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Maintenance of the Unit of Resistance at KFUPM Research Institute

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ABSTRACT. The paper presents a technique of maintaining and calibrating similar and non-similar standard resistors based on double ratio set using one reference standard only. This technique is further applied in matrix method of calibrating a group of similar resistors to yield better precision in values and maintain the unit of resistance at KFUPM Research Institute. A group of standard resistors of values 1 Ohm, 1 k Ohms and 10 k Ohms were calibrated and the results compared with the determinations made through direct substitution method using double ratio set which requires two resistance standards with one as the reference. Performance of calibration is also checked on the basis of closeness between calibrated values of a standard resistor, obtained through use of similar type of standards as reference. The stability requirement of less than 1 ppm/year is achieved.

Recent years have brought challenges to the scientific and technological communities that were barely discernible a few decades ago. Advances made in meeting these have been possible only through the more precise and accurate measurement of physical quantities. The word precision when applied to resistors in the field of measurements, means a resistor adjusted within 0.001% of its nominal value, and of such quality and stability as to maintain this value over long periods of time. Precision resistors such as Rosa Type, Thomas Type, etc., are used as reference standards for calibrating other resistors or resistive devices in laboratories requiring measurements of extremely high precision. Some standards find their use in industrial and educational precision electrical measuring laboratories for purpose of resistor comparison and, for comparison in low resistance measurements, etc.

In carrying out the task of maintaining reference and working standards at metrology laboratories, such techniques as could provide and maintain traceability to the world's highest level laboratories and result in increasing the span of periodic external calibration of traceability check must be employed. Direct current comparator potentiometer bridges, Wheatstone or Kelvin Bridges (including the Wenner Bridge), etc., are commonly used to compare the reference standard to other resistors under test (Wells and Gard 1971, Baker and Dziuba 1983). In resistance measurements temperature controlled environment is a necessity which is achieved through the use of Oil Baths. Three different methods of calibrating and maintaining a standard resistor, employing two reference standards and or one reference standard at a time, will be discussed here. The standard resistors were calibrated first at a National Laboratory Level and then recalibrated every month in the Measurement Standards Laboratory (MSL), KFUPM, to check stability while retaining traceability to the world's highest level laboratories and also maintaining the unit of resistance at MSL. The standard resistors at MSL are sent to a National Laboratory for calibration every two years. The location of KFUPM makes frequent access to National Laboratories difficult. It often takes more than two years to have the resistors calibrated because of paper work and red tape relative to shipment, customs documentation and clearance, etc. Also the time spent in shipping the resistors to and from the National Laboratory usually takes more than six months. It was therefore felt necessary to carry out more in-house intercomparisons of resistors to maintain unit and traceability than to depend totally on outside calibration. The unit of resistance at MSL is maintained with a group of stable one-ohm Thomas type standard resistors traceable to National Institute of Standards and Technology (NIST, formerly National Bureau of Standards or NBS). Some of the noble contributions in the field of standard resistors metrology still referred by NIST are from NBS (1968) to Thomas (1968), and Wenner (1961). At NIST the unit of resistance is maintained with a group of stable one-ohm standard resistors; and is found not to differ by more than one part per million (ppm) with the units maintained at other National Standardizing Laboratories.

System of Measurement

The measurement system consists of a Guildeline model 9975 direct current comparator (DCC) resistance bridge, and a Guildline model 9734 variable temperature bath. The standard resistors of Leeds and Northrup Company, selected for calibration are three model 4210, Thomas type one-ohm standards (stability: less than 1 ppm/year); three model 4035-B, U.S. Bureau of Standards type 1k Ohm standards; and three model 4214; 10k Ohm standards (stability: less than 2 ppm/year approximately).

The model 9975 DDC resistance bridge determines resistance by measuring the ratio of the unknown resistor (R_x) to a known resistance standard (R_s), with accuracy to 0.2 ppm of reading. Four terminal resistance measurements were performed. Prior to measurements all resistors were submerged in well-stirred Oil Bath at a constant temperature of 25°C, while ambient conditions in the Laboratory were maintained at 23 ±1°C and relative humidity of 45 ± 5%, for maximum accuracy in determining the actual value and repeated verification of the value.

Methods of Calibration

The method of calibrating a standard resistor using double ratio set with one reference standard, and its use in matrix method of calibrating similar resistors, provides a new means of precision calibration. The method based on direct substitution using double ratio set with two resistance standards of which one serves as reference, is also discussed.

