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Understanding SIR

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Many electronics manufacturers perform SIR testing to evaluate solder materials and sometimes the results they obtain differ significantly from those stated by the solder material provider. The difference in the results is typically the result of SIR coupon preparation. This paper will discuss the issue of SIR coupon preparation, board cleaning techniques, and how board cleanliness directly affects SIR results.

We will also discuss the differences between two of the industry's most common SIR specifications J-STD-004A and -004 B. The subjective nature of SIR testing on water washable/soluble materials will also be reviewed. In addition, testing for SIR when the assembly process has multiple residue sources, such as paste, wave solder flux, rework flux, etc., will be considered.

SIR (surface insulation resistance) is an important test in determining the long term electrical reliability of flux residues in most electronics devices. The primary purpose of SIR testing is to understand the impact of flux residues on the electrical reliability of a device, specifically the **conductive <u>and</u> corrosive** nature of the residue, regardless of whether the residue is removed or allowed to remain on the board post-reflow. SIR can be a little difficult to understand because it provides a measurement of conductivity of the residue in "ohms per square". People are often thrown by a "unit-less" value. Ohms per square what - square centimeter, square inch, square meter? In fact, it can be whatever unit you would like as long as it is a square measure of area.

"Ohms per square is the unit of an electrical measurement of surface resistivity across any given square area of a material. It is the measurement of the opposition to the movement of electrons across an area of a material's surface and normalized to a unit square. This measurement is intended to be a basic material parameter and not dependent on absolute area, length, or thickness. Unlike resistance, resistivity is not exactly a point-to-point measurement. It is a measurement where the electrons can take multiple paths across a uniform surface. However, the electrons are considered to generally flow only on the surface."[1]

There are two basic electronics equations that will help to understand why the size of the square area does not matter.

Resistors in Series:
$R_T = R_1 + R_2 + R_3 + \ldots\ldots R_N$

Resistors in Parallel:
$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots\ldots 1/R_N$

Let us look at two pictorial representations (Figures 1 and 2) of how these equations come in to play where SIR is concerned and why the size of the area has no impact in this measurement. (A basic knowledge of electrical circuits will be needed.)

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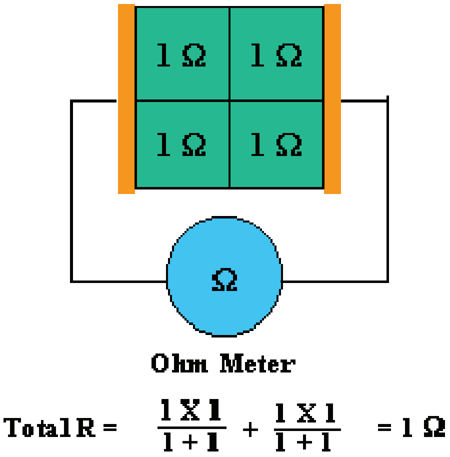
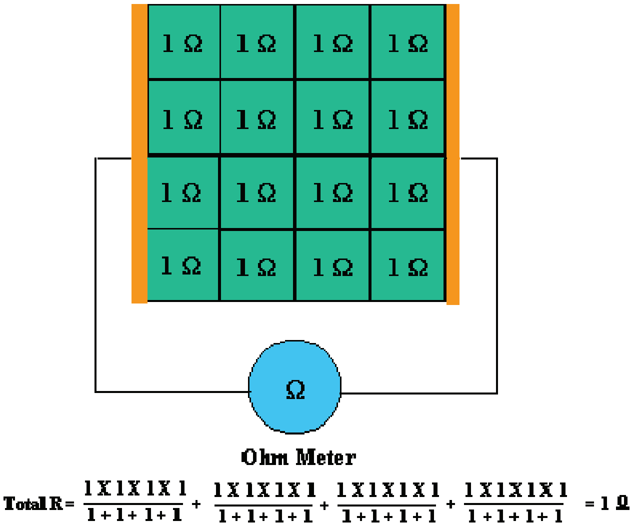
[1] ESDJournal.com



[2]

Figure 1 - Circuit 1



[3]

Figure 2 – Circuit 2

SIR also measures the corrosiveness of a residue by looking at the formation of dendrites (Figure 3).
As a flux residue corrodes a metal, such as silver, positively (+) charged metal ions are formed. Because the metal ions have a positive charge, they migrate toward the negatively charged trace, which is facilitated by the presence of moisture. Once they reach the negatively charged trace, the positive metal ions loose their positive charge and revert back to the metal. As the metal ions continue to "deposit" on the negatively charged trace, a little tree or dendrite of metal starts to grow, beginning at the negatively charged trace back toward the positively charged trace. If the dendrite grows large enough to span the gap between the positively and negatively charged trace, an electrical short is formed. In SIR testing it is not necessary for the dendrite to form a short, but because dendrites effectually reduce the gap between conductors, they can negatively impact the SIR value achieved in that circuit. Therefore, the size of any dendrites formed is important in determining a pass or fail SIR test.

