Evaluation of a ASR-103

10 kΩ resistance standard

of Alpha Electronics

- snr 98F0353 -

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1. Introduction

Until recently, the national standard of resistance in many countries was formed by a set of 1 Ω resistors. A second reference group was maintained at the level of 10 kΩ, in order to provide a starting point for measurement of high ohmic resistances. The discovery of the quantum Hall effect (QHE) changed this situation. The most important advantage of the QHE is the fact that it is a quantum standard, so that it does not depend on the environment or on time. The QHE itself is now often the formal national standard, replacing the former 1 Ω resistors. The value of the QHE plateaus is 25812.807/n Ω with n an integer, mostly 2 or 4 so that the reference levels are 12 906 Ω and 6 543 Ω respectively. Using a cryogenic current comparator, 100 Ω resistance standards are directly measured against the QHE. This increased the need for good quality resistors at the 100 Ω level. The 10 kΩ resistors are still important as the starting (reference) point for higher ohmic values. In addition, the 10 kΩ value is close to the QHE values so that these resistors can also be measured directly against the QHE, using highly stable and linear digital voltmeters (DVMs) [Riet96, Riet98]. Two recent reviews are available in the literature that describe the state of the art in resistance measurements and the quantum Hall effect [Witt98, Jeck01].

A good resistor has several properties a.o.:

- A small drift in value per year.
- A small temperature coefficient and a no hysteretic effects upon variations in temperature.
- A good travelling behaviour (insensitive to shock).

At the highest level of resistance measurements, also the pressure and humidity may become relevant parameters influencing the resistance value. The travelling behaviour of a resistor is especially important if the resistor is to be used in (international) comparisons.

In this report the results are presented of an evaluation of an ASR-103 resistor with a value of 10 kΩ, made by Alpha Electronics, Japan. The evaluation concentrated on measurement of the drift in time. In the evaluation the behaviour of the ASR-103 resistor is compared to that of the TEGAM / ESI SR104 resistor. The SR104 type of resistors is used in many laboratories as the reference at the 10 kΩ level.

2. Data of the ASR-103 resistor

Figure 1 shows some pictures of the evaluated resistor. The general datasheets of this type of resistor is given in appendix 1. The resistive element is of the metal foil type, based on the type HK of Alpha electronics (zero TCR, hermetically sealed). There are several advantages of metal foil type resistors over the normal wire wound ones: compact size, a small temperature coefficient, and a low inductance and capacitance. This latter property is especial useful in applications with ac current. The temperature coefficient is made small by a cancellation of the temperature dependence of the metal foil by the dependence caused by the expansion of the substrate onto which the foil is glued. The low inductance and capacitance is achieved by the planar geometry of the resistive element.

The hermetical sealing of the resistive element helps diminishing external influences on the resistance value, like those of humidity and pressure.

a) b)

Figure 1. Photographs of the evaluated ASR-103 resistor.

The temperature dependence *R*(T) of the resistance value of a resistor can be modelled by

$$R(\mathrm{T}) = R_{23} + \alpha_{23} \cdot \Delta T + \beta_{23} \cdot \Delta T^2,$$

with R_{23} is the value of the resistor at 23 °C, α_{23} and β_{23} the linear and quadratic temperature coefficients at 23 °C respectively, and $\Delta T = T - 23$ °C with T the temperature in degrees Celsius. The temperature coefficients as measured by the manufacturer are:

α_{23} = +0.18 ppm/°C
β_{23} = -3.36 ppb/°C^2

These values are just within the specifications of the resistor (see appendix 1; temperature coefficient is specified as ≤ 2 ppm/°C). The temperature during the measurements at NMi varied between 22.0 °C and 23.0 °C. A fit was made to the raw measurement data with both time and temperature as variables. From this fit, the following value of the linear temperature coefficient was obtained:

$\alpha_{23,\ fit}$ = (+0.15 ± 0.02) ppm/°C

Since this value agrees well with the value given by the manufacturer, in the remaining data analysis, the value of α_{23} as given by the manufacturer was used in order to correct for temperature effects.

The evaluated resistor has the serial number 98F0353. The size of the box containing the resistor is quite convenient: 10 cm x 11 cm x 16 cm, and the weight of the box is 2.5 kg.

3. Measurement set-up

The measurement set-up used in the evaluation is based on high-resolution digital voltmeters (DVMs). Figure 2 gives a schematic depiction of the measurement set-up. The basic principle is that the ratio of the voltages across the two resistors is equal to their resistance ratio, if the same current is flowing through them. This furthermore assumes a perfect linearity of the DVM.