(1) Direct Substitution Method Using Double Ratio Set

This method requires two resistance standards, of which one serves as working standard R_s and the other a dummy standard R_D. The value of the standard R_s must be known within the accuracy and precision desired, whereas the value of dummy standard R_D need not to be known. The calibration steps are as follows: (i) Connect the dummy standard R_D and the reference standard R_s to the R_s and R_x terminals of the bridge respectively. Obtain a null balance reading for the standard as Reading 1. (ii) Disconnect the standard from R_x terminals and replace it with the resistor under test R_x. Obtain a null balance reading for the resistor under test as Reading 2. (iii) The deviation D_{xN} in the ppm of the resistance under test R_x from its nominal value is calculated.

$$D_{XN} = \text{Reading } 2' - \text{Reading } 1' + D_{SN}$$

where D_{SN} = deviation in ppm of R_S from its nominal value

Reading 1′ = deviation in ppm of the ratio R_S/R_D from the nominal resistance ratio

Reading 2′ = deviation in ppm of the ratio R_X/R_D from the nominal resistance ratio

(2) Interchanging Method Using Double Ratio Set

This method requires only one resistance standard. The steps of calibration are as follows:

(i) Connect the standard resistor R_s and the resistor under test R_x to R_s and R_x terminals of the bridge respectively. Obtain a null balance reading for the resistor under test as Reading 1x.

(ii) Interchange the connections of the resistors to the bridge, that is, connect resistors R_s and R_x to terminals R_x and R_s of the bridge respectively. Obtain a null balance reading for the standard resistor as Reading 1s.

(iii) Calculate a factor (DF1) with sign, which is the difference of two reading divided by 2.

$$DF1 = (\text{reading } 1x - \text{Reading } 1s)/2$$

(iv) Calculate another factor (DF2), which is defined as

$$DF2 = (DF1^2 + 1)^{1/2}$$

(v) Finally calculate the value of the resistor under test:

$$R_x = (\text{certified value of } R_s) \times (DF1 + DF2)$$

Note: The value of unknown resistor can also be calculated by

$$R_x = R_s \left(\frac{1 + \text{Reading } 1x}{1 + \text{Reading } 1s}\right)$$

The results obtained through the above formula are same as those obtained in step (v).

(3) Matrix Method Using Double Ratio Set

In this method of calibration each resistor is compared with the similar type of other resistors and the data entered in the matrix form. Consider a set of standard resistors S_1, S_2, S_3, ..., S_N. Compare each resistor against other and note down the null balance reading (R_x/R_s) as shown in table M1 ($N \times N$ matrix). The different steps of calibration are as follows:

(A) Consider standard resistor S_1 as reference standard

(i) Using the technique of method 2, compute the values of resistors S_2, S_3, ..., S_N with resistor S_1 as reference standard, and complete column 1 of Table M2 (if method 1 technique is used then the value of each resistor will be an average of N-2 values). The values of first column Y_{21}, Y_{31},..., Y_{N1} will now be used as reference values of resistors S_2, S_3, ... S_N, respectively, in order to complete the entries of columns 2,3, ..., N of table M2 using method 2 technique. Complete all entries of table M2.

(ii) In Table M2, calculate the sum of each row as H_1, H_2, H_3, ..., H_N, and sum of each column as V_1, V_2, V_3, ..., V_N. Let D_1, D_2, D_3, ..., D_N, be the deviations from the mean value for resistors, S_1, S_2, S_3, ..., S_N, respectively, then

$$D_1 = \frac{H_1 - V_1}{2N}, \quad D_2 = \frac{H_2 - V_2}{2N}, \quad D_3 = \frac{H_3 - V_3}{2N}, \text{ and } D_N = \frac{H_N - V_N}{2N}$$

The sum $\sum_{i=1}^{N} D_i$ should be equal to zero.

Note: The denominator is multiplied by a constant of 2 in order to improve precision in calibrated values.

(iii) Since resistor S_1 is considered as reference standard, it is used to get the values of other resistors, then the mean group value = $S_1 - D_1 = M_1$. Therefore the calibrated values of other resistors are

$$S_2 = M_1 + D_2, \quad S_3 = M_1 + D_3, \; ....., \; S_N = M_1 + D_N$$

(B) Consider standard resistor S_2 as reference standard

(i) With the value of resistor S_2 as reference value, complete the column 2 of table M2 for resistors S_1, S_3, ..., S_N using the data of table M1 based on the technique of method 2. Let the computed values of column 2 be Z_{12},Z_{32}, ... Z_{N2} for resistors S_1, S_3, ... S_N respectively. Using these Z values as reference values and data of table M1, compute the values of resistors in order to complete the entries of columns 1,3, ... N of table M2. Let the new table of computed values with resistor S_2 as reference standard be M2.

(ii) In table M2, calculate the sum of each row as H_1^1, H_2^1, H_3^1, ..., H_N^1; and sum of each column as V_1^1, V_2^1, V_3^1, ..., V_N^1; then the deviation of each resistor from mean value is given by

$$D_1^1 = \frac{H_1^1 - V_1^1}{2N}, \quad D_2^1 = \frac{H_2^1 - V_2^1}{2N}, \quad D_3^1 = \frac{H_3^1 - V_3^1}{2N}, \; ..., \; D_N^1 = \frac{H_N^1 - V_N^1}{2N}$$

The sum $\sum_{i=1}^{N} D_i^1$ should be equal to zero. (See note in A(ii)).

