Automated Hamon Transfer Standard for High Resistance Traceability in the Range from 100 MΩ to 10 GΩ

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Abstract

A new automated Hamon transfer standard (NAHTS) has been presented in this paper as a novel contribution to provide parallel, series, or series/parallel configurations automatically. Also by using our NAHTS, the National Institute of Standards (NIS), Egypt capability and traceability of the dc resistance measurements have been extended to 10 GΩ instead of 100 MΩ. Design of the demonstrated NAHTS is mainly based on one micro-controller and eleven reed relays. Design and construction of the NAHTS are introduced. The NAHTS is automatically calibrated by using the DMM-based method at 100 V applied voltage. To verify its behavior, the relative differences between its three connections are automatically determined at 1:10 and 1:100 ratios. Stability of the NAHTS is also studied during ten days. The voltage coefficient of the NAHTS is also determined. The NAHTS is reliably used to calibrate unknown resistances up to 10 GΩ automatically at 1:1 ratio.

Keywords: Hamon transfer standard resistors, Traceability chain, High resistance measurements, Uncertainty.

1. Introduction

The quantum Hall resistance (QHR) is the most accurate resistance standard so, it is considered the primary standard of resistance. Accurate measurements of the high resistance standards should be done with respect to the QHR to insure suitable measurement traceability. There are several methods are used for high resistance measurements where the standard resistors which have the same nominal values are compared at 1:1 ratio. For high resistance standards which their nominal values different by 10 times and 100 times, the comparison can be done by using high resistance Hamon transfer standards (HTSs) [1]. The HTSs are used for disseminating the uncertainties and extending the traceability of the dc resistance measurements at 1:1 ratio. HTS is a resistance network which consists of ten resistors with the same nominal values that can be connected in series, parallel, or both (series and parallel) to obtain accurate resistance values of 10, 0.1 or 1 times, respectively, of the nominal value. At NIS, traceability chain of the high resistance measurements up to 100 MΩ is achieved by the NIS high performance 10 kΩ standard resistor calibrated at BIPM and two commercial HTSs; 100 kΩ and 10 MΩ at 1:1 ratio by using different measurement methods. One of them is the DMM-based method [2] which is used for all measurements performed in this paper.

In this paper, a new automated Hamon transfer standard (NAHTS) is studied and introduced. This NAHTS is designed and fabricated at NIS to also extend the capability of the dc resistance measurements up to 10 GΩ. The NAHTS is made of ten 1 GΩ nominal value resistors to achieve the traceability chain from 100 MΩ to 10 GΩ. The presented HTS is automatically operated to be easily transferred among the three connections to save time and effort during the resistance measurements. The design, the guard circuit, and the automatic calibration of the NAHTS are presented. Verification of this new Hamon standard, its voltage coefficient and its short-term stability are demonstrated. The NAHTS is also used to calibrate 100 MΩ, 1 GΩ, and 10 GΩ unknown resistors and their obtained values are compared with their actual values to evaluate its performance.

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2. Design of the New Automated Hamon Transfer Standard

As demonstrated in Fig. 1 the NAHTS design is based mainly on ATmega 8A- PU micro-controller [3], and ten reed relays (Re) model VR05R121A [4] that are represented by their coils and contacts. Re_1 to Re_{10} are switched to give the required configuration. One different reed relay at the output model VR05R121C [5] is used to switch between the three connections, and ten 1 GΩ thick film resistors; R_1 to R_{10} are used as main resistors to realize the Hamon theory.

