

A Gage Study of an Intercomparison Evaluation to Implement the Use of Fine-Pitch Test Patterns for Surface Insulation Resistance (SIR) Testing of Solder Fluxes

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ABSTRACT

SIR is a recognized tool for establishing electrochemical reliability of electronic assemblies. Currently the test patterns in the standards reflect coarse pitch components. An intercomparison has been completed with the aim of establishing the introduction of a fine pitch (Surface Insulation Resistance) SIR pattern with a 200µm gap. This exercise included the contribution from seven international participants. This new pattern moves the test method forward into the realm of current technologies where components of this pitch are commonplace. The study reported here validates the basis for the introduction of the new pattern and confirms acceptable Gage R&R for the SIR technique. The analysis also highlights the challenges in controlling humidity to achieve comparable results between different users. The results also point to the challenges in achieving acceptable Gage R&R when measuring resistances >1011Ω.

Keywords: SIR testing, Gage R&R, Humidity sensitivity, Update to standards, Fine pitch, Electrochemical reliability

INTRODUCTION

It is well known that fine pitch components and circuitry are more susceptible to corrosion issues and electrochemical migration (ECM) problems. Characterization of flux residues in terms of ECM are commonly characterized using SIR testing. A key parameter of the SIR test is the comb pattern used and gap between the electrodes. A summary of SIR patterns is given in Table 1.

Table 1. SIR pattern information

		B24	B25	New
Track/ Gap	(µm)	400/500	318/318	400/200
	(mil)	15.7/19.7	12.5/12.5	5.7/7.9
Number of squares ^b		1 020	1 950	5 125
Field Strength (V/mm) ^a		40.0	62.9	100.0

^a The field strength is calculated using an applied bias of 20 V.

^b An explanation of the “Number of Squares” is given at the end of the “Test Board Design” section

The current IPC B24 and B25 [1] with their 500-µm and 318-µm gap patterns are not representative of fine pitch products being manufactured today. Hence, the proposal to use a 200-µm gap pattern in a previous study [2]. This earlier intercomparison took the three designs in Table 1 and incorporated them into a single test board, and this new board was registered in the IPC standards PCB series as B-53. For the intercomparison the National Physical Laboratory prepared fluxed boards of this design and circulated them to participants for SIR testing. The results were returned to National Physical Laboratory who analyzed the data and prepared a paper [2].

To provide a stronger validation of the introduction of the 200-µm gap pattern a statistical analysis has been undertaken and the results of that study are presented in this paper. A standard method was used, the Gage Repeatability and Reproducibility (Gage R & R) methodology. Gage R&R is used to define the amount of variation in the measurement data due to the measurement system. It then compares measurement variation to the total variability observed, consequently defining the capability of the measurement system. Measurement variation consists of two important factors, repeatability and reproducibility. Repeatability is due to equipment variation and reproducibility is due to inspector or operator variation.

In this paper the results of a Gage R&R study are reported and used to validate the intercomparison given in the earlier paper. The study sets out to validate the use of a new test board, IPC B53, that included the IPC B24 and B25 patterns, and with an additional 200-µm pattern, with each pattern duplicated, giving six patterns in all on each test board. This work was motivated to update IEC 61189-5-501, now published, and IPC 2.6.3.7. A protocol for the testing was developed that took a standardized test rosin flux and defined the flux loading (5µl/cm²) and thermal conditioning (5 minutes at 100°C). Seven laboratories took part from five countries. The test boards were prepared by one participant and then distributed and tested in the seven laboratories [given in the acknowledgements]. The Gage R&R analysis aim is to validate the 200-µm pattern.

Test Board Design

In the intercomparison study [2] a 200- μm gap pattern was included that had been developed and defined in an earlier joint European project [3,4]. This pattern was compared for backwards compatibility with two SIR patterns in common use today, the IPC B24 and a pattern from the B25, with 400- μm /500- μm and 318- μm /318- μm track and gap, respectively. A board was designed that included these three SIR patterns, duplicating each pattern, and named at the research stage by NPL as TB144. A board was designed and has the designation in IPC as “B53”, as shown below in Figure 1.

In Figure 1, the number of squares is also given, and as can be seen, the number of squares for the 400- μm /200- μm pattern are significantly higher. It can also be seen that there are only small differences in overall size between the patterns. All test patterns have the same applied voltage and, in this work, was set to 20 V. This meant that the electric field strength was different for the three SIR patterns, as occurs on products.