Table M1: The ratio R_x/R_s data when unknown is compared with the similar type of other resistors as standard

Standard $R_s \rightarrow$ / Unknown $R_x \downarrow$	Standard Resistor S_1	Standard Resistor S_2	Standard Resistor S_3		Standard Resistor S_N
Standard Resistor S_1		R_{12}	R_{13}		R_{1N}
Standard Resistor S_2	R_{21}		R_{23}		R_{2N}
Standard Resistor S_3	R_{31}	R_{32}			R_{3N}
Standard Resistor S_N	R_{N1}	R_{N2}	R_{N3}		

(iii) Since resistor S_2 is considered as reference standard, it is used to get the values of other resistors, then the mean group value $= S_2 - D_2^{\prime} = M_2$. Therefore the calibrated values of other resistors are $S_i = M_2 + D_i^{\prime}$, $i = 1,3,4, \ldots, N$.

Similarly by considering each of the remaining standard resistors (S_3, S_4, ..., S_N) as a reference standard at a time, complete first the entries of the column against the reference standard considered using table M1 data with method 2 Technique. These column values will now be referred as reference values for completing the other entries of table M2 which will be used to calculate the deviation of each resistor from mean value and then the mean group value for calculating calibrated value of each resistor with respect to the reference standard considered. Thus the mean of N-1 values will be the final calibrated value of each resistor.

Results

The calibration of resistors of values one Ohm (resistors 1.1.-3), 1 k Ohms (resistors 2.1-3) and 10 k Ohms (resistors 3.1-3) was performed first using the methods 1 and 2 in order to make a comparison in between them. The reported value of each resistor group in terms of deviation from nominal in ppm as given in tables 1,2 and 3 for a period of twelve months, is the average of two values each

Table M2: Computed values of R_x obtained using data of Table M1 with the technique of method 2

Standard $R_s \rightarrow$ / Unknown $R_x \downarrow$	Standard Resistor S_1	Standard Resistor S_2 Y_{21}	Standard Resistor S_3 Y_{31}		Standard Resistor S_N Y_{N1}
Standard Resistor S_1	×	–	–		–
Standard Resistor S_2	Y_{21}	×	–		–
Standard Resistor S_3	Y_{31}	–	×		–
				×	
Standard Resistor S_N	Y_{N1}	–	–		×

obtained using other resistor of the same family as standard. The value of reference standard used in calculating the value of unknown resistor for each month is based on the value obtained in the immediately preceding month. The average absolute difference (and uncertainty) between resistance values obtained through methods 1 and 2 over twelve months period for resistors 1.1, 1.2 and 1.3 is 0.05 (±0.02), 0.07 (±0.05) and 0.05 (±0.03) ppm respectively; for resistors 2.1, 2.2 and 2.3 is 0.03 (±0.01), 0.06 (±0.02) and 0.06 (±0.03) ppm respectively; and for resistors 3.1, 3.2 and 3.3 is of the order of 0.02 (±0.01), 0.03 (±0.01) and 0.03 (±0.01) ppm respectively. The uncertainty (±) is calculated based on eleven degrees of freedom and 95% confidence level. In some months the difference between the calibrated values of methods 1 and 2 is higher than 0.1 ppm, but as a decision the values obtained through method 2 are considered favourable because they show closeness with the values which are obtained through reverse check on reference standard using the general way of calibration in which unknown resistor is calibrated by multiplying the dial ratio R_x/R_s with the certified value of the standard.

The absolute difference with respect to nominal in ppm between two resistance values of a resistor, each obtained using other two resistors of same type as reference standards according to the techniques of methods 1 and 2, is tabulated in tables 4,5 and 6 for 1Ω, 1k Ω and 10k Ω resistor groups respectively. In case of 1Ω resistors (table 4) the maximum difference obtained between two calibrated values through method 1 for resistors, 1.1, 1.2 and 1.3 is approximately 0.3, 0.5

and 0.5 ppm respectively; whereas through method 2 it is of the order of 0.06, 0.2 and 0.2 ppm, respectively, lesser than method 1. Also for 1kΩ and 10kΩ resistors (tables 5 and 6 respectively) the method 2 technique yields comparatively better closeness in two values of a resistor, each obtained using separate reference standard of same type. The method 2 technique can be considered a favourable way of precise calibration of similar and non-similar resistors.

