded length of resistive element (mm)	142
Inside shield diameter (mm)	116
Shield thickness (mm)	4
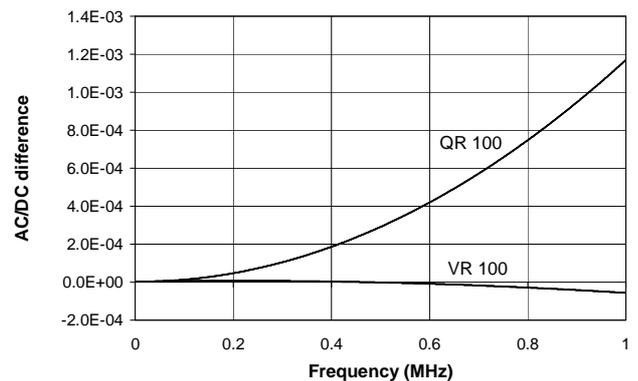
Fig. 5. Frequency prerformances of resistors QR 100 and VR 100. AC/DC difference = relative change of resistance from its DC value

An Agilent 4284A precision LCR meter was used in 1:1 comparisons of VRs and QRs. The procedure was as follows:
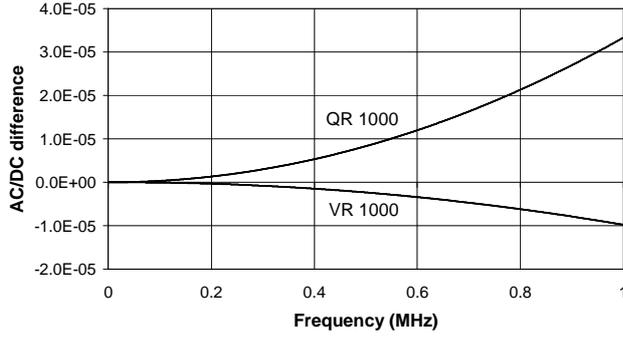
Fig. 6. Frequency performances of resistors QR 1000 and VR 1000

1) For a number of appropriately-spaced frequencies f_k, $k = 1, \ldots, n$, resistances $R_{VR}(f_k)$ and $R_{QR}(f_k)$ were measured. These resistances can be expressed as

$$R_{VR}(f_k) = R_{VR0}\left[1 + \alpha_{VR}(f_k)\right] \qquad (1)$$

and

$$R_{QR}(f_k) = R_{QR0}\left[1 + \alpha_{QR}(f_k)\right] \qquad (2)$$

where R_{VR0}, R_{QR0} are their DC values and $\alpha_{VR}(f_k)$, $\alpha_{QR}(f_k)$ their AC/DC differences.

2) Ratios

$$\frac{R_{VR}(f_k)}{R_{QR}(f_k)} = \frac{R_{VR0}}{R_{QR0}} \frac{1 + \alpha_{VR}(f_k)}{1 + \alpha_{QR}(f_k)} \qquad (3)$$

have been calculated and, by extrapolation to zero frequency, ratio R_{VR0}/R_{QR0} has been determined.

3) Since $|\alpha_{VR}(f_k)| \ll 1$ and $|\alpha_{QR}(f_k)| \ll 1$, ratios (3) can be approximately expressed as

$$\frac{R_{VR}(f_k)}{R_{QR}(f_k)} \cong \frac{R_{VR0}}{R_{QR0}}\left[1 + \alpha_{VR}(f_k) - \alpha_{QR}(f_k)\right] \quad (4)$$

Then

$$\alpha_{VR}(f_k) \cong \alpha_{QR}(f_k) \frac{R_{VR}(f_k)}{R_{QR}(f_k)} \frac{R_{QR0}}{R_{VR0}} - 1 \quad (5)$$

In Figs. 4 and 5 AC/DC differences of VR 100, QR 100 and VR 1000, QR 1000 are plotted as functions of frequency.

Once the frequency dependence of VR 100 or VR 1000 is known, this resistor can serve as a reference in measuring frequency dependences of resistors of lower or higher decimal values by a step-down or step-up procedure using a 10:1 four terminal-pair bridge. A bridge with inductively coupled ratio arms is being developed for this purpose.

To be used as ratio arms of this bridge, various versions of a 10:1 inductive voltage divider have been prepared recently. As an example, Fig. 6 shows a two-stage test divider which has been wound on two nanocystalline Vitroperm toroidal cores. Exciting winding of this divider has 44 turns, ratio arms are formed by 4 and 40 turns. While the exciting winding is wound on one core only, ratio
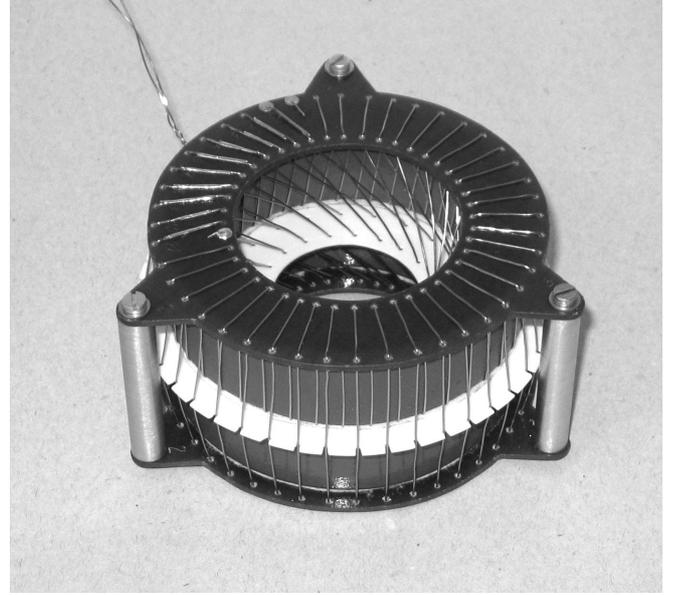
Fig. 7. 10:1 divider

winding is wound around both cores and has been realized as follows:

The circumference of the toroid formed by the stacked cores has been divided into 4 sectors with 11 positions, and 11 conductors have been used to realize the ratio winding. Starting with the first conductor, 1 turn of it was wound on the first position of the first sector, 1 turn on the first position of the second sector, 1 turn on the first position of the third sector and 1 turn on the first position of the fourth sector. Continuing with the second conductor, 1 turn of it was wound on the second position of the first sector, 1 turn on the second position of the second sector, etc. After all remaining conductors were wound in a similar manner, the conductors were connected in series to form the ratio winding, and a tapping lead has been connected to the junction of the first and the second conductor.

Tests of the realized divider have shown that, as expected, the exciting winding does not improve accuracy at higher frequencies. This winding will be omitted in the final version of the ratio arms for the 10:1 bridge.

CONCLUSION

Inexpensive resistance standards applicable to calibrations of wideband LCR meters have been prepared using surface mount metal foil resistors. Additional measurements of frequency performances of these standards are planned in which monofilar coaxial resistors with calculable frequency perfomance [3] will serve as references.

ACKNOWLEDGMENTS

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