Track/Gap (μm)	Squares
400/200	5125
400/500	1020
318/318	1950

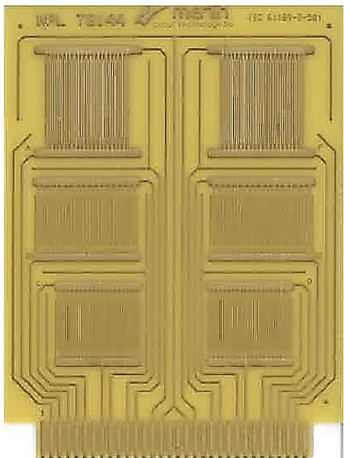


Figure 1. IPC B53

The number of squares in each pattern is important as it effects the overall resistance of a SIR pattern. To compare SIR patterns we use the concept of ohms per square. Ohms per square is the unit of an electrical measurement of surface resistivity across any given square area of a material. Measurement of surface resistivity is given in ASTM D-254. As for resistors if the number of squares between the electrodes goes up, the resistance increases, as is the case for resistors in series. An alternative example is if the gap is one square but we add adjacent squares, this is the same as adding resistors in parallel, and hence the resistance drops. To calculate the ohms per square in this case, the resistance is first measured between two parallel opposing electrodes. Then the number of squares is calculated by dividing the overlapping length of the two electrodes by the gap, giving the number of squares. The ohms per square is then the resistance multiplied by the number of squares. For a SIR pattern, with interdigitated electrodes we add the squares from successive gaps between the pattern fingers to calculate the total number of squares. If a conductive residue is uniformly added to achieve a constant ohms per square across the three different

pitch SIR patterns on the above board the measured resistance for each SIR pattern will vary depending on the number of squares. For example if the ohm per square is 1012Ω then the measured resistance for the B24, B25 and the new 400/200 μm patterns will be $9.8 \times 10^8\Omega$, $5.13 \times 10^8\Omega$ and $1.95 \times 10^8\Omega$ respectively.

Gage R&R Analysis

Typically, a Gage R&R study aims to achieve better than 10%, but for a test method with a measurement range over 10 orders of magnitude is this achievable? We consider the factors that impact on accuracy and repeatability of the SIR technique.

There is a defined accuracy statement for the electrical measurements given in the IPC and IEC standards. There, the resistance accuracy statement states that measurements shall be better than the following limits from IPC 2.6.3.7 and IEC 61189-5-501 released in 2021; 5% of full scale up to $1010\Omega @ 5\text{V}$, 10% of full scale up to $1011\Omega @ 5\text{V}$, 20% of full scale above $1011\Omega @ 5\text{V}$. Here we are not measuring resistors, but fluxed boards, and each instrument is measuring different boards, all be it that they were prepared identically. This error is unknown.

Temperature and relative humidity chambers also have tolerances, and in IEC 60068-2-78 these are stated as $\pm 2.0^\circ\text{C}$ and $\pm 3.0\%\text{RH}$. For humidity chambers used for SIR testing the tolerance values are more typically $\pm 0.3^\circ\text{C}$ and $\pm 2.5\%\text{RH}$. In themselves these numbers are not helpful; we need the difference they make to the adsorbed water film thickness. The water layer thickness will be closely related to the SIR value, and this is shown already in the earlier results where the resistance drops as we change from $40^\circ\text{C}/93\%\text{RH}$ to $85^\circ\text{C}/85\%\text{RH}$. In “Tencer et al” paper [5] a calculation for the water film thickness based on temperature and humidity are given. Absolute water layer thicknesses have not been calculated here, rather ratios of water thickness have been taken. This avoids the problem of knowing the constants in the calculation for this system. Using the accuracy statements from the IEC standard for temperature and humidity, the adsorbed moisture layer varies by $\pm 7.1\%$ and 5.4% at the nominal 40°C and 85°C respectively, whereas it varies by $\pm 45\%$ and 23% at the nominal $93\%\text{RH}$ and $85\%\text{RH}$ respectively. Using the accuracy statements for chambers used for SIR testing for temperature and humidity tolerances, the adsorbed moisture layer varies by $\pm 1.1\%$ and 0.8% at the nominal 40°C and 85°C respectively, whereas it varies by $\pm 38\%$ and 20% at the nominal 93% and $85\%\text{RH}$ respectively.

Adding these independent errors in quadrature for the above, we have $\pm 47\%$ for $40^\circ\text{C}/90\%\text{RH}$ and $\pm 24\%$ for $85^\circ\text{C}/85\%\text{RH}$ respectively, and summing all errors for a typical SIR chamber, we have $\pm 39\%$ for $40^\circ\text{C}/93\%\text{RH}$ and $\pm 21\%$ for $85^\circ\text{C}/85\%\text{RH}$. This variance in the water layer thickness is important as it directly relates to the conductance of this film through which we measure the SIR. As the water film thickens the number and mobility of ionic transfer will increase. It is clear that the humidity control in the chamber has the greatest influence on SIR. This analysis indicates the level of accuracy for SIR analysis will not typically be within the expected $\pm 10\%$ range.

Data Analysis

The data set can be analyzed by two different approaches. The first approach discussed considers the two climatic conditions as separate data sets. The data from the two climatic conditions are now plotted as box and whisker plots in Figure 2 for 40°C/93%RH and Figure 3 for 85°C/85%RH. In the following plots the lower quartile of the box is colored green, and the upper quartile is colored orange. Previously the raw data was given in [2].