The method 2 technique is used in the matrix method of calibrating a group of similar type of resistors. The calibrated values of one ohm resistors (1.1.-3) obtained through method 3 are tabulated in table 7. Through method 3 technique the absolute difference in ppm between two values of a resistor measured with separate standards, has reduced showing a good closeness in two values. The results obtained through method 3 were found in close agreement with National Lab certified values. The method 3 provides a new means of maintaining similar type of standard resistors with traceability to world's highest level laboratories. The unit of resistance at MSL is maintained using the method 3 technique with a group of stable one-ohm Thomas type standard resistors.

An approximate value of the absolute change and the slope of the best fit line based on least square method over one year period data for all standard resistors, as shown in table 8, is calculated from the calibrated values obtained through the three methods and the General Method. In General Method, the resistors were calibrated by multiplying the ratios (R_x/R_s) with corresponding reference standard's value and then averaged. The results through method 3 (*i.e.* slope, drift rate etc.) were found to be in more agreement with the national level calibration reports than the results of methods 1 and 2. In table 8, the Thomas type one ohm standard resistors are stable within 0.02 ppm over the period through method 3 measurements. The values of all resistor groups in terms of deviation from nominal in ppm, obtained through method 3 are plotted in figures 1, 2 and 3.

Conclusion

The interchanging technique of method 2 using double ratio set provides good means of calibrating similar and non similar resistors. The method 2 technique provides better closeness in values when an unknown resistor is calibrated using more than one similar type of reference standards. In calibrating a group of similar type of standard resistors it is recommended to use method 3 technique, which also involves method 2 technique,in order to achieve better precision in values and also to keep traceability to the world's highest level laboratories. The General Method way of calibration should not be used alone or in method 3 as it does not provide precision in values.

Note: Effective January 1, 1990 the international practical realization of resistance will change. The new quantum-Hall-effect standard will increase the value of the U.S. Ohm representation by 1.69 ppm (Taylor 1989). At MSL the values of standards will be adjusted by −1.69 ppm from January 1990 in terms of new unit of Ohm.

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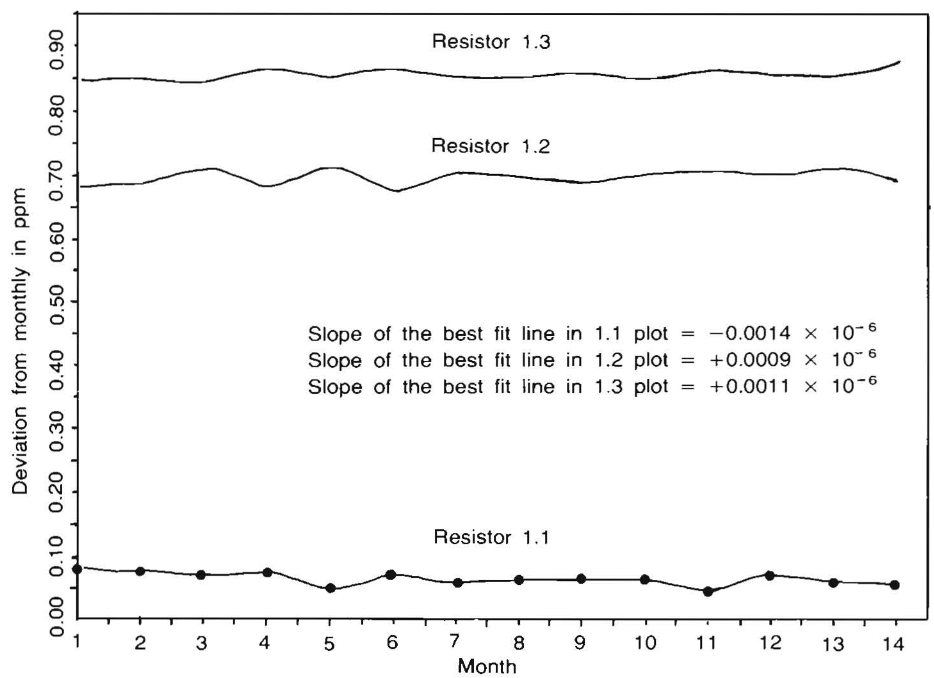

Fig. 1. Monthly calbrated values of 1k-Ohm standard resistors in terms of deviation from Nominal in ppm as obtained through method 3.

