How to Calibrate Thermometry Bridges: Ensuring Accurate Temperature Measurements

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Introduction

Thermometry bridges play a crucial role in temperature measurement, particularly when it comes to the interpolation of the Standard Platinum Resistance Thermometer (SPRT) specified by the ITS-90. However, to achieve precise and reliable results, it is essential to calibrate these bridges accurately. In this article, we will explore the history of bridge calibration, common methods used for verification, and introduce a solution known as the Resistance Bridge Calibrator (RBC) developed by Rod White at MSL New Zealand [1].

The Linearity Check: A Simple Starting Point

One straightforward method for checking the accuracy of a resistance bridge involves measuring two resistors separately and then measuring them in series. Ideally, the series measurement should equal the sum of the individual measurements. This linearity check provides an initial assessment of the bridge's performance and its ability to deliver accurate readings.

Complement Checks: Assessing Reciprocity

Another convenient way to evaluate a bridge is through complement or reciprocal checks. By connecting a resistor to the "reference side" of the bridge (Rs) and another resistor to the unknown side (Rx), one can compare the two reciprocal ratios. If properly calibrated, the product of these ratios should be unity, indicating accurate bridge performance.

Verifying Performance over the Entire Range: The Challenge

While linearity and complement checks are valuable tools, they are not sufficient for verifying bridge performance over a wide measurement range. Standard resistors with the necessary tolerance and stability are limited in availability, making it challenging to cover the entire operating range. Also, assuming that the bridge meets specifications from limited tests at a limited number of points can be risky.

Introducing the Resistance Bridge Calibrator (RBC): A Solution to Overcome the Limitations of Traditional Calibration Methods

Rod White developed the Resistance Bridge Calibrator (RBC). This innovative device utilizes a network of four base resistors that can be switched in various series parallel combinations, allowing for the realization of 35 distinct four-terminal resistances.

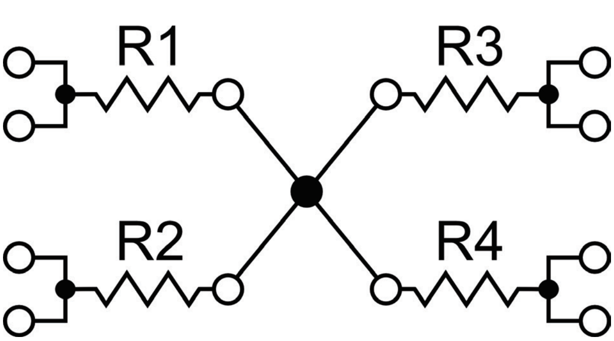


Figure 1. The Four Base Resistors

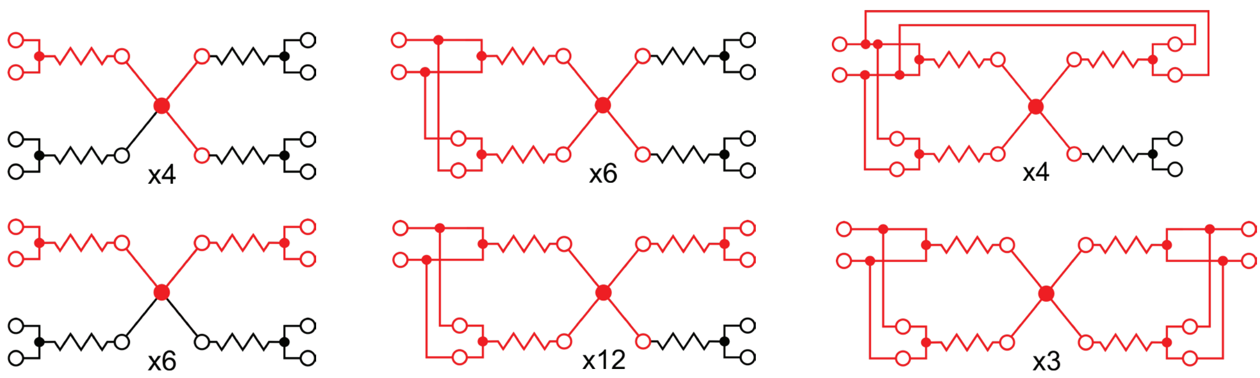


Figure 2. The 35 available connections from parallel series connections

In order to ensure the current divides in proportion to the conductance of the resistors and the potentials are averaged correctly, it is necessary to use both current and potential sharing resistors.

Tremendous care is needed at the common zero-ohm point; even small variations in the PCB material can limit the performance. The principle is simple, but the implementation is demanding.