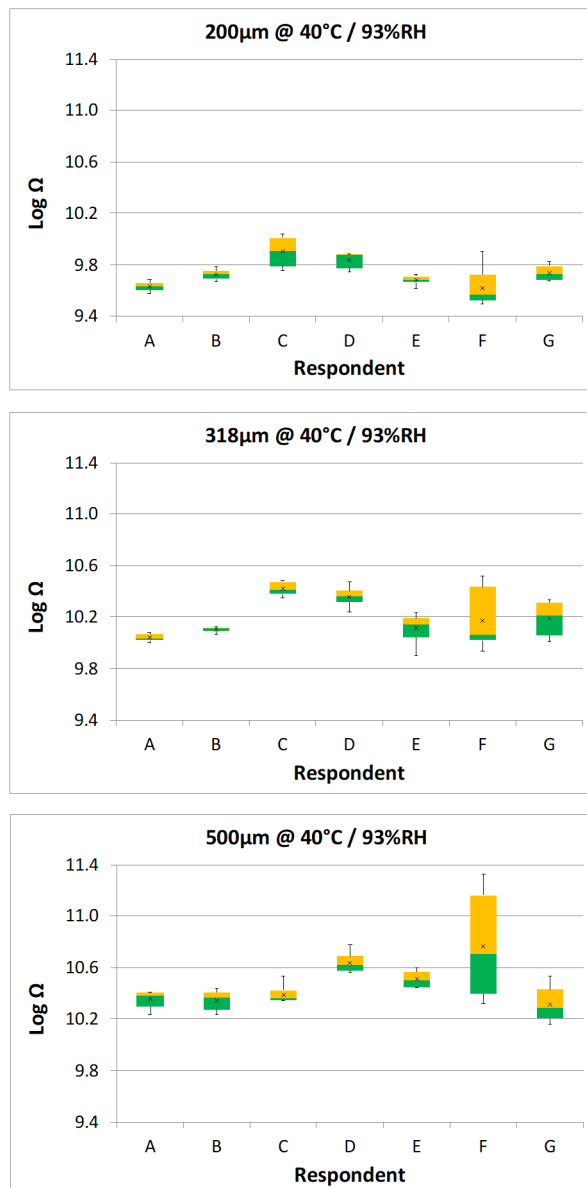


Figure 2. Participants values for each pattern at 40°C/93%RH

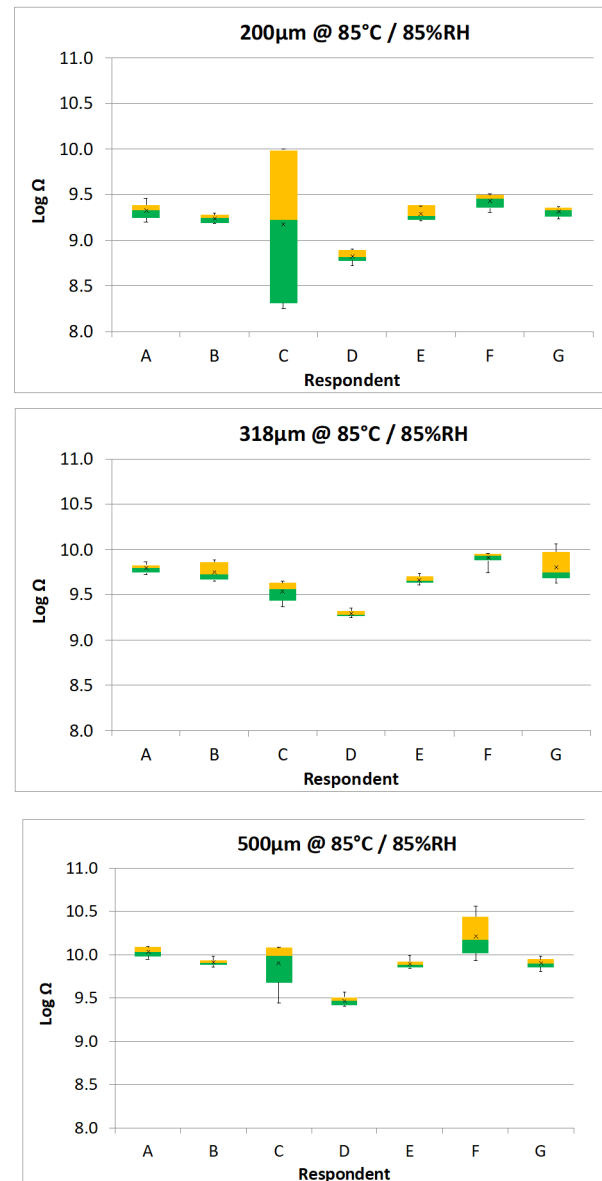


Figure 3. Participants values for each pattern at 85°C/85%RH

It is clear for both climatic conditions there is a trend to higher resistance as the number of squares (see Table 1) decrease, as shown the 500μm pattern has the highest resistance. We now consider the Gage R&R performance of these data. In the context of a Gage R&R study the parts are the three different SIR patterns, the operator are the seven participants (respondents), and the quality characteristic measured is the SIR value. The participants ran two experiments, one at 40°C/93%RH and the second at 85°C/85%RH. A Gage R&R analysis was run for each climatic condition, and these are given in Table 2.