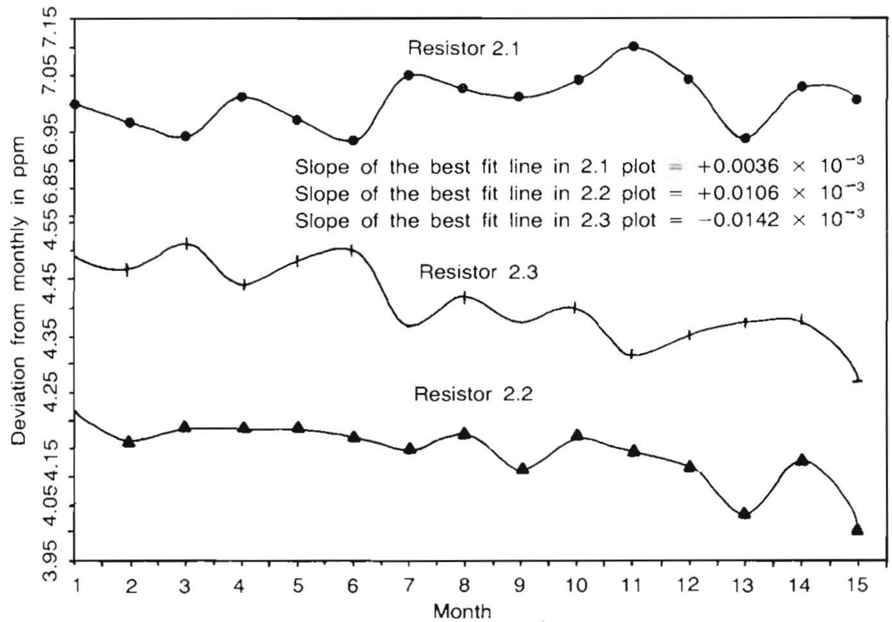

Fig. 2. Monthly calbrated values of 1k-Ohm standard resistors in terms of deviation from Nominal in ppm as obtained through method 3.

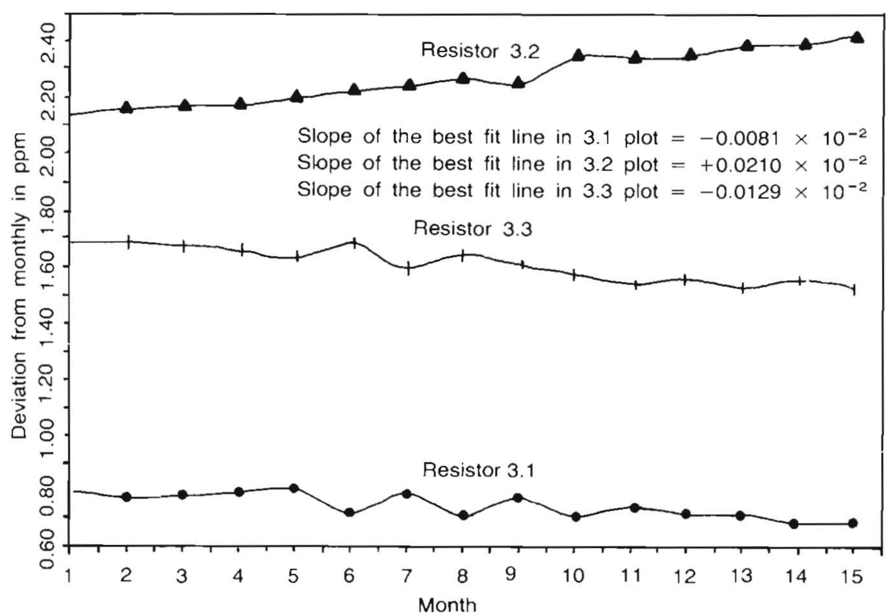

Fig. 3. Monthly calbrated values of 10k-Ohm standard resistors in terms of deviation from Nominal in ppm as obtained through method 3.

Table 1. Deviation from nominal in ppm of the calibrated value for each 1-Ohm resistor

Month	Deviation from nominal in ppm of the calibrated value which is based on the average of the two values through two standards								
	for Resistor 1.1			for Resistor 1.2			for Resistor 1.3		
	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]
	Method 1	Method 2		Method 1	Method 2		Method 1	Method 2	
1	+0.08	+0.08	0.00	+1.55	+1.25	0.30	+1.47	+1.65	0.18
2	+0.19	+0.07	0.12	+1.22	+1.31	0.09	+1.70	+1.60	0.10
3	+0.09	+0.05	0.04	+1.39	+1.32	0.07	+1.63	+1.61	0.02
4	+0.11	+0.06	0.05	+1.32	+1.29	0.03	+1.68	+1.63	0.05
5	+0.07	+0.02	0.05	+1.38	+1.34	0.04	+1.66	+1.63	0.03
6	+0.10	+0.06	0.04	+1.33	+1.28	0.05	+1.68	+1.65	0.03
7	+0.09	+0.04	0.05	+1.37	+1.33	0.04	+1.65	+1.62	0.03
8	+0.10	+0.05	0.05	+1.35	+1.32	0.03	+1.66	+1.63	0.03
9	+0.09	+0.05	0.04	+1.35	+1.31	0.04	+1.68	+1.64	0.04
10	+0.07	+0.05	0.02	+1.37	+1.33	0.04	+1.69	+1.63	0.06
11	+0.08	+0.02	0.06	+1.39	+1.34	0.05	+1.67	+1.65	0.02
12	+0.11	+0.06	0.05	+1.36	+1.32	0.04	+1.68	+1.63	0.05