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[2] ESDJournal.com
[3] ESDJournal.com

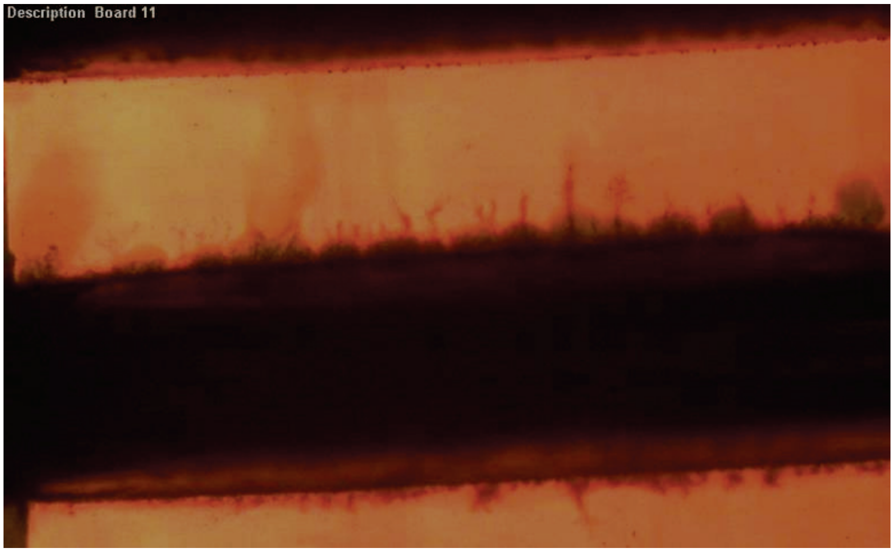


Figure 3 - Dendrite formation

In a perfect world, this sort of testing would be pretty straight forward. Apply solder paste or flux to the appropriate test coupon, submit it to a reflow cycle, put in an environmental chamber, apply voltage, and take measurements. However, our world is prone to contamination and SIR testing is by no means immune. Cleanliness of the test coupon is of paramount importance. Both J-STD-004A and -004B call for the use of the B-24 test coupon for SIR (Figure 4). The board is FR4, the traces are bare copper, and no solder mask is applied to the board surface. The board materials, residues from the board manufacturing process, other environmental contamination, and handling (fibers, dust, sweat, hand oils, spittle) can significantly reduce SIR readings. **It cannot be stressed enough that an SIR test coupon that has not been properly cleaned and handled will produce errant results, including false SIR failures.**

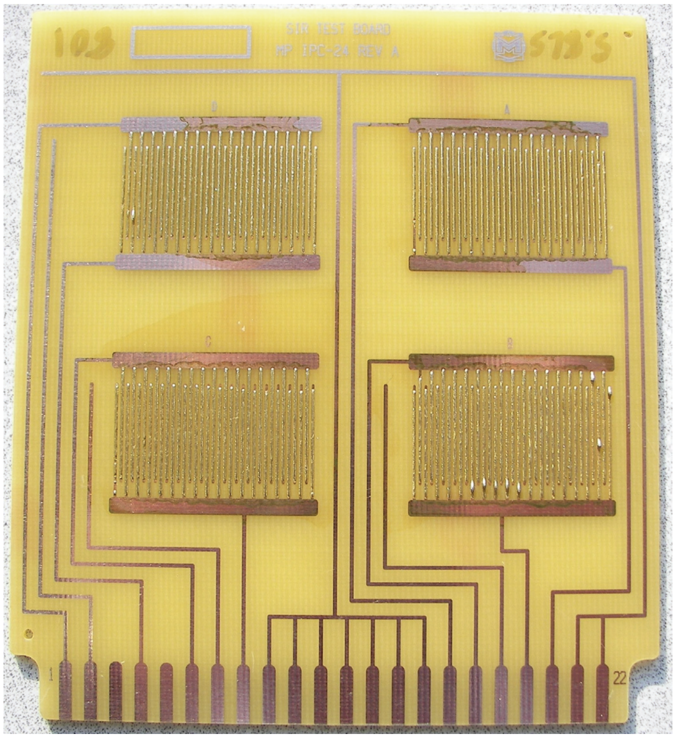


Figure 4 - B-24 SIR Test Coupon

Even different cleaning techniques can produce variances in SIR results for the bare test coupon. Table 1 shows the differences in SIR values among five different cleaning techniques. SIR testing was performed per J-STD-004A.