Table 2. Gage R&R results for the two climatic conditions**40°C/93%RH**

Test for Significance of Part*Operator Interaction				
Alpha to test interaction:	0.05			
P-Value:	0.02			
Interaction is significant				
	Variance (VarComp)	%Contribution	Standard Deviation	%Study Variation
Part-to-part	0.1369	81%	0.370	90%
Operator	0.0065	4%	0.081	20%
Repeatability	0.0158	9%	0.126	31%
TOTAL Variation	0.1697	100%	0.412	100%
Part*Operator	0.0105	6%	0.103	25%
Reproducibility	0.0171	10%	0.131	32%
TOTAL Gauge R&R	0.0329	19%	0.181	44%
No. of Distinct Categories:				
	2			

85°C/85%RH

Test for Significance of Part*Operator Interaction				
Alpha to test interaction:	0.05			
P-Value:	0.92			
Interaction is not significant				
	Variance (VarComp)	%Contribution	Standard Deviation	%Study Variation
Part-to-part	0.1086	60%	0.330	77%
Operator	0.0404	22%	0.201	47%
Repeatability	0.0321	18%	0.179	42%
TOTAL Variation	0.1811	100%	0.426	100%
Part*Operator	0.0000	0%	0.000	0%
Reproducibility	0.0404	22%	0.201	47%
TOTAL Gauge R&R	0.0725	40%	0.269	63%
No. of Distinct Categories:				
	1			

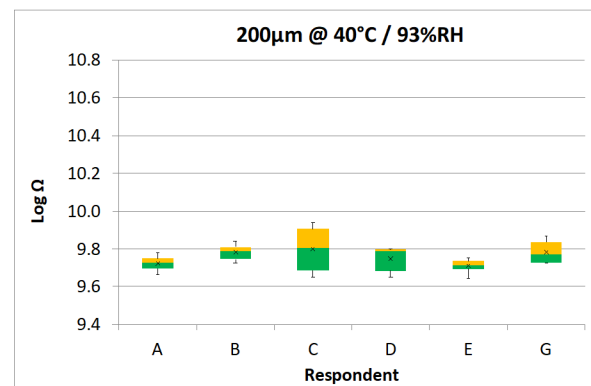
The 19% Gage R&R at 40°C/93%RH, and the 40% Gage R&R at 85°C/85%RH are outside the 10% tolerance expected for Gage R&R. The earlier tolerances of $\pm 39\%$ and 21% for 40°C/93%RH and 85°C/85%RH respectively for water layer thickness and hence the anticipated SIR tolerance can be compared to the results in Table 2. The 19% Gage R&R at 40°C/93%RH is within the $\pm 39\%$ water layer tolerance, but the 40% Gage R&R at 85°C/85%RH is outside $\pm 21\%$ water layer thickness.

Both climatic data sets show systematic behavior across the three SIR patterns and point to differences between the participants. As the analysis of errors highlighted the most likely source of error, or divergence from participant to participant, is probably in the accuracy of the humidity condition to the nominal condition at each participants facility. The aim of this study is to explore the relative performance of the 200 μ m pattern. For this purpose, it is useful to look into the relative performance from each participant.

In further analysis, therefore, for each participant the divergence from the mean in each plot is calculated. The two climatic conditions are treated separately. This divergence is averaged for the three plots, pattern styles, and this average divergence is corrected for each participant, in each plot. Further inspection of the 85°C/85%RH data reveals that participant C was repeatability poor. In the earlier report [2] it was noted that participant C and their use

of hand soldering to the board point to their data set not being consistent with the other participants. Typically in a Gage R&R study all operators must undertake exactly the same procedures. The use of connectors mounted in racks is the preferred technique of connecting the test board to the resistance measurement instrument, but the standards do allow this soldering procedure. These results highlight the challenge of using hand soldering to connect to the SIR coupons. That participant C did not use connector system, when all other participants did could be grounds from excluding them from the Gage R&R study. However, here we will adopt a more selective approach. As described before [2] a number of results were rejected due to visual and low SIR values. In a similar fashion the results of participant F in the 40°C/93%RH data are not consistent with other participants. This is very probably due to the high resistance values measured by partner F. High resistance values are taken from very low current measurements, and very low current measurements are particularly sensitive to noise problems. Partner F used a different resistance measurement instrument to the majority of participants which could measure lower currents. Clearly noise was an issue with these measurements that reduces the benefit of this extra sensitivity. Hence a further analysis was undertaken, correcting for local chamber climatic variations, removing participant C from the 85°C/85%RH data, and removing participant F from the 40°C/93%RH data.

This analysis is undertaken for comparative purposes, as we will see later in a different approach that all data are included, and the analysis is run with and without environmental correction. The current approach taken here in this analysis is to focus on the effect of the 200 μ m pattern for each participant. Two participant outliers were removed to clarify the results and the effect of the 200 μ m pattern. These results are shown in Figures 4 and 5.