Table 2. Dcviation from nominal in ppm of the calibrated value for each 1k Ohm resistor

Month	Deviation from nominal in ppm of the calibrated value which is based on the average of the two values through two standards								
	for Resistor 2.1			for Resistor 2.2			for Resistor 2.3		
	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]
	Method 1	Method 2		Method 1	Method 2		Method 1	Method 2	
1	+7.00	+7.00	0.00	−15.44	−15.35	0.09	+1.99	+1.89	0.10
2	+6.97	+6.93	0.04	−15.27	−15.37	0.10	+1.84	+1.98	0.14
3	+6.89	+6.88	0.01	−15.45	−15.35	0.10	+2.10	+2.01	0.09
4	+7.08	+7.03	0.05	−15.34	−15.37	0.03	+1.81	+1.89	0.08
5	+6.98	+6.94	0.04	−15.43	−15.36	0.07	+2.00	+1.97	0.03
6	+6.84	+6.87	0.03	−15.28	−15.33	0.05	+1.99	+2.01	0.02
7	+7.08	+7.11	0.03	−15.30	−15.29	0.01	+1.77	+1.73	0.04
8	+7.02	+7.05	0.03	−15.30	−15.34	0.04	+1.83	+1.84	0.01
9	+7.05	+7.02	0.03	−15.23	−15.21	0.02	+1.73	+1.74	0.01
10	+7.06	+7.09	0.03	−15.30	−15.33	0.03	+1.79	+1.79	0.00
11	+7.25	+7.20	0.05	−15.41	−15.28	0.13	+1.71	+1.63	0.08
12	+7.13	+7.08	0.05	−15.13	−15.23	0.10	+1.55	+1.70	0.15

Table 3. Deviation from nominal in ppm of the calibrated value for each 10k Ohm resistor

Month	Deviation from nominal in ppm of the calibrated value which is based on the average of the two values through two standards								
	for Resistor 3.1			for Resistor 3.2			for Resistor 3.3		
	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]
	Method 1	Method 2		Method 1	Method 2		Method 1	Method 2	
1	+0.80	+0.80	0.00	+3.52	+3.48	0.04	+2.56	+2.58	0.02
2	+0.77	+0.75	0.02	+3.54	+3.53	0.01	+2.57	+2.59	0.02
3	+0.78	+0.77	0.01	+3.51	+3.55	0.04	+2.60	+2.56	0.04
4	+0.82	+0.80	0.02	+3.55	+3.56	0.01	+2.52	+2.53	0.01
5	+0.80	+0.81	0.01	+3.60	+3.61	0.01	+2.49	+2.46	0.03
6	+0.66	+0.64	0.02	+3.69	+3.65	0.04	+2.54	+2.58	0.04
7	+0.83	+0.78	0.05	+3.67	+3.70	0.03	+2.39	+2.39	0.00
8	+0.65	+0.62	0.03	+3.79	+3.75	0.04	+2.45	+2.49	0.04
9	+0.72	+0.74	0.02	+3.73	+3.70	0.03	+2.44	+2.42	0.02
10	+0.60	+0.61	0.01	+3.89	+3.90	0.01	+2.40	+2.35	0.05
11	+0.72	+0.68	0.04	+3.92	+3.89	0.03	+2.25	+2.29	0.04
12	+0.66	+0.63	0.03	+3.92	+3.91	0.01	+2.32	+2.32	0.00

Table 4. Absolute difference in ppm between two resistance values of a resistor, each obtained using separate standard for each 1 ohm resistor

Month	Absolute difference in ppm between two resistance values each obtained using separate standards								
	for Resistor 1.1			for Resistor 1.2			for Resistor 1.3		
	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]
	Method 1	Method 2		Method 1	Method 2		Method 1	Method 2	
1	0.000	0.005	−0.005	0.457	0.228	+0.229	0.457	0.223	+0.234
2	0.337	0.055	+0.282	0.115	0.042	+0.073	0.326	0.065	+0.261
3	0.175	0.008	+0.167	0.042	0.009	+0.033	0.167	0.025	+0.142
4	0.076	0.041	+0.035	0.028	0.002	+0.026	0.072	0.027	+0.045
5	0.071	0.024	+0.047	0.029	0.019	+0.010	0.052	0.067	−0.015
6	0.058	0.044	+0.014	0.011	0.013	−0.002	0.039	0.073	−0.034
7	0.044	0.051	−0.007	0.011	0.007	+0.004	0.029	0.046	−0.017
8	0.008	0.021	−0.013	0.020	0.008	+0.012	0.030	0.009	+0.021
9	0.014	0.015	−0.001	0.019	0.005	+0.014	0.009	0.012	−0.003
10	0.031	0.008	+0.023	0.043	0.019	+0.024	0.004	0.023	−0.019
11	0.030	0.007	+0.023	0.015	0.031	−0.016	0.005	0.028	−0.023
12	0.011	0.005	+0.006	0.003	0.053	−0.050	0.060	0.032	+0.028