Method A – IPC manual brush and rinse method followed by 2 hour 50°C bake

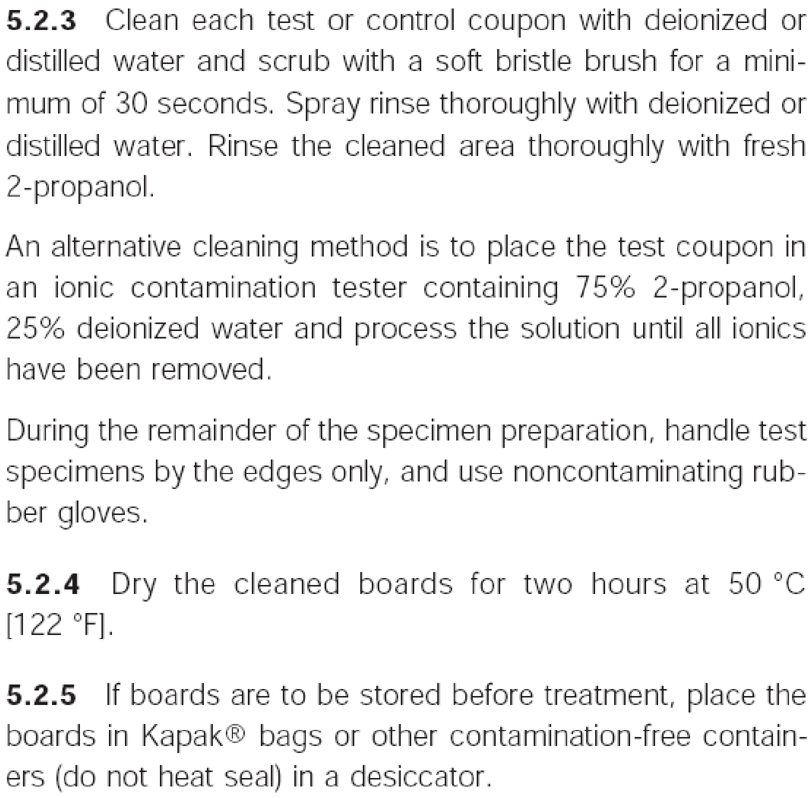
Method B – Cleaning with commercially available aqueous solution in inline cleaning equipment
Method C – No cleaning – as received from PCB manufacturer
Method D – Brush scrubbed with alcohol, brush scrubbed with DI water, brush scrubbed with alcohol, no bake
Method E – Alternative IPC cleaning method (ionic contamination method)

Table 1 – Impact of various cleaning methods on SIR results

Cleaning Method	24 HR AVG	96 HR AVG	168 HR AVG
A	1.99E+10	1.59E+10	1.06E+10
B	8.92E+09	7.44E+09	4.85E+09
C	6.53E+09	5.93E+09	3.93E+09
D	1.70E+10	1.22E+10	9.39E+09
E	1.63E+10	1.24E+10	9.37E+09

In terms of SIR performance of the bare coupon, the ranking of cleaning methods from best to worse are: A, D, E, B, and C

Both J-STD-004A and -004B employ the same cleaning and handling techniques. (Figure 5)



5.2.3 Clean each test or control coupon with deionized or distilled water and scrub with a soft bristle brush for a minimum of 30 seconds. Spray rinse thoroughly with deionized or distilled water. Rinse the cleaned area thoroughly with fresh 2-propanol.

An alternative cleaning method is to place the test coupon in an ionic contamination tester containing 75% 2-propanol, 25% deionized water and process the solution until all ionics have been removed.

During the remainder of the specimen preparation, handle test specimens by the edges only, and use noncontaminating rubber gloves.