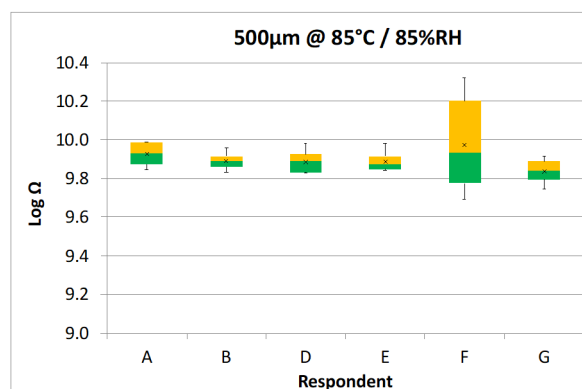
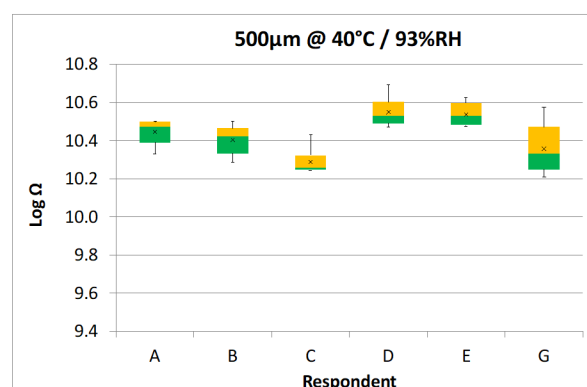
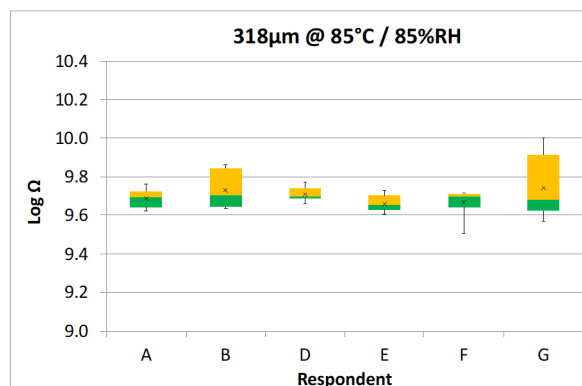
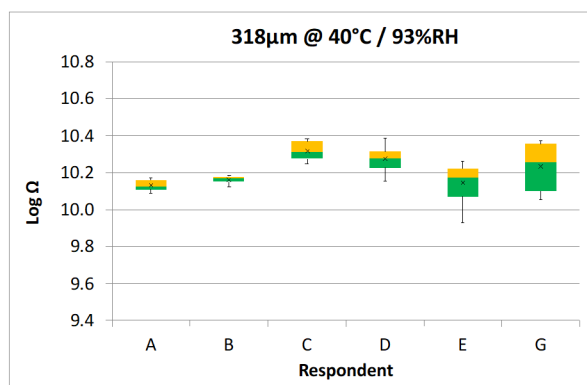


Figure 4. Participant F removed and environmental correction made at 40°C/93%RH

Figure 5. Participant C removed, and environmental correction made at 85°C/85%RH

Figures 4 and 5 when compared to Figures 2 and 3 respectively show an improvement in reproducibility between the climatic conditions and participants. There no longer appears to be systematic differences in the data. The Gage R&R analysis is repeated, and the data is shown in Table 3.

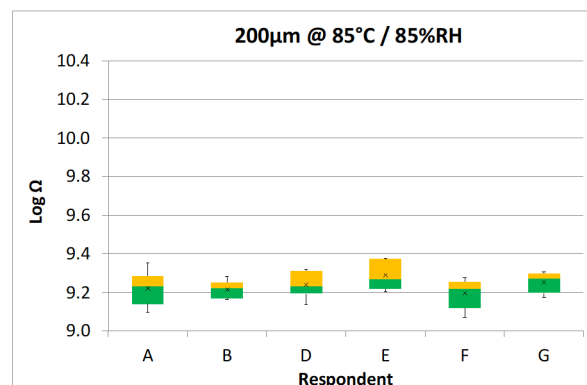


Table 3. Gage R&R results for the two climatic conditions**40°C/93%RH**

Test for Significance of Part*Operator Interaction				
Alpha to test interaction:		0.05		
P-Value:		0.01		
Interaction is significant				
	Variance (VarComp)	%Contribution	Standard Deviation	%Study Variation
Part-to-part	0.1142	91%	0.338	95%
Operator	0.0000	0%	0.000	0%
Repeatability	0.0059	5%	0.077	22%
TOTAL Variation	0.1254	100%	0.354	100%
Part*Operator	0.0054	4%	0.073	21%
Reproducibility	0.0054	4%	0.073	21%
TOTAL Gauge R&R	0.0113	9%	0.106	30%
No. of Distinct Categories:		4		

85°C/85%RH

Test for Significance of Part*Operator Interaction				
Alpha to test interaction:	0.05			
P-Value:	0.37			
Interaction is not significant				
	Variance (VarComp)	%Contribution	Standard Deviation	%Study Variation
Part-to-part	0.1109	93%	0.333	96%
Operator	0.0000	0%	0.000	0%
Repeatability	0.0085	7%	0.092	27%
TOTAL Variation	0.1193	100%	0.345	100%
Part*Operator	0.0000	0%	0.000	0%
Reproducibility	0.0000	0%	0.000	0%
TOTAL Gauge R&R	0.0085	7%	0.092	27%
No. of Distinct Categories:		5		

The 9% Gage R&R at 40°C/93%RH and the 7% Gage R&R at 85°C/85%RH are now within typical limits expected from a Gage R&R study of better than 10%, and well within limits for this study where humidity tolerances can have a big effect.