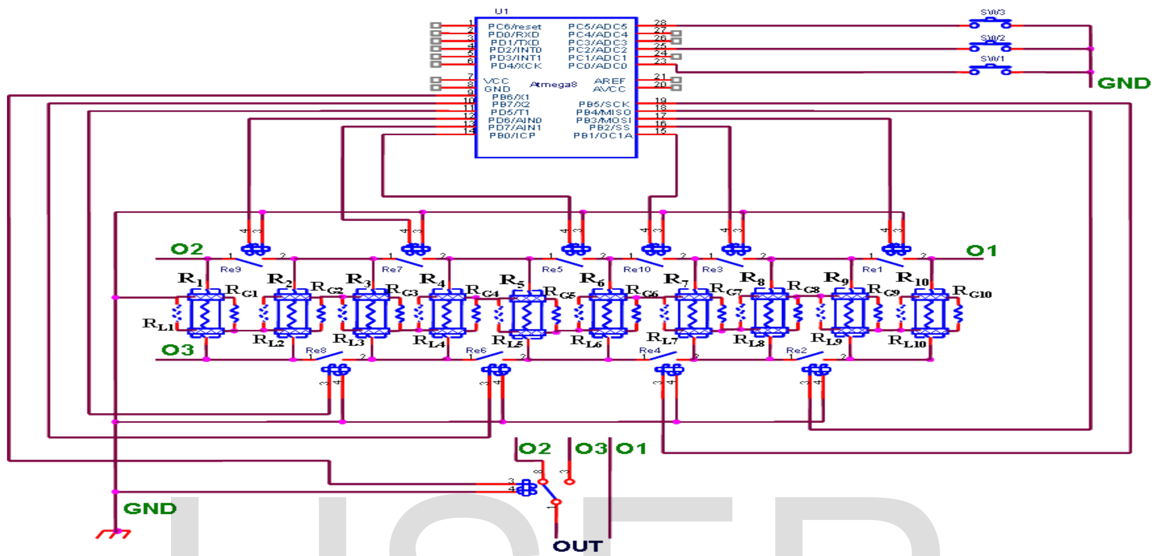

Fig.1. Scheme of the new Automated Hamon transfer standard

Ten 100 MΩ guard resistors, R_{G1} to R_{G10}, are mounted on their corresponding main resistors surfaces through 2 conducting rings. R_{L1} to R_{L10} represent leakage resistance for each main resistor respectively, which is in the order of 10^{14} Ω. The control code is stored in the micro-controller ROM through a specially prepared C- program to close or open the relays according to the required selected configuration, which can be series, parallel or series/parallel. Selection of one of these configurations is accomplished manually using the switches sw1, sw2 and sw3, or automatically using a computer serial port through a LabVIEW program specially designed for this aim, which is shown in Fig. 2.

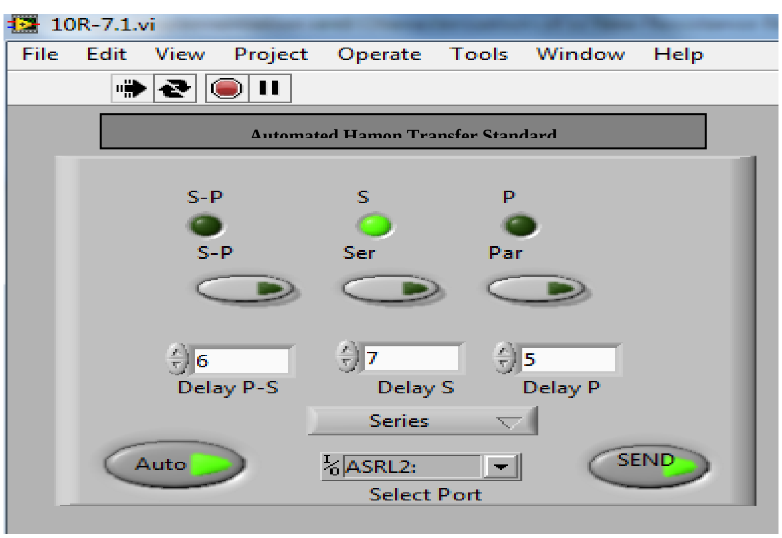

Fig.2. Front panel of the LabVIEW program that controls the NAHTS

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This construction is placed inside an aluminum case. The transfer between the three different configurations is occurred automatically as following.

2.1 Parallel Connection

For 100 MΩ resistance standard value, it could be obtained by using the ten resistors R_1 to R_{10} under specific conditions where Re_1 to Re_{10} are closed, short circuit, as depicted in Fig. 3a. Due to this connection, the ten main resistors are in parallel and the output value will be obtained from the output terminals O1and O3.

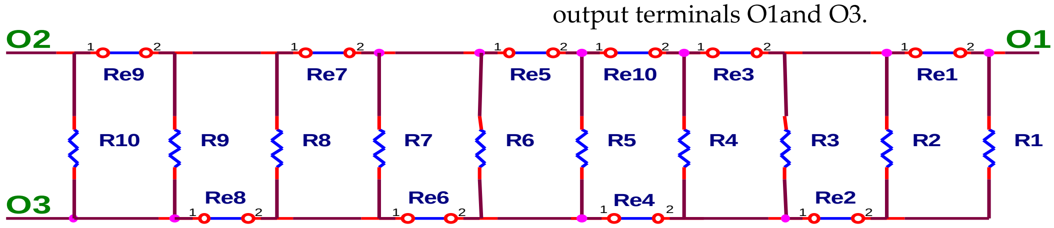

Fig.3a. Parallel connection of the NAHTS to get 100 MΩ

2.2 Series/Parallel Connection

1 GΩ resistance standard value is obtained by using the ten resistors R_1 to R_{10} with Re_1 to Re_7 and Re_9 are closed, and Re_8 and Re_{10} are opened with having contact insulation resistances with values in the order of $10^{15}\Omega$. In this case, all the 10 main resistors are used as two parallel resistors are connected in series with two groups of four parallel resistors. The output value will be obtained from the output terminals O1 and O3 as illustrated in Fig. 3b.