5.2.4 Dry the cleaned boards for two hours at 50 °C [122 °F].

5.2.5 If boards are to be stored before treatment, place the boards in Kapak® bags or other contamination-free containers (do not heat seal) in a desiccator.[4]

Figure 5 – SIR board cleaning procedure

Great care must also be taken when printing solder paste or applying any kind of solder, such as flux-cored wire, to the test coupon. The formation of solder bulges on the traces is particularly important. SIR measurements are made for a known distance between the copper traces; in the case of the B-24 test coupon it is .020” or .508mm. A solder bulge effectively reduces the spacing and, therefore, reduces the amount of resistance between the traces.

Solder bulges (Figure 6) are often the result of stencil printing solder paste by hand. Using a full sized stencil in an automated stencil printer virtually eliminates any defects associated with the printing of solder paste on SIR test coupons.

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[4] IPC-TM-650 Number 2.6.3.3

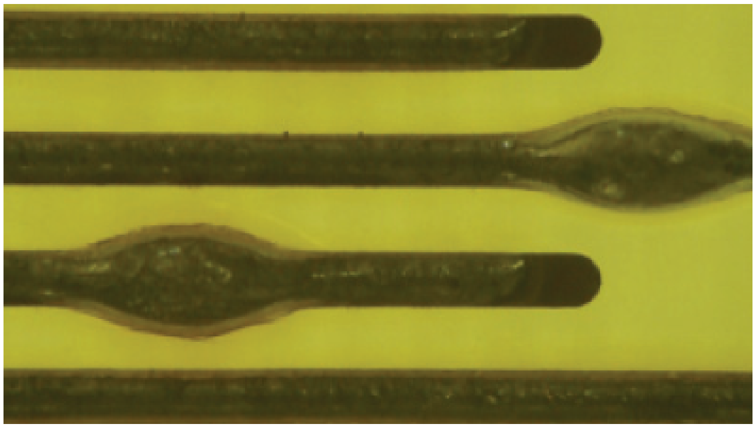

Figure 6 - Solder bulges on SIR test coupon traces

There are a number of solder pastes and fluxes that produce residues which need to be cleaned with DI water, solvents, and/or aqueous cleaning chemistries. Users of these pastes and fluxes sometimes require SIR results from the paste or flux manufacturer, and while the manufacturer may have SIR data for testing that they have performed, their results may not be representative of the SIR results that the user would obtain. The reason for this is simple - solder pastes and fluxes that require cleaning are likely to require cleaning because the residues are corrosive and/or conductive and would fail SIR in the un-cleaned state; whereas, an SIR coupon sufficiently cleaned of the residue would pass SIR with no problem. Therefore, the SIR results are, in effect, more a measure of the efficacy of the flux removal process and cleaning materials than the flux residue itself.

Another issue is that PCB assemblers may use multiple flux chemistries on a given assembly, including solder paste, wave solder flux, tacky flux, liquid rework flux, and flux-cored solder wire. In certain situations, some or all of these flux residues can come in contact with each other on the PCB, which brings up the question of flux residue compatibility. This is of specific concern in a no-clean process where the intermingled fluxes will remain on the PCB for the life of the device. In the spirit of due diligence, it would be ideal to perform SIR testing on the combination of fluxes. However, this poses a significant challenge to SIR coupon preparation. There is no good way to apply all the fluxes to a single coupon and then submit the coupon to a single reflow (heating) cycle. Instead the fluxes are often applied sequentially, as one would expect them to be applied in the actual manufacturing environment, and submitted to an appropriate heating cycle after each material has been applied to the coupon. Then, SIR testing is performed on the coupon. However, in such a situation, it is possible for a given flux to be exposed to multiple heating cycles, if it was one of the first fluxes to be applied to the coupon. Exposing a flux to multiple heating cycles has the possibility of "artificially" improving the SIR performance of a flux residue. This is because many of the ingredients in the flux that adversely affect SIR performance also decompose when exposed to heat. This would seem to diminish the validity of the SIR results. However, a counterargument is that SIR testing is often required in such situations not to simply measure SIR in the traditional sense but to research if there are any interactions between the flux chemistries whose by-product(s) could significantly reduce the SIR performance of the flux combination. While this is a valid concern, it is the authors' experience that if several no-clean fluxes pass SIR testing individually, they will likewise pass SIR when tested in combination. Whenever a combination of fluxes fails SIR it can always be traced back to a flux that had questionable or poor SIR performance by itself or that the flux was not prepared/processed properly.