Up to 70 Ratio Values

When combined with a single reference resistor and reciprocal measurements, a total of 70 ratios can be generated to measure bridge performance across the entire operating range.

A Sample Test Report

The software allows the desired ratio values to be selected. Here we are using 34 ratio values, no complements (Figure 4).

As well as automatically gathering the readings and calculating the fitted values and residuals, we can plot the bridge linearity (Figure 5).

The uncertainty can be calculated and a certificate printed.

Standard deviation of residuals: 1.033×10^{-8}

Standard uncertainty in the corrected readings: 1.033×10^{-8}

Number of fitted parameters: 4

Number of readings: 34

Number of degrees of freedom: 30

Expanded uncertainty in the corrected readings at the 95 % level of confidence: 2.110×10^{-8}

Coverage factor: 2.04

History and Development of the RBC

Initially, the RBC underwent rigorous testing on 38 different resistance bridges, including both AC and DC types. The results revealed that one in five of the tested bridges were faulty, indicating the need for a reliable calibration solution. The concept of the RBC, with its four base resistors and versatile connections, proved to be a simple yet effective approach.

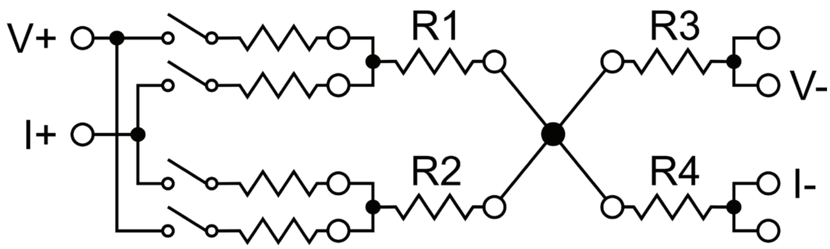
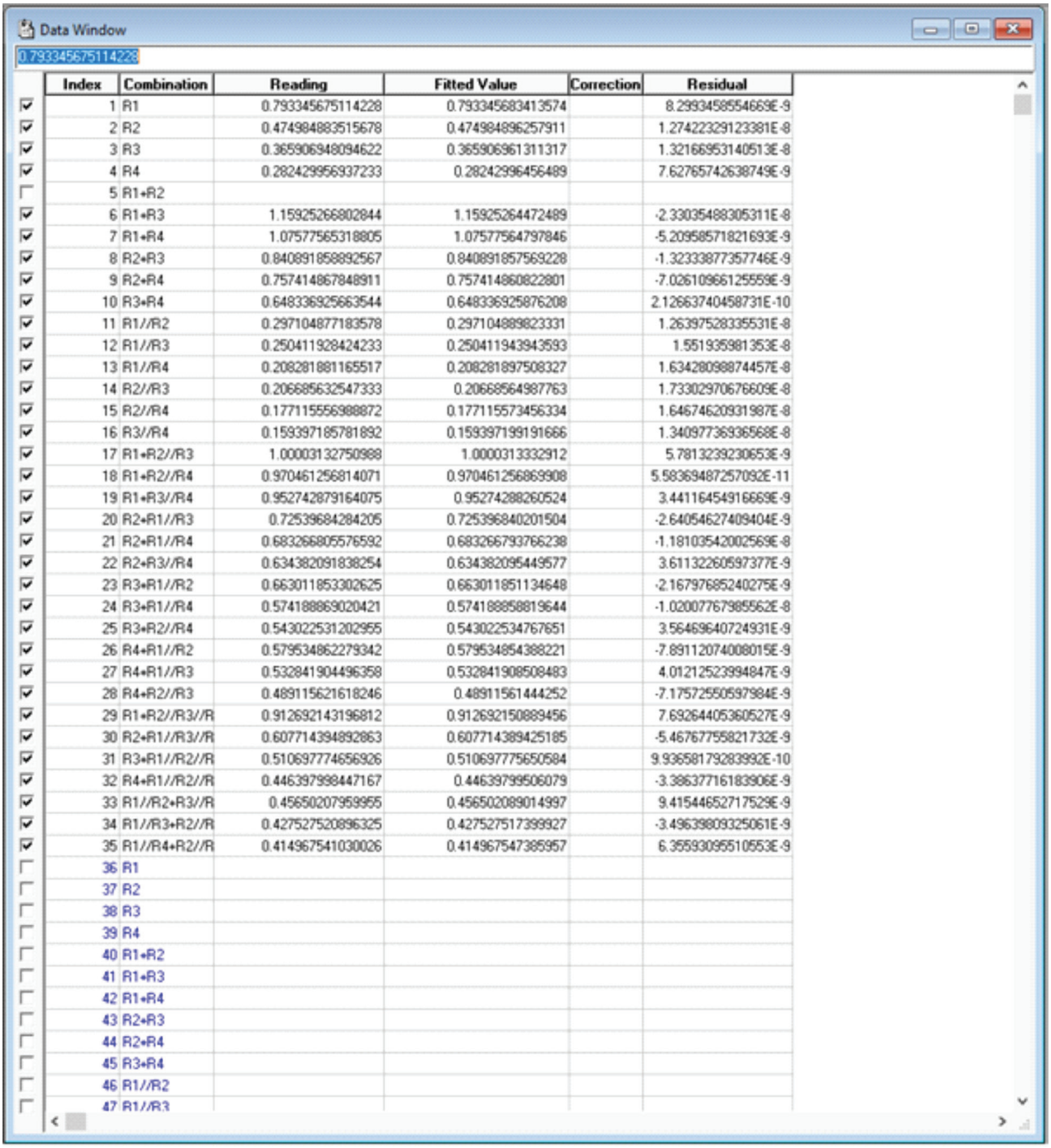