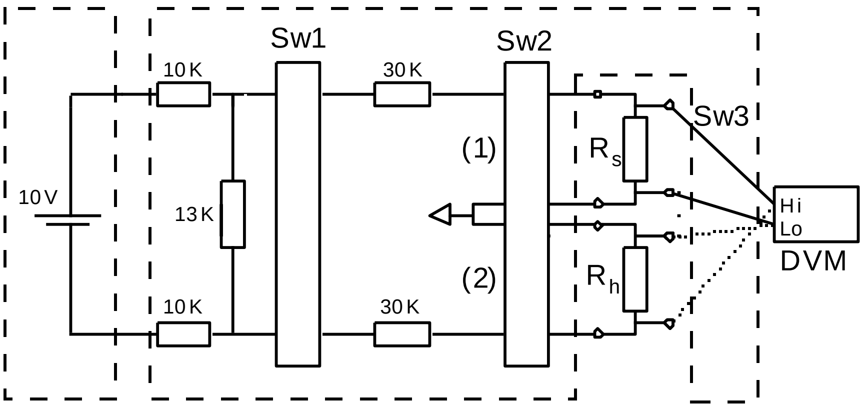


Figure 2. Schematic view of the measurement set-up used in the resistance evaluation with a 10 V voltage source, a relay box with relays and current determining resistors, and a long scale DVM. The resistance standards that are compared, Rs and Rx, are in position 1 and 2 respectively. The low of the DVM is always near ground.

A central element in the set-up is an automated switch-box (sw1 – sw 3 in figure 2), that arranges switching of the current polarity, switching of the DVM voltage connections and switching of the position resistors in the measurement circuit. The current is supplied by a battery operated zener-diode voltage reference. In the actual measurement set-up, two voltmeters are used in order to increase the number of data obtained in a certain measurement time and in order to check the results between the two DVMs. The voltmeters used are two HP3458A digital multimeters.

The measurements are completely automated, and a matrix scanner (not shown in figure 2) allows for comparison of a large series of resistors in one run. The noise is the measurements is 0.017 ppm for a 20 minute measurement. The total uncertainty of the set-up is approximately 0.04 ppm [Riet98]. This uncertainty is dominated by the non-linearity of the DVMs.

The cryogenic system for generating the quantum Hall effect is a ^{4}He cryostat that can reach temperatures of about 1.5 K with a 8 T magnet. Several quantum Hall effect samples were used that were well characterised before their use as resistance reference.

The whole measurement set-up is located in a Faraday cage which has a controlled environment (temperature and humidity). The temperature of the resistors is measured with a scanner system using thermistors as temperature sensors.

The ASR-103 resistor was received early July 2000, and the measurements were started immediately. However, the resistor needed some time to stabilise and only measurements after three weeks of stabilisation are taken into account in the present evaluation. The resistor was sent to the manufacturer in Japan in December 2001, and received back again in July 2002. After a stabilisation period, the resistor was again measured.

In the measurements, the resistor was compared directly against the quantum Hall effect, as well as against two ESI SR103 resistors from which the value was well known from measurements against the quantum Hall effect. The measurement time for the measurements against the QHE was approximately 20 minutes, and for those against the ESI resistors 45 minutes.

4. Measurement results and discussion

All measurements against the QHE, corrected for temperature coefficient of the resistor, are given in figure 3. First of all it is clear that the resistance value is quite close to nominal value, which is indicative of the measurement capability in the manufacturing process.

In figure 3, two lines are drawn. One is a least squares fitted straight line (dashed line) of the data from July 2000 until December 2001. The second line is a similar fit based on all data (solid line). It can be seen that the drift of the resistor is reasonably small, namely (0.106 ± 0.01) ppm/year. The noise of the measurements around the fit is 0.024 ppm. This is slightly more than the noise of the measurement set-up of 0.017

ppm (for a 20 minute measurement). This may be caused by the fact that the box containing the resistor has no thermometer well, so that the temperature of the resistive element cannot be accurately measured.

If the fit on the data before December 2001 is used to predict a value 9 months ahead (dashed line), in September 2002, the value differs only 0.02 ppm from the actual measured value. If a temperature coefficient of 0.15 ppm/°C is used in the analysis, the difference is even less than 0.01 ppm. This is a quite good result, given the relatively short history on which the prediction is based, as well as the fact that the standard has been travelling in this period from Europe to Japan and vice versa.

Figure 4 contains all measurement data, both those against the QHE, as well as those obtained from measurements against the two ESI SR103 resistors.