Keeping in mind the importance of heating, relative to a no-clean flux residue, it is critical to note that if a no-clean flux is not exposed to adequate heat, as recommended by the flux manufacturer, the user has no guarantee that the flux residue will meet SIR requirements. Again, generally speaking, higher process heat improves SIR values; whereas, lower process heat reduces SIR values. Table 2 shows the average SIR values of a low solids, alcohol-based, no-clean wave flux submitted to two different wave soldering preheat conditions (the SIR coupons were not allowed to contact the solder wave). Preheat condition A achieved a top side temperature of 65°C. Preheat condition B achieved a top side temperature of 90°C. Notice that a 25°C increase in the peak preheat temperature resulted in nearly a tenfold improvement in the average SIR value.

Table 2 – Effects of Heat on SIR

Preheat Condition	Average SIR Value
A (65C)	7.20E+10
B (90C)	6.09E+11

In December 2008, IPC released J-STD-004B, which superseded J-STD-004A. SIR testing has undergone some significant changes in the new release. J-STD-004A specified the use of IPC-TM-650 Number 2.6.3.3; whereas J-STD-004B specifies the use of IPC-TM-650 Number 2.6.3.7. Both are available, free of charge, at www.ipc.org. Table 3 highlights the main differences of SIR testing for J-STD-004A and J-STD-004B.

Table 3 – SIR: J-STD-004A versus J-STD-004B

		SIR	
Parameters		**J-STD-004A**	**J-STD-004B**
Temp. Humidity & Stress	**Temp/Humidity**	85°C, 85%RH, 168 hours	40C, 90%RH, 168 hours
	Stress Bias	45 - 50 Volts DC	5V (8 mil spacing) or 25V/mm
	Pre-Bias Stabilization Period	3 hours at T&H	1 hour at T&H
	Measurement Bias	-100 Volts DC	5V (8 mil spacing) or 25V/mm
	Time of Readings	24, 96, 168 hours	At least once every 20 minutes
Criteria	**Control**	>1E9 Ohms, 96 hours to end	>1E9 Ohms, 96 hours to end
	SIR data	>1E8 Ohms @ 96, 168 hours	>1E8 Ohms @ All Measurments
	Dendrites/Corrosion	None > 25% of spacing	None > 20% of spacing

For the reader there may be the obvious question as to why these changes were made. The stress and measurement bias of 5 volts is believed to better mimic the typical operating voltage of most electronics products on the market as opposed to 45-50 and 100 volts. The lower voltage is also less apt to “fry” a shorting dendrite, should one form, making it easier to detect. The substantial increase in the frequency of SIR measurements (every 20 minutes as opposed to at 24, 96, and 168 hours) is also designed to better detect a shorting dendrite. With the old method it was possible for a dendrite to form and “fry” without ever being detected due to the greater intervals of time between readings. The chamber temperature is also considerably lower, dropping from 85°C to 40°C. The wisdom here is directly related to what was mentioned earlier about the effects of heating on the SIR performance of a flux residue. A chamber temperature of 85°C is actually high enough to decompose certain flux ingredients, artificially improving the SIR performance of the flux residue that otherwise would have reduced the SIR performance.

Table 4 – SIR results typical of J-STD-004A for a no-clean flux residue

Bd ID – Comb	INITIAL	24 hours	96 hours	168 hours	FINAL	Visual Findings
-13 A	9.33E+12	7.24E+08	1.23E+09	9.77E+08	2.09E+12	No Anomalies Observed
-13 B	7.24E+12	6.92E+08	7.41E+08	9.55E+08	2.40E+12	No Anomalies Observed
-13 C	5.25E+12	7.59E+08	6.17E+08	1.05E+09	2.40E+12	No Anomalies Observed
-13 D	6.76E+12	7.59E+08	1.29E+09	1.05E+09	2.34E+12	No Anomalies Observed
-14 A	7.08E+12	6.31E+08	5.62E+08	8.51E+08	1.10E+12	No Anomalies Observed
-14 B	9.77E+12	5.25E+08	5.62E+08	6.31E+08	1.74E+12	No Anomalies Observed
-14 C	7.76E+12	4.17E+08	4.90E+08	5.75E+08	1.62E+12	Solder Bulges[1]
-14 D	6.92E+12	6.31E+08	6.61E+08	8.71E+08	2.00E+12	Solder Bulges
-15 A	6.61E+12	4.90E+08	7.24E+08	6.31E+08	1.78E+12	No Anomalies Observed
-15 B	6.46E+12	4.27E+08	8.91E+08	5.13E+08	1.41E+12	No Anomalies Observed
-15 C	6.46E+12	3.98E+08	5.50E+08	5.25E+08	1.48E+12	Solder Bulges
-15 D	6.03E+12	5.89E+08	1.26E+09	7.59E+08	1.82E+12	No Anomalies Observed
-16 A	6.76E+12	4.68E+08	1.17E+09	6.31E+08	1.91E+12	No Anomalies Observed
-16 B	7.24E+12	2.69E+08	3.55E+08	3.80E+08	1.82E+12	No Anomalies Observed
-16 C	7.59E+12	4.07E+08	4.47E+08	5.01E+08	1.26E+12	No Anomalies Observed
-16 D	8.91E+12	4.90E+08	9.77E+08	6.46E+08	1.78E+12	Fiber Observed[1]