For the 40°C/93%RH data both the original and the modified data are satisfactory for SIR results. Table 3 show that the variation in the results is now dominated by the parts (SIR patterns). There are clearly 3 different categories, the three SIR patterns, but we also see an extra category in the corrected data. This is probably two respondents appearing to behave very similarly.

The 85°C/85%RH data showed a significant improvement in the Gage R&R reducing down from 40% to 7%. The data are far more scattered with the inclusion of Respondent C and no environmental correction. Both Gage R&R studies showed similar values in Table 3, with virtually identical number of categories, this will include the three SIR patterns with an added contribution from some participants behaving similarly. The p values are dissimilar, with the 40°C/93%RH data with a value of 0.01 and the 85°C/85%RH data with a value of 0.37.

This analysis shows that the new 200µm pattern behaves in a similar fashion to the older patterns. It does have a lower resistance as expected from an ohm.square consideration. As seen above the study treated the two climatic studies separately and focused on the effect of the different patterns. With the results of this analysis, we can now move to combine the results for both climatic conditions from each partner, using the ohm.square values from all SIR runs. Hence, re-analyzing using the concept of ohm.squares a normalization of the results for each climatic condition is achieved. This presumption assumes that the electrical response from the different patterns behave in a predictable ohmic fashion, and that there is no anomalous electrochemical behavior. The experimental setup and this analysis confirms' this assumption can be applied here.

The data was re-analyzed using the ohm.square concept and are replotted in Figure 6 for both climatic conditions and includes all participants and no correction is made for systematic effects between participants, which we have attributed environmental differences in each of the chambers from the nominal condition.

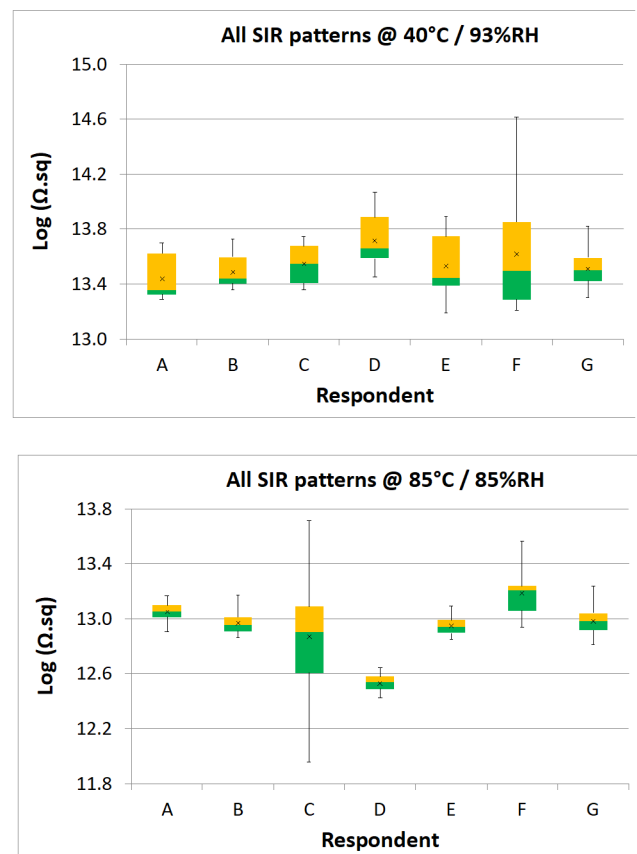


Figure 6. Participants values for $\Omega.sq$ for all patterns at 40°C/93%RH and 85°C/85%RH

These results show broadly, within the scatter of the results, that the three patterns conform to the same Ω_{sq} . At 40°C/93%RH the mean = $35 \times 10^{12} \Omega_{sq} \pm 1.7\%$, and at 85°C/85%RH the mean = $8.6 \times 10^{12} \Omega_{sq} \pm 2.0\%$. The resistance ratio between these values is 4.1 and using Tencer, with an energy of evaporation of 0.3eV, we achieve a ratio of 4.0 in the water layer thickness. This shows agreement and confirms the sensitivity to humidity between the predicted water thickness and the measured resistance. As before these results show the same systematic variance between participants that has been assumed to be due to climatic differences in the participants chambers. The same environmental correction method applied before is applied here, and the results are presented in Figure 7.