Table 5. Absolute difference in ppm between two resistance values of a resistor, each obtained using separate standard for each 1k ohm resistor

Month	Absolute difference in ppm between two resistance values each obtained using separate standards								
	for Resistor 2.1			for Resistor 2.2			for Resistor 2.3		
	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]
	Method 1	Method 2		Method 1	Method 2		Method 1	Method 2	
1	0.003	0.000	+0.003	0.277	0.139	+0.138	0.280	0.140	+0.140
2	0.025	0.016	+0.009	0.268	0.201	+0.067	0.323	0.065	+0.258
3	0.362	0.033	+0.329	0.150	0.086	+0.064	0.006	0.009	−0.003
4	0.450	0.030	+0.420	0.130	0.270	−0.140	0.240	0.020	+0.220
5	0.235	0.016	+0.219	0.146	0.132	+0.014	0.061	0.041	+0.020
6	0.191	0.047	+0.144	0.163	0.031	+0.132	0.116	0.104	+0.012
7	0.224	0.167	+0.057	0.209	0.389	−0.180	0.261	0.084	+0.177
8	0.302	0.025	+0.277	0.181	0.245	−0.064	0.303	0.124	+0.179
9	0.132	0.274	−0.142	0.334	0.073	+0.261	0.272	0.022	+0.250
10	0.208	0.049	+0.159	0.093	0.054	+0.039	0.075	0.184	−0.109
11	0.230	0.251	−0.021	0.392	0.074	+0.318	0.016	0.142	−0.126
12	0.079	0.097	−0.018	0.233	0.229	+0.004	0.476	0.011	+0.465

Table 6. Absolute difference in ppm between two resistance values of a resistor, each obtained using separate standard for each 10k ohm resistor

Month	Absolute difference in ppm between two resistance values each obtained using separate standards								
	for Resistor 3.1			for Resistor 3.2			for Resistor 3.3		
	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]	Calibrated Using		Difference = [Method 1 − Method 2]
	Method 1	Method 2		Method 1	Method 2		Method 1	Method 2	
1	0.002	0.004	−0.002	0.005	0.001	+0.004	0.007	0.003	+0.004
2	0.031	0.045	−0.014	0.014	0.055	−0.041	0.071	0.044	+0.027
3	0.010	0.017	−0.007	0.045	0.050	−0.005	0.055	0.013	+0.042
4	0.066	0.035	+0.031	0.098	0.030	+0.068	0.018	0.019	−0.001
5	0.005	0.108	−0.103	0.060	0.027	+0.033	0.097	0.001	+0.096
6	0.042	0.060	−0.018	0.135	0.187	−0.052	0.139	0.145	−0.006
7	0.023	0.194	−0.171	0.281	0.187	+0.094	0.058	0.093	−0.035
8	0.047	0.037	+0.010	0.168	0.170	−0.002	0.195	0.143	+0.052
9	0.107	0.050	+0.057	0.138	0.087	+0.051	0.009	0.153	−0.144
10	0.081	0.202	−0.121	0.004	0.070	−0.066	0.243	0.192	+0.051
11	0.105	0.045	+0.060	0.204	0.075	+0.129	0.043	0.058	−0.015
12	0.073	0.010	+0.063	0.060	0.061	−0.001	0.069	0.031	+0.038

Table 7. Deviation from nominal in ppm of the calibrated value (and the absolute difference in ppm between two resistance values) for each 1 ohm resistor obtained using technique of method 3

Month	Deviation from nominal in ppm of the calibrated value which is based on the average of two values through two standards (and absolute difference in ppm between two resistance values of whose mean is the calibrated value)					
	for Resistor 1.1		for Resistor 1.2		for Resistor 1.3	
1	+0.08	(0.000)	+0.68	(0.114)	+0.85	(0.114)
2	+0.08	(0.015)	+0.69	(0.012)	+0.85	(0.000)
3	+0.07	(0.019)	+0.71	(0.007)	+0.84	(0.014)
4	+0.07	(0.032)	+0.68	(0.016)	+0.86	(0.022)
5	+0.05	(0.030)	+0.71	(0.013)	+0.85	(0.032)
6	+0.07	(0.032)	+0.68	(0.006)	+0.86	(0.032)
7	+0.06	(0.021)	+0.70	(0.002)	+0.85	(0.023)
8	+0.06	(0.001)	+0.70	(0.003)	+0.85	(0.006)
9	+0.06	(0.012)	+0.69	(0.001)	+0.86	(0.009)
10	+0.06	(0.020)	+0.70	(0.002)	+0.85	(0.001)
11	+0.05	(0.002)	+0.71	(0.017)	+0.86	(0.013)
12	+0.07	(0.002)	+0.70	(0.013)	+0.85	(0.025)