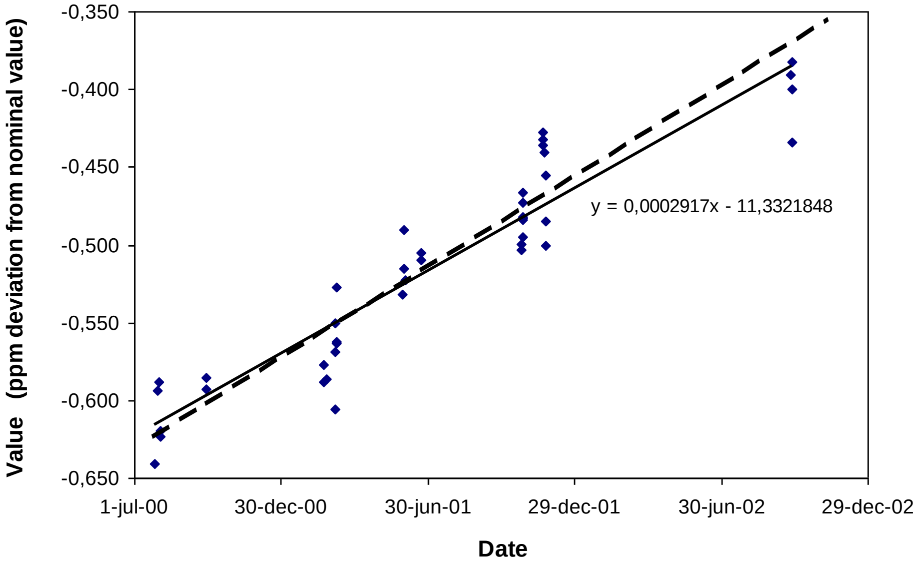


Figure 3. Results of the measurements of the Alpha Electronics SR103 resistor against the quantum Hall effect.

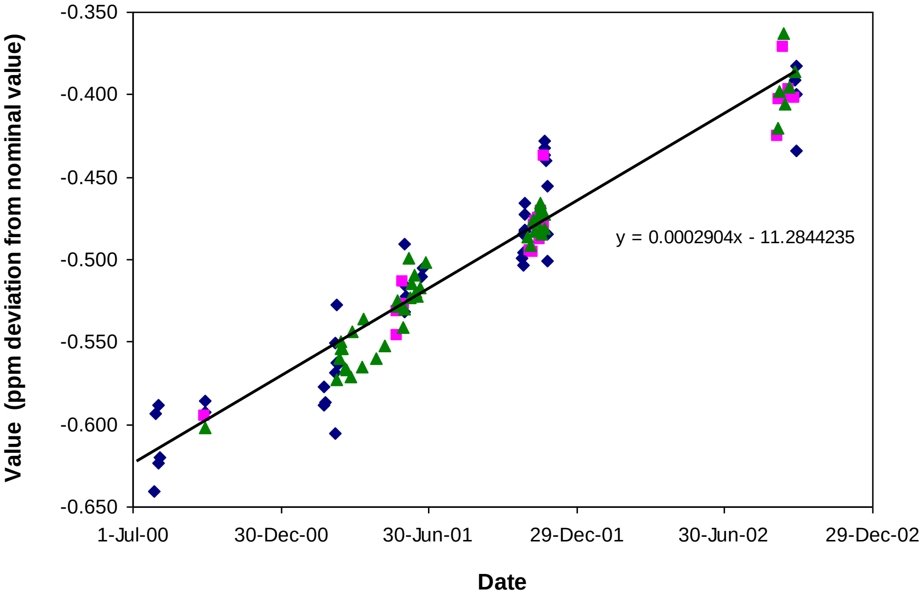


Figure 4. Results of the measurements of the Alpha Electronics SR103 resistor against the QHE (diamonds) and against two ESI SR104 resistors (squares and triangles).

5. Conclusions and recommendations

The ASR103 resistance standard is a high quality resistance standard. The box enclosing the resistive element has been very nicely finished off, and furthermore has a convenient size and weight.

The value of the linear temperature coefficient as given by the manufacturer, namely +0.18 ppm/°C, agrees well with the value obtained in our measurements, but is somewhat large compared to the best 10 kΩ resistance standards. Combined with the fact that there is no thermometer well in the resistor housing this leads to extra uncertainty in the measurements. The temperature measurement should be done with an uncertainty of better than 0.05 °C for final uncertainties in the resistance measurement of lower than 0.01 ppm.

The main recommendation of this study therefore is to (try to) lower the value of the linear temperature coefficient and at least add a thermometer well to the housing of the resistor so that the temperature of the resistive element can be more accurately measured. Adding thermal isolating material to the inner of the resistor housing would also help to damp fast temperature variations in the environment. It is likely that part of the extra noise seen in our measurements is caused by differences between the temperature of the thermometer and that of the resistor.