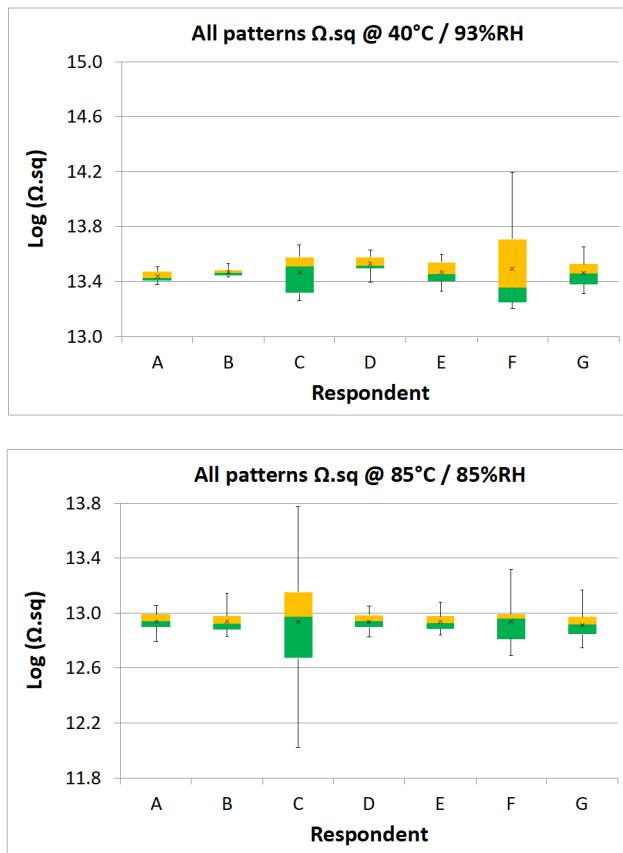


Figure 7. Participants values for Ω_{sq} for all patterns at 40°C/93%RH and 85°C/85%RH with an environmental correction made

Figure 7 shows a reduced scatter of the results, and at 40°C/93%RH the mean = $30 \times 10^{12} \Omega_{sq} \pm 1.1\%$, and at 85°C/85%RH the mean = $8.6 \times 10^{12} \Omega_{sq} \pm 1.4\%$.

The Gage R&R analysis is now run on both data sets, but now the parts are no longer the SIR patterns, but the two climatic conditions and the measurements are the Ω_{sq} values. Hence, now all the data in the intercomparison is now analyzed in one calculation. This analysis is presented below in Table 4.

Table 4. Gage R&R results for Ω_{sq} values

Uncorrected data

Test for Significance of Part*Operator Interaction				
Alpha to test interaction:	0.05			
P-Value:	0.00			
Interaction is significant				
	Variance (VarComp)	%Contribution	Standard Deviation	%Study Variation
Part-to-part	0.1377	78%	0.371	88%
Operator	0.0000	0%	0.000	0%
Repeatability	0.0152	9%	0.123	29%
TOTAL Variation	0.1762	100%	0.420	100%
Part*Operator	0.0232	13%	0.152	36%
Reproducibility	0.0232	13%	0.152	36%
TOTAL Gauge R&R	0.0384	22%	0.196	47%
No. of Distinct Categories: 2				

Environmentally corrected

Test for Significance of Part*Operator Interaction				
Alpha to test interaction:	0.05			
P-Value:	0.90			
Interaction is not significant				
	Variance (VarComp)	%Contribution	Standard Deviation	%Study Variation
Part-to-part	0.1410	91%	0.376	95%
Operator	0.0000	0%	0.000	0%
Repeatability	0.0146	9%	0.121	31%
TOTAL Variation	0.1556	100%	0.394	100%
Part*Operator	0.0000	0%	0.000	0%
Reproducibility	0.0000	0%	0.000	0%
TOTAL Gauge R&R	0.0146	9%	0.121	31%
No. of Distinct Categories: 4				

Analyzing the uncorrected data from all participants and applying no correction the overall Gage R&R is 22% and is within our calculated humidity tolerance for these measurements. The P-value at 0.0 is very low and there is a significant interaction between the participants. This is not surprising as we have noted a systematic variation, and this is very likely due to the accuracy and repeatability of the climatic chambers. There are also just two categories, which will be the two climatic conditions.

The environmentally corrected data for all participants resulted in a Gage R&R of 9%, an excellent result. There are 4 categories, the two environmental conditions plus two groupings between the participants.

The results in Table 6 confirm that the SIR technique and the introduction of the 200 μ m pattern are both within the acceptable tolerances for this technique.

DISCUSSION

The aim of the intercomparison [2] was to validate the use of a new 200- μm gap SIR pattern. The work benchmarked this new pattern against the existing IPC B24 (400 μm /500 μm) and B25 (318 μm /318 μm) patterns and demonstrated that the 200 μm pattern produces results that are consistent and in line with those from the coarser patterns. For a SIR Gage R&R study with 7 participants across 3 continents is a challenging task.

An important observation was that Participant C was the only participant to connect using hand soldering to the coupon, and in their 85 °C/85 % RH results a small downward trend was seen with pattern pitch. Hence, hand soldering to the coupon is fraught with flux residue contamination issues, and should be done with extreme care, and fine-pitch patterns, the 200 μm pattern used here, will be more sensitive to contamination issues. Some results were filtered from the study as being clearly outside the expected set of results, in some cases these could be attributed to physical defects on the test boards.