Figure 3.



Data Window

0.793345675114228

Index	Combination	Reading	Fitted Value	Correction	Residual
1	R1	0.793345675114228	0.793345683413574		8.2993458554669E-9
2	R2	0.474984883515678	0.474984896257911		1.27422329123381E-8
3	R3	0.365906948094622	0.365906961311317		1.32166953140513E-8
4	R4	0.282429956937233	0.28242996456489		7.62765742638749E-9
5	R1+R2				
6	R1+R3	1.15925266802844	1.15925264472489		-2.33035488305311E-8
7	R1+R4	1.07577565318805	1.07577564797846		-5.20958571821693E-9
8	R2+R3	0.840891858892567	0.840891857569228		-1.32333877357746E-9
9	R2+R4	0.757414867848911	0.757414860822801		-7.02610966125559E-9
10	R3+R4	0.648336925663544	0.648336925876208		2.12663740458731E-10
11	R1//R2	0.297104877183578	0.297104889823331		1.26397528335531E-8
12	R1//R3	0.250411928424233	0.250411943943593		1.551935981353E-8
13	R1//R4	0.208281881165517	0.208281897508327		1.63428098874457E-8
14	R2//R3	0.206685632547333	0.20668564987763		1.73302970676609E-8
15	R2//R4	0.177115556988872	0.177115573456334		1.64674620931987E-8
16	R3//R4	0.159397185781892	0.159397199191666		1.34097736936568E-8
17	R1+R2//R3	1.00003132750988	1.0000313332912		5.7813239230653E-9
18	R1+R2//R4	0.970461256814071	0.970461256869908		5.58369487257092E-11
19	R1+R3//R4	0.952742879164075	0.95274288260524		3.44116454916669E-9
20	R2+R1//R3	0.72539684284205	0.725396840201504		-2.64054627409404E-9
21	R2+R1//R4	0.683266805576592	0.683266793766238		-1.18103542002569E-8
22	R2+R3//R4	0.634382091838254	0.634382095449577		3.61132260597377E-9
23	R3+R1//R2	0.663011853302625	0.663011851134648		-2.16797685240275E-9
24	R3+R1//R4	0.574188869020421	0.574188858819644		-1.02007767985562E-8
25	R3+R2//R4	0.543022531202955	0.543022534767651		3.56469640724931E-9
26	R4+R1//R2	0.579534862279342	0.579534854388221		-7.89112074008015E-9
27	R4+R1//R3	0.532841904496358	0.532841908508483		4.01212523994847E-9
28	R4+R2//R3	0.489115621618246	0.48911561444252		-7.17572550597984E-9
29	R1+R2//R3//R	0.912692143196812	0.912692150889456		7.69264405360527E-9
30	R2+R1//R3//R	0.607714394892863	0.607714389425185		-5.46767755821732E-9
31	R3+R1//R2//R	0.510697774656926	0.510697775650584		9.93658179283992E-10
32	R4+R1//R2//R	0.446397998447167	0.44639799506079		-3.38637716183906E-9
33	R1//R2+R3//R	0.45650207959955	0.456502089014997		9.41544652717529E-9
34	R1//R3+R2//R	0.427527520896325	0.427527517399927		-3.49639809325061E-9
35	R1//R4+R2//R	0.414967541030026	0.414967547385957		6.35593095510553E-9
36	R1				
37	R2				
38	R3				
39	R4				
40	R1+R2				
41	R1+R3				
42	R1+R4				
43	R2+R3				
44	R2+R4				
45	R3+R4				
46	R1//R2				
47	R1//R3				

Figure 4.