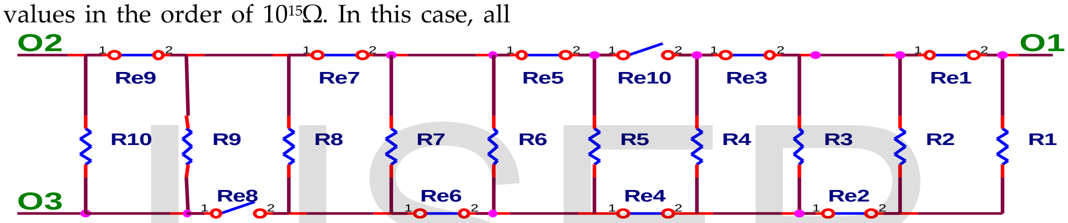

Fig.3b. Series/parallel connection of the NAHTS to get 1 GΩ

2.3 Series Connection

10 GΩ resistance standard value could be obtained by using the ten resistors R_1 to R_{10} under specific conditions, Re_1 to Re_9 are opened; with insulation resistances, and Re_{10} is closed. So, the main resistors become in series and the output value will be obtained from the output terminals O1 and O2 as illustrated in Fig. 3c.

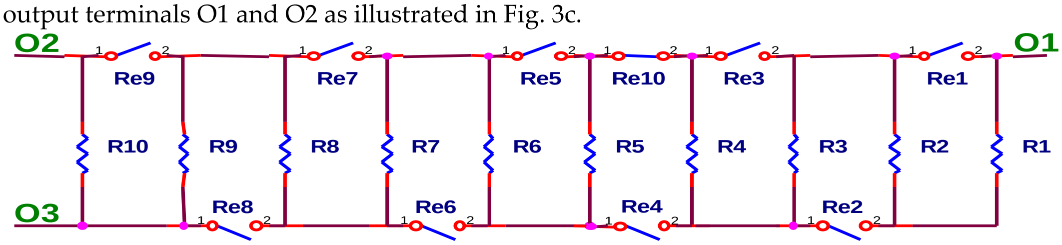

Fig.3c. Series connection of the NAHTS to get 10 GΩ

3. Guarded Circuit of the New Automated Hamon Transfer Standard

One of the important factors that effects on the HTS accuracy is its internal guarded network which reduces the errors caused by leakage currents flowing from the main resistor network to ground [6,7]. In the introduced NAHTS, the guarded circuit is made by using ten 100 MΩ thick film resistors. Each 100 MΩ resistor is used as guard resistor by fixing it on the outer surface of the main resistor using special conducting rings to construct the guard circuit as shown in Fig. 4a. So, the guard resistors are connected in series, and then with the circuit ground. The PCB insulation material, vertical hashed parts, has an insulation resistance in the order of 10^{15} Ω, which represents an additional insulation for the fabricated NAHTS circuit to be a double insulation circuit as shown in Fig.4b. These guard resistors are then connected to the NAHTS case and the relays grounds to have the same potential to limit the leakage current which flows through the insulator material of the resistors.

Therefore, the main network resistors are subjected to double isolation from the ground. One of them by using the guard resistors network and the other by using the PCB material; FR4 coated with Epoxy green mask where the main resistors are mounted. The insulation resistance between the connectors and the case is in the order of 10^{14} Ω. The insulation resistance of the connectors is in the order of 10^{15} Ω which suitable for high value resistance measurements.