The specific resistor in this evaluation had a value very close to nominal, being just 0.5 ppm below the nominal value. The drift of the resistor amounted 0.106 ppm per year, as measured over a period of more than two years, which is a conveniently low value. The drift furthermore appears to be quite linear: from measurements in the first year, the value after nine months could be predicted within 0.02 ppm. This difference is quite small, especially given the fact that the resistor had been travelling between Europe and Japan in these nine months. This is an indication that the standard might be specifically suited for comparisons.

There are several limitations in the present research that might be studied in the future. The temperature coefficient is not separately determined and the standard has not been checked for any pressure dependence (which is expected to be small, given the metal foil element and the hermetically sealed housing).

In conclusion: the evaluated ASR-103 resistance standard has a value close to nominal, with a low drift rate per year, and a reasonably low temperature coefficient. In general, the ASR-103 resistor has a compact size but can be improved upon by adding a thermometer well to the housing.

6. References

[Jeck01] B. Jeckelmann and B. Jeanneret, "The quantum Hall effect as an electrical resistance standard", *Rep. Prog. Phys.* **64**, pp 1603 – 1655, 2001.

[Riet96] G. Rietveld, "A DVM-based accurate measurement set-up for QHE resistance measurements", *CPEM96 conference digest* ,1996.

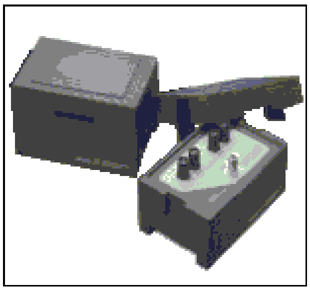
[Riet98] G. Rietveld, "Uncertainty analysis of a DVM-based quantum Hall measurement set-up", *CPEM98 conference digest*, 1998.

[Witt98] T. J. Witt, "Electrical resistance standards and the quantum Hall effect", Rev. Sci. Instrum. **69**, pp 2823 – 2843, 1998.

Appendix 1 Data sheet of the ASR-103 resistor

ASR Series

STANDARD RESISTORS ASR Series



The Series ASR is a highly precise and stable standard resistor constructed with metal foil for resistive elements having an extremely low temperature coefficient. With the extreme stability of resistor to temperature change, the ASR standard resistor can be used in air without oil bath or critical environmental temperature control which is inconvinient and expensive. The usability-in-air gives the ASR resistor a broad usage or applicability. The Series ASR is designed to work both for precise calibration on a production floor and for a reference standard in a corporate traceability system.
In order to avoid a measurement error due to thermal emf, a removable lid can be placed to cover the connection board when in use. Resistor is mounted in a small sturdy box with terminals fixed protectively from mechanical shock.

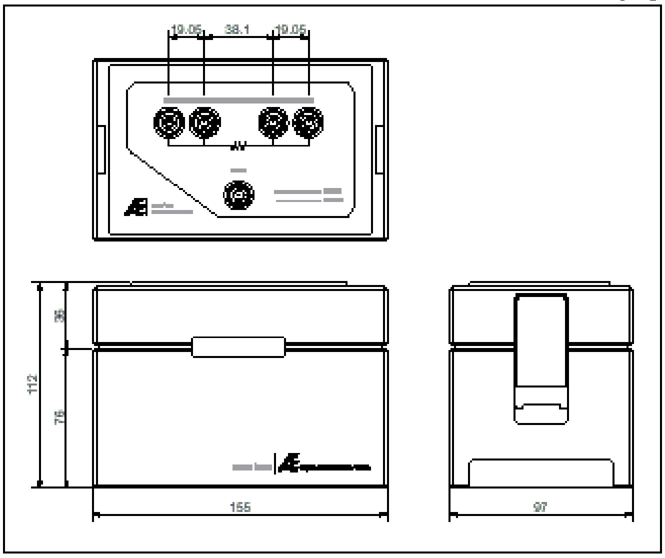
Specifications

Model	Resistance Value	Accuracy		Max. Wattage	Stability		Terminal Structure
		ppm	ppm/°C	W	ppm/year	ppm	
ASR-1R0	1Ω	5	≦0.2	0.5	5	5	5
ASR-100	10Ω	5	≦0.2	0.1	5	5	5
ASR-101	100Ω	5	≦0.2	0.1	5	5	5
ASR-102	1kΩ	5	≦0.2	0.1	5	5	5
ASR-103	10kΩ	5	≦0.2	0.1	5	5	5
ASR-104	100kΩ	5	≦0.2	0.1	5	5	3
ASR-105	1MΩ	5	≦0.2	0.1	5	5	3
ASR-106	10MΩ	10	≦0.5	0.1	10	10	3

Weight≒2.5kg

Configuration

[mm]



Features

- Excellent in long-term stability of resistance
- Usable in air without oil bath or critical environmental control
- Packaged in a small sturdy box which can be fitly stacked one on another during storage
- Optimally weighted to be free from vibration causing possible measurement error