Temperature Control: Minimizing Uncertainty

The RBC's uncertainty is primarily influenced by the temperature coefficients of the resistors and ambient temperature variations. The resistors used in the RBC are carefully selected, offering temperature coefficients within ±0.3 ppm/°C at temperatures ranging from 20 °C to 23 °C. To maintain accuracy, it is recommended to operate the RBC in a laboratory

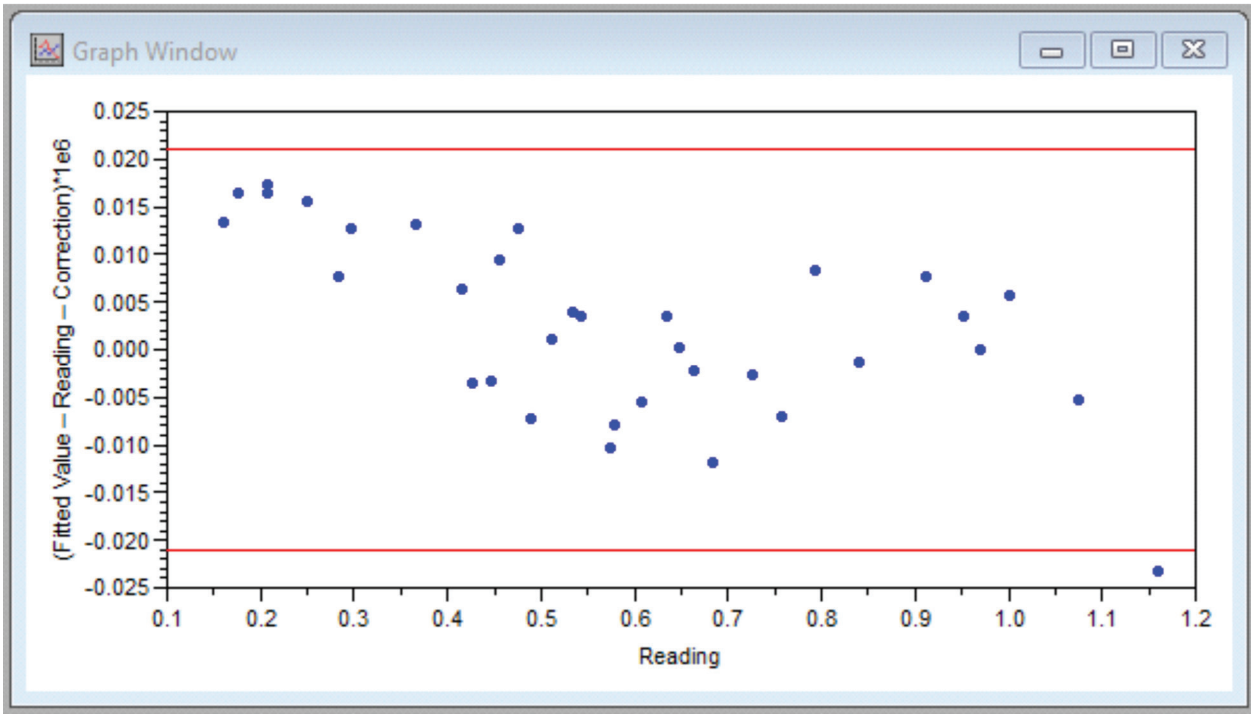


Figure 5.

with precise temperature control, minimizing variations and ensuring optimal performance within the practical limits.

Further Development

The Automatic Resistance Bridge Calibrator builds upon the success of the manual RBC, leading to an improved version introduced as the RBCA. This automated model offers several benefits, including the ability to be placed into a temperature-controlled oil or air bath, effectively overcoming the temperature coefficient limitation. With enhanced internal circuitry, the Automatic Resistance Bridge achieves an impressive accuracy of 0.01 ppm (at 100 Ω). Additionally, automated operation eliminates the need for manual data capture and entry, streamlining the calibration process.

Results and Future Applications

The performance of resistance bridges, including the RBC, has been subject to comprehensive analysis. Researchers, such as Jon Pearce et al. at NPL, have published papers characterizing the performance of AC and DC resistance bridges [2].

References

[1] White D.R., A Method for Calibrating Resistance Bridges. Proceedings TEMPMEKO 1996, 129-134.

[2] Pearce, J.V., Gray, J. & Veltcheva, R.I. Characterisation of a Selection of AC and DC Resistance Bridges for Standard Platinum Resistance Thermometry. *Int J Thermophys* 37, 109 (2016). https://doi.org/10.1007/s10765-016-2113-6

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