Fig. 4a Fabricated circuit of NAHTS

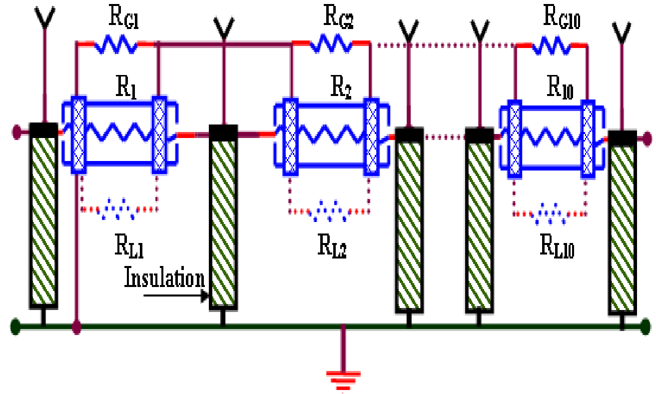

Fig. 4b Double-isolation scheme of NAHTS

Fig.4. Circuit of the new automated Hamon transfer standard

4. Calibration and Verification of the NAHTS

The NAHTS; R_x is automatically calibrated by directly comparing its value with another standard resistor, R_s by using the DMM-based method. The measurement is done at a temperature of (23 ± 0.5) °C and relative humidity of (50 ± 10) %. The used standard resistor, R_s, is 10 × 10 MΩ HTS. This standard resistor is traceable to the QHR through the NIS traceability chain which is started from the NIS 10 kΩ standard resistor. The standard Hamon resistor is connected in series and the NAHTS is connected in its parallel configuration to be calibrated at 1:1 ratio at 100 MΩ value. The applied voltage for this measurement is 100 V. The value of the NAHTS in its parallel connection is obtained from:

$$Rx = (V_x / V_s)\ Rs \qquad (1)$$

Where V_x / V_s is the ratio reading of the DMM for the voltage drops across R_s, and R_x.

The calibration uncertainty is evaluated for the NAHTS according to the GUM [8] at the 100 MΩ range. The sources of uncertainty are divided into Type A and Type B. Type A reflects the level of precision. Type B has many contributions such as the calibration, drift, temperature coefficient, power coefficient and voltage coefficient of R_s. There are also the ratio accuracy, and the calibration and the resolution of the DMM. It found that the relative deviation of the NAHTS in its parallel configuration; 100 MΩ from its nominal value is 2.6×10^{-3} and its associated expanded uncertainty is 19.5 µΩ/Ω.

The verification of the NAHTS is automatically done to verify its behavior by measuring its series/parallel connection at a 1:10 ratio and its series connection at a 1:100 ratio by using the same 10 × 10 MΩ HTS in its series connection at 100 V dc applied voltage by using the DMM-based method. The two calibrated values are then compared to the NAHTS value obtained in the parallel connection. It's found that the relative difference between its parallel connection and its series/parallel connection is 4.6×10^{-6} and the relative difference between its parallel connection and its series connection is 8.4×10^{-6}. These results assure that the NAHTS can be used as a very accurate transfer of the values of standard resistances in the ratios 1:10 and 1:100. This relative differences; transfer errors between parallel and series/parallel connections and between parallel and series connections of the NAHTS are put into consideration when using it as a transfer device to higher values resistance standards. Table 1 shows the expanded uncertainties of the NAHTS for its different connections after considering the transfer errors between them.

Table 1 The expanded uncertainty of the NAHTS for its different connections

Standard Resistor Value	Expanded Uncertainty, µΩ/Ω
100 MΩ	19.5
1 GΩ	20.2
10 GΩ	21.8

5. Main Specifications of the New Automated Hamon Transfer Standard

There are some specifications of the NAHTS are determined. These specifications are the voltage coefficient and the stability with time.

5.1 Voltage Coefficient

The voltage coefficient of the NAHTS is determined at its highest value, 10 GΩ, for its series connection at voltages 20 V, 40 V, 60 V, 80 V, and 100 V. The value of the resistance at different voltages is simply obtained from [1]:

$$R= R_o(1+\alpha v\ \Delta V) \quad (2)$$

Where, αv is the voltage coefficient of the standard resistor. It is found that the voltage coefficient of the NAHTS is about 3.5×10^{-5}/V.

5.2 Short-term Stability

The stability of the NAHTS is also studied during ten days in its parallel connection with applied voltage of 100 V. This study is done to verify its short-term stability in the same condition of its use in the Hamon scaling technique. Fig. 5 shows the NAHTS stability during the mentioned time.