Table 8. Approximate absolute change in ppm and slope of the best fit line in twelve months calibrated values for all resistors

Standard Resistor	Absolute change in ppm over a year based on calibration data of								Slope of best fit line in twelve months calibrated values in case of			
	Method 1		Method 2		Method 3		General Method					
	*	**	*	**	*	**	*	**	Method 1	Method 2	Method 3	Gen. Method
1.1	0.03	0.04	0.02	0.04	0.01	0.02	0.17	0.08	-0.0029×10^{-6}	-0.0029×10^{-6}	-0.0018×10^{-6}	$+0.0043\times10^{-6}$
1.2	0.19	0.01	0.07	0.05	0.02	0.02	0.03	0.10	-0.0023×10^{-6}	$+0.0042\times10^{-6}$	$+0.0012\times10^{-6}$	$+0.0137\times10^{-6}$
1.3	0.21	0.09	0.02	0.02	0.00	0.01	0.12	0.13	$+0.0084\times10^{-6}$	$+0.0010\times10^{-6}$	$+0.0006\times10^{-6}$	$+0.0130\times10^{-6}$
2.1	0.13	0.21	0.08	0.18	0.04	0.09	1.00	1.10	$+0.0187\times10^{-3}$	$+0.0185\times10^{-3}$	$+0.0091\times10^{-3}$	-0.1032×10^{-3}
2.2	0.31	0.09	0.12	0.11	0.11	0.07	1.20	1.20	$+0.0142\times10^{-3}$	$+0.0111\times10^{-3}$	$+0.0068\times10^{-3}$	-0.1140×10^{-3}
2.3	0.44	0.29	0.19	0.27	0.14	0.15	1.80	1.65	-0.0325×10^{-3}	-0.0287×10^{-3}	-0.0158×10^{-3}	-0.1612×10^{-3}
3.1	0.14	0.10	0.17	0.12	0.08	0.06	1.18	1.04	-0.1409×10^{-3}	-0.1521×10^{-3}	-0.0734×10^{-3}	$+1.0074\times10^{-3}$
3.2	0.40	0.39	0.43	0.40	0.21	0.20	1.62	1.51	$+0.4174\times10^{-3}$	$+0.4052\times10^{-3}$	$+0.2052\times10^{-3}$	$+1.5286\times10^{-3}$
3.3	0.24	0.28	0.26	0.28	0.13	0.14	0.98	0.84	-0.2662×10^{-3}	-0.2708×10^{-3}	-0.1320×10^{-3}	$+0.8591\times10^{-3}$

* Calculated by dividing the difference between first and last reading with the nominal

** Calculated by dividing the difference between means of initial two and last two readings with the nominal

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تقدم هذه الورقة أسلوباً للمحافظة على معايرة وحدة مقاومة قياسية متشابهة وغير متشابهة قائمة على أساس طقم ذو نسب مزدوجة وذلك باستخدام مرجع قياس واحد فقط. وتم تطبيق هذا الأسلوب على الطريقة المصفوفة لمعايرة مجموعة من المقاومات المتشابهة بغرض الوصول على قدر أعلى من الدقة في القيم اضافة إلى المحافظة على وحدة المقاومة بمعهد البحوث ـ جامعة الملك فهد للبترول والمعادن.

هذا وقد تمت معايرة بعض المقاومات القياسية التي تحمل قيماً مختلفة: أوم واحد، كيلو أوم واحد، عشرة كيلو أوم. وجرت مقارنة النتائج بالقيمة التي تمَّ تعيينها بطريقة التعويض المباشر مستخدمين النسبة المزدوجة التي تتطلب استخدام وحدتي مقاومة قياسية للرجوع اليهما تكون احداهما مرجعاً. وتم فحص المعايرة أيضاً على ضوء القرب بين القيم التي تمت معايرتها من المقاومة القياسية وتم الحصول عليها عن طريق استخدام مقياس مشابه للرجوع اليه. وقد تحقق استقرار قدره أقل من جزء من المليون/ في العام.

ترسل المقاومات القياسية بمختبر المقاييس والمعايير إلى المختبر الوطني لمعايرتها كل عامين. ولكن موقع جامعة الملك فهد للبترول والمعادن يجعل الاتصال المستمر

بالمختبر الوطني شاق بعض الشيء. وغالباً ما تتم عملية المعايرة بعد كل عامين نظراً للروتين من شحن وتخليص وجمارك . . . الخ لذا كان من الضروري القيام بالمقارنات الداخلية للمقاومات حتى تضمن أداءها بدلاً من الاعتماد الكامل على المعايرة في الخارج. وظلت وحدة المقاومة بمختبر المقاييس والمعايير على أساس أوم واحد من طراز توماس ومعلومة لدى المعهد الوطني للمقاييس والتكنولوجيا.