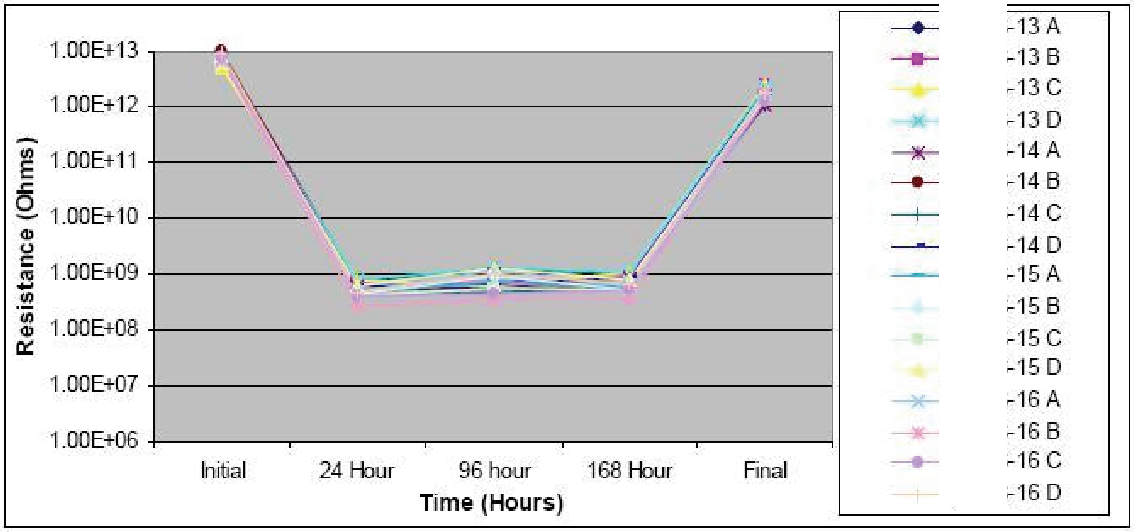

Figure 7 - SIR results typical of J-STD-004A for a no-clean flux residue

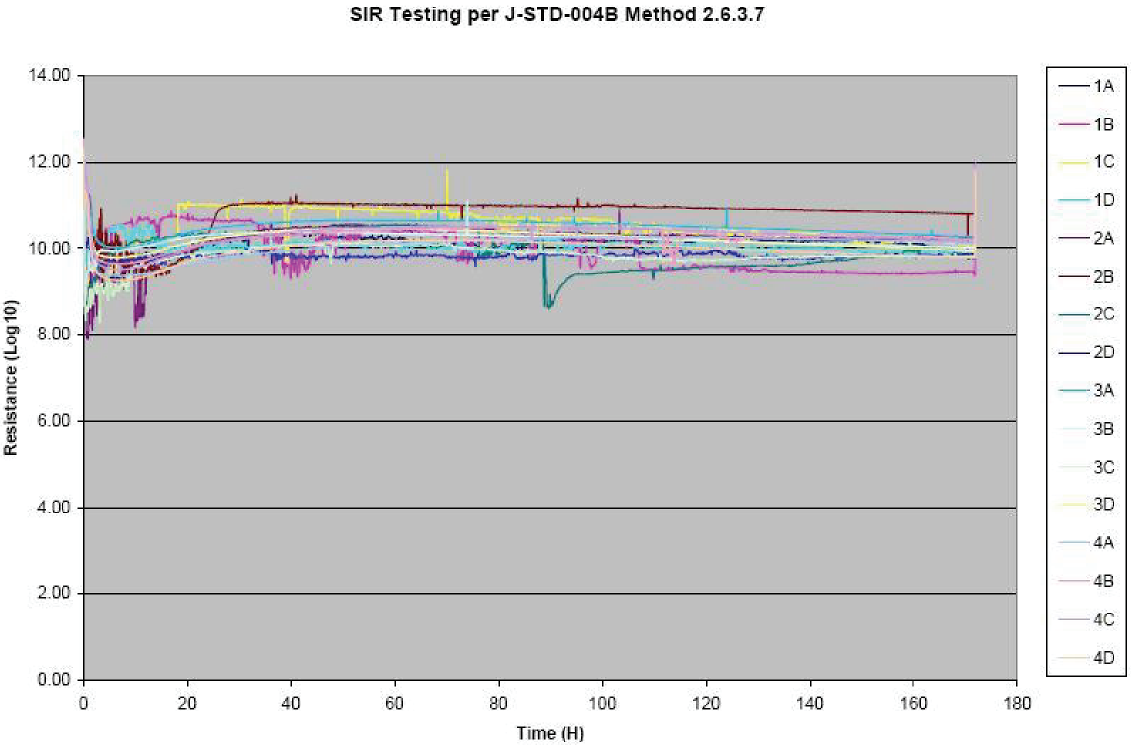

Figure 8 - SIR results typical of J-STD-004B for a no-clean flux residue

Both test methods must result in measurements exceeding 100 MΩ (1.0E+08). The difference, as discussed previously, in J-STD-004A the measurements must exceed 100 MΩ (1.0E+08) at 96 and 168 hours (failure is allowed at 24 hours as long as the resistance rebounds by 96 hours); whereas with J-STD-004B the measurements must exceed 100 MΩ (1.0E+08) at every measurement interval (Table 4 and Figures 7 and 8). There is, however, a stabilization period for both methods where the test coupons are in the chamber while the chamber is allowed to stabilize for a specified amount of time. Therefore, depending at what point the measurements begin, any readings taken during the stabilization period do not count.

If one looks closely at a typical J-STD-004B SIR plot (Figure 8), one will notice that the SIR readings are a bit erratic during the first ~20 hours. This would indicate that the flux residue is still becoming “acclimated” to the test conditions. The IPC is aware of this situation and recognizes that the data taken during that time may not represent the true SIR performance of a flux residue. With this in mind, the IPC is looking to change the SIR procedure to only require passing SIR values after 24 hours. Readings will be taken during the first 24 hours but will not be considered for pass/fail criteria.

There is also a theory as to how different flux chemistries will respond to the different environmental conditions of J-STD-004A and J-STD-004B SIR (Table 5). The chamber temperature and the amount or lack of rosin in the flux is of specific interest. In 004A the chamber temperature is 85°C; whereas, in 004B it