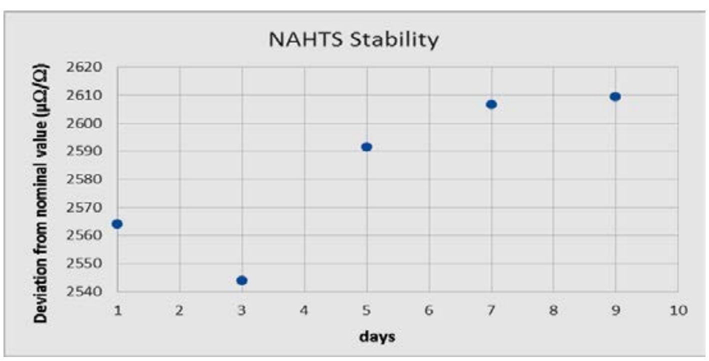

Fig.5. Stability of the NAHTS at its parallel connection

It is found that the NAHTS has good short-term stability in the order of 8×10^{-6} so, it is reliable in usage as a transfer device for a short period without the need for recalibration.

6. Extension of the High DC Resistance Traceability up to 10 GΩ

The NAHTS is used to extend the NIS traceability chain to the 10 GΩ. It transfers the traceability to the unknown resistances (UR) up to 10 GΩ as shown in Fig. 6.

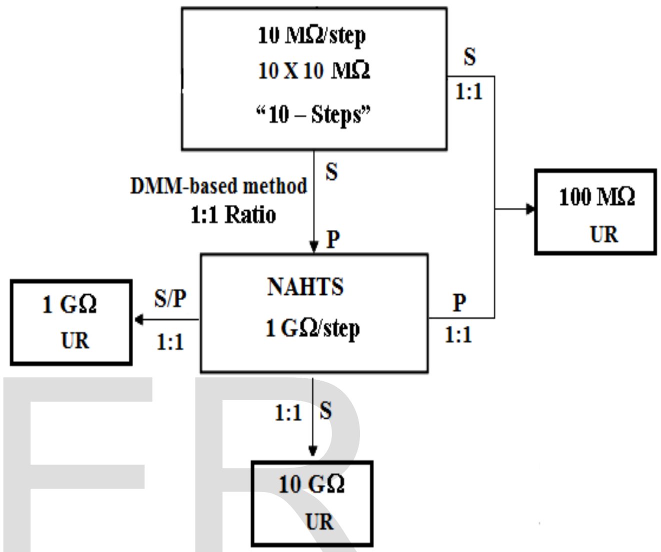

Fig.6. Traceability chain for the UR up to 10 GΩ

So, it is used to calibrate 1 GΩ, and 10 GΩ UR. It could also used in calibration of the 100 MΩ UR. To evaluate the performance of the NAHTS, the obtained values by using the NAHTS are compared with the actual values of the UR obtained from their calibration certificate. Table 2 shows the relative deviation of the values obtained by NAHTS and the actual values for the UR from their nominal values associated with their expanded uncertainties. All the measurements are done at 1:1 ratio.

Table 2 Calibrated values of the 100 MΩ, 1 GΩ, and 10 GΩ UR and their uncertainties

Nominal Value	Relative Deviation obtained by (NAHTS)	Expanded Uncertainty (k=2), %	Relative Deviation obtained from calibration certificate	Expanded Uncertainty (k=2), %
100 MΩ	2.6×10^{-3}	0.14	2.0×10^{-3}	0.10
1 GΩ	5.3×10^{-3}	0.24	3.9×10^{-3}	0.10
10 GΩ	-1.2×10^{-3}	0.26	-7×10^{-4}	0.10

It is shown that the results obtained by using the NAHTS are very close to the actual values of the UR at the specified values. It indicates that the NAHTS is accurate and reliable

transfer standard and can be used to extend the NIS traceability to 10 GΩ.

7. Conclusion

The introduced automated Hamon transfer standard has a new design to be operated automatically. It has been constructed to also extend the NIS dc resistance measurements to 10 GΩ. It can be controlled manually or automatically through specially prepared programs using micro-controller technique and eleven reed relays. The presented HTS is automatically operated to be easily transferred among the three different connections to save time and effort during the resistance measurements. The uncertainty of its 100 MΩ calibration; in its parallel configuration is 19.5 μΩ/Ω with 4.6×10^{-6} and 8.4×10^{-6} transfer errors between this connection and its series/parallel and series connections respectively by using the same standard resistor. The NAHTS has a voltage coefficient of 3.5×10^{-5}/V with good short-term stability in the order of 8×10^{-6}. 100 MΩ, 1 GΩ, and 10 GΩ unknown resistance values have been automatically calibrated using our NAHTS. These obtained values are then compared with the UR actual values as a practical confirmation for its reliability as a transfer standard.

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