This Gage R&R has highlighted two important points regarding SIR measurements: (i) sensitivity to humidity conditions within the environmental chamber tolerance, and (ii) that very low current measurements present a significant challenge in achieving good Gage R&R. This second point was encountered with the highest resistance measurements taken on the 500 μm gap pattern at 40°C/93%RH. Partner F made SIR measurements that were $>1011\Omega$, hence currents $<10\text{pA}$.

Analysis of the data in Figures 2 and 3 revealed there were systematic variances between participants, and this was attributed to humidity effects. An analysis showed that humidity can have a large effect on SIR within the humidity chamber tolerances. Humidity chambers today typically have $\pm 2.5\%$ tolerance in RH, and with the two climatic conditions used here resulted in significant changes to the overall tolerance in SIR. The concomitant variance in water film thickness, and hence SIR, varies by $\pm 38\%$ and 20% at the nominal 93% and 85%RH respectively. Summing humidity, temperature and resistance errors, a $\pm 39\%$ and 21% range for 40°C/93%RH and 85°C/85%RH is observed. It is clear that the humidity control in the chamber has the greatest influence on SIR.

An analysis was run removing the systematic variations due to individual participants temperature and humidity conditions, which did greatly improve the data. While this approach may be challenged, we can see in the final analysis, such corrections are not necessary to achieve acceptable Gage R&R for SIR testing. An additional point to note is that the study's aim evaluated the introduction of the new 200 μm pattern, and that evaluation was based on the relative measurements seen by each partner for the three SIR patterns. Hence, there is a justification for removing systematic difference between partners.

The Gage R&R was run treating the three SIR patterns as the parts, and hence there are seven operatives. Before the environmental correction the Gage R&R was 19 and 40% for 40°C/93%RH and 85°C/85%RH respectively. Before correcting for systematic differences for each environmental condition there was one participant whose measurements had a significantly larger

scatter, and these were removed, and further analysis was run. The final plots for the SIR pattern intercomparison in Figures 4 and 5 show good agreement between participants, and the final Gage R&R analysis revealed values of 9% at 40°C/93%RH and 7% at 85°C/85%RH, shown in Table 5.

The aim of this intercomparison was to validate the use of a 200- μm gap SIR pattern, and the data in Table 5 supports this. Having established that the 200 μm pattern behaved similarly to the other two SIR patterns the data set was reanalyzed using the Ω .square concept. Using this and comparing Ω .sq values for the three patterns, a standard deviation of $\pm 2\%$ was achieved, for the results plotted in Figure 6. This was for no environmental correction and all partners included.

The initial analysis considered the two environmental conditions separately, and the three SIR patterns were the parts in the analysis. Having established that the Ω .sq holds for the three patterns, the Gage R&R analysis was run on the complete data set with the two environments as the parts. For the uncorrected data from all participants and applying no correction the overall Gage R&R at 22%, is within our calculated humidity tolerance for these measurements. The environmentally corrected data for all participants, removing systematic effects, resulted in a Gage R&R of 9%.

The results in Table 4 confirm that the SIR technique and the introduction of the 200 μm pattern are both within the acceptable Gage R&R tolerances for this technique.

The analysis has shown overall the intercomparison approached has worked and is within Gage R&R expectations. This SIR intercomparison has demonstrated that SIR can achieve good levels of repeatability and reproducibility, well within the requirements of the technique. It has also shown unequivocally that the new 200 μm pattern can be used with the same confidence as the B24 and B25 patterns.

The study was run with two conditions 40 °C/93 % RH, and 85 °C/85 % RH. That we achieved the same result for the new 200 μm fine pitch pattern compared to the coarser pitch patterns reflects the careful setup of this intercomparison. Ordinarily we can expect failures far quicker with a 200 μm compared to a 500 μm pattern on production boards.

In any similar future intercomparison it is recommended that each humidity system is characterized using the same sensor.

CONCLUSIONS

This intercomparison established the relative performance of the new 200- μm pattern and met Gage R&R tolerance expectations for the SIR technique, it also provides a data set for justification and inclusion in any new standard.

This SIR Gage R&R study has a strong basis, having seven global participants from Denmark, Germany, Japan, the UK, and the USA.

This Gage R&R study revealed that absolute humidity control is a critical parameter for intercomparison work. Current industry environmental chambers with a $\pm 2.5\%$ tolerance corresponds to a significantly variance in SIR values, up to $\pm 38\%$ at 40°C/93%RH.

High resistance and low current measurements are more challenging in achieving good Gage R&R. Current measurements below 10pA will be difficult to validate in a Gage R&R study and will require extra caution.

It is known that hand soldering to SIR test coupons must be done with the upmost care, and this work has shown that moving to finer pitch exacerbates the sensitivity to leaving flux residues.

The approach used here was developed at NPL, and NPL prepared all the test boards and sent them directly to the participants. This ensured that sample variation was minimized and was an important factor in achieving good Gage R&R

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BIOGRAPHY



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