is 40°C - significantly lower. Rosin provides an encapsulating barrier against moisture. In addition, the large organic chain molecules in rosin are very effective at trapping and immobilizing materials within the residue. Most rosins have a softening point somewhere around 90°C. Therefore a chamber temperature of 85°C may compromise the encapsulating properties of a rosin containing residue. However, at 40°C, well away from the softening point of rosin, the residue will be harder and rather “impermeable”, and have better “immobilizing” or encapsulating ability. Therefore, it can be argued that 004B conditions are “easier” for a rosin-containing residue as opposed to 004A conditions. Alternately, low rosin or rosin-free residues benefit from the 85°C chamber temperature, which is hot enough to decompose certain flux activators, thereby artificially improving its SIR performance. On the other hand, 40°C is not hot enough to cause significant decomposition. So it could be argued that low rosin or rosin-free residues perform better under 004A conditions at 85°C as opposed to 004B conditions at 40°C. Examples of rosin-containing products would be most no-clean and RMA-type solder pastes and tacky fluxes. Examples of low rosin or rosin-free fluxes would be many liquid fluxes, including no-clean and low residue wave fluxes, flux pens, etc.

Table 5 – Anticipated SIR performance

	Anticipated SIR Performance	
	004A (85°C)	**004B (40°C)**
Low Rosin/Rosin Free	**Better**	**Worse**
Rosin Containing	**Worse**	**Better**

J-STD-004B has changed the way SIR is performed. These changes have allowed for an open discussion on SIR testing as a whole. Hopefully, this work has shed some light in all the various aspects of SIR testing, placing the focus on board cleaning and preparation, and highlighting the main differences between J-STD-004A and -004B.