An Evaluation of the Insulation Resistance and Surface Contamination of Printed Circuit Board Assemblies

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Abstract
The overall effectiveness of 20 circuit board assembly processes, made up of 4 solder/flux combinations and 6 cleaning processes was investigated by using *in-situ* surface insulation resistance measurement, resistivity of solvent extract test, ion chromatography test, and optical inspection. The cleanliness of each process was represented by one board produced according to the IPC B-52 layout and design. Together with 4 unpopulated control boards, 24 boards in total were investigated. Surface insulation resistance test evaluated the propensity of a printed circuit board to develop leakage currents and undergo metal migration when subjected to temperature-humidity-bias conditions of 40°C and 90 ± 3% relative humidity (consistent with IPC TM 650-2.6.3.7) and 5 V. The resistivity of solvent extract test inspected the cleanliness of a printed circuit board by extracting the ionizable surface contaminants and quantifying them in terms of an equivalent amount of sodium chloride. The ion chromatography test identified the specific types and amounts of ions present on the surface of a printed circuit board. Optical inspection was a visual check of the cleanliness and possible defects associated with manufacturing processes. By taking into account all the results of the 4 methods, this study clearly shows a relative ranking of the 20 samples provided, and a pass-fail assessment of the 20 processes. A good correspondence between surface insulation resistance and surface contamination levels was observed. The conductivity of the extract was consistent with the presence of ion types and concentrations, especially inorganic anions. This study also indicates that a good solder/flux combination must be paired with an appropriate cleaning process in order to be successful.

Introduction

After the announcement of 1987 Montreal Protocol, no clean flux, aqueous based water soluble flux and some other flux systems have been investigated in order to reduce detrimental impact to environments, lower the operating cost and simplify manufacturing processes [1]. However, even if with the use of these fluxes such as no clean or water soluble fluxes, electrical shorts due to electrochemical migration can still occur [2][3]. Thus it triggers the need to combine the flux systems and cleaning processes to increase the reliability of printed circuit boards associated with surface contamination and metal migration issues.

Although some new cleaning processes, such as laser cleaning [4] and low-pressure plasma cleaning [5] have been developed partly to replace traditional wet cleaning, wet cleaning processes are still being used due to their capability of providing required surface cleanliness for subsequent manufacturing process. A combination of methods, such as copper mirror test, surface insulation resistance (SIR) test, electrochemical tests (polarization, cyclic voltammetry) and subsequent ESEM, XPS can be used to check the corrosivity of different flux systems [6], but there is still a lack of combined methodological approaches to identify the optimal combination of fluxing systems and cleaning processes and differentiate them in terms of their cleanliness delivering level and the resultant reliability issues. So the major purpose of this paper is to use SIR test, resistivity of solvent extract (ROSE) test, ion chromatography (IC) test and optical inspection to differentiate the combinations of flux and cleaning processes.

Experimental Setup

In order to represent the mainstream manufacturing materials and processes and investigate surface cleanliness associated with manufacturing processes, IPC B-52 design was used for the test boards. Dummy components such as connectors, BGAs, QFPs and capacitors were assembled using the solder/flux systems and cleaning processes intended for evaluation. The board is shown in Figure 1.

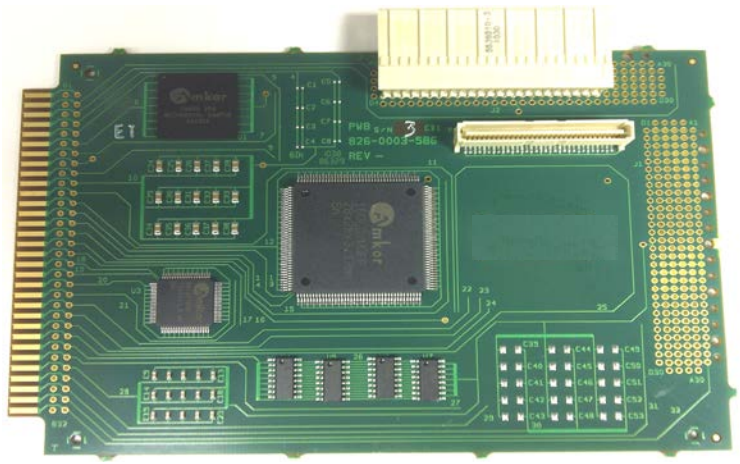

Figure 1: IPC B-52 Board Design Used for SIR and Cleanliness Tests

There are 5 types of components on the boards, but not every one was tested. At least 4 components were chosen to represent those component types and were monitored on each test board. The monitored components were selected from among the following:

- CON: Connector-Through Hole-Horizontal
- BGA: 256 I/O, full 16x16 array, 1.0 mm pitch, 17 mm body size
- QFP160: Interdigitated comb structure under quad flat pack with 160 I/O, 28 mm square body, with a 0.65 mm pitch.
- QFP80: Interdigitated comb structure under quad flat pack with 80 I/O, 12 mm square body, with 0.5 mm pitch and a 2 mm lead footprint
- Cap: Array of 15 0603 surface mount ceramic capacitors-10.0pF

The test boards were connected to an SIR test system by card edge connectors. The SIR test system was used to detect leakage current. The SIR test system comprised a computer, a high resistance meter, low noise switches, a temperature-humidity chamber, a DC power supply, triax cabling, and the test boards. The power supply used a HP Harrison 6268A DC power supply with a 40V maximum voltage output and 30A maximum current output. The multichannel high resistance meter was an Agilent 4349B with a measurement range from 10^3 Ohms to 10^{15} Ohms. Its accuracy ranges from 2.5% to 3.1%. Agilent E5252A low noise switches provided the ability to multiplex 48 channels to the resistance meter, allowing an SIR reading to be collected once every 3.6 minutes for each comb pattern. A 1-megohm current limiting resistor was placed in series with each comb pattern in order to minimize the fusing of dendrites in the event of a drop in SIR, while still providing the opportunity to observe SIR behavior over about 4 orders of magnitude in resistance. The temperature-humidity-bias (THB) conditions used 40°C and 90 ± 3% R.H., which were consistent with IPC TM 650-2.6.3.7. 5 V bias was used to represent the signal line voltages in normal usage conditions. The SIR failure threshold was 100 MOhms, which was consistent with the criteria cited in IPC J-STD-004A method 3.4.5.1 and IPC-9201.

In parallel with SIR test, ROSE and IC tests were performed to investigate the surface cleanliness. The ROSE test procedure was based on IPC-TM-650 2.3.25, "Detection and Measurement of Ionizable Surface Contaminants by

Resistivity of Solvent Extract (ROSE)," and IPC-TM-650 2.3.28, "Ionic Analysis of Circuit Boards, Ion Chromatography Method." To do the ROSE test, standard NaCl solutions with different concentrations had to be made first and their conductivities were measured to build up a calibration curve. Then the test boards were immersed into a wash solution to allow for surface contaminants to be extracted. The wash solution consisted of 75% isopropanol and 25% DI water. DI water has a conductivity of 18.2 MOhm-cm. The conductivity of the solution was measured and compared with the calibration curve, thus generating the amount of surface contaminants of the boards in terms of a NaCl equivalent concentration. Although IPC method 2.3.25 recommends rinsing the surface with a fine stream of wash solution and collecting the runoff solution, the ionizable ions on the board surface may not be thoroughly dissolved due to the short rinsing time and the low temperature of the solution (20ºC). So instead a hot water bath (80ºC) was used for an hour, recommended by IC method 2.3.28, in order to thoroughly extract the board's contaminants from the surface and keep consistency with the IC experiments. So each board was given a hot water bath and extracted, thus generating 2 identical solution samples, one for ROSE and one for IC.

IC is a method used to separate and analyze mixtures of ions based on their ionic properties and their interaction with the sorbents in a packed bed column. The IC system used in this study, a DIONEX-600 System, employs a type of liquid ion-exchange chromatography, which exploits ionic interaction and competition to separate analytes.

As shown in Table 1, A-D represents the flux systems, and 1-10 represents the cleaning processes. Every pair of odd and even numbers, such as 1 and 2, or 3 and 4 is from the same cleaning process. 20 boards were used for SIR test, show as the odd numbers in Table 1. Another 20 boards were used for ROSE and IC test, shown as the even numbers in Table 1. 4 controls were used for both SIR and cleanliness tests. The 4 control boards were identical to the PCBs used for the test boards, but were not populated with any component. Test board distribution in the SIR tests and positions within the chamber were randomized.

Table 1 Cleaning Method and Fluxes Used on the IPC-B-52 Boards

A -1	**A -3**	**A -5**	**A -7**	**A -9**	**n/a**
A -2	**A -4**	**A -6**	**A -8**	**A -10**	**n/a**
B -1	**B -3**	**B -5**	**B -7**	**B -9**	**n/a**
B -2	**B -4**	**B -6**	**B -8**	**B -10**	**n/a**
C-1	**C-3**	**C-5**	**C-7**	**C-9**	**n/a**
C-2	**C-4**	**C-6**	**C-8**	**C-10**	**n/a**
D-1	**D-3**	**n/a**	**D-7**	**D-9**	**D-5**
D-2	**D-4**	**n/a**	**D-8**	**D-10**	**D-6**

Results and Discussion

1. Ranking of 20 Boards

A common trend existed among all the boards including the control and testing boards. They demonstrated initial low SIR values, but their SIRs increased and stabilized at relatively high values in the later stage of testing, as shown in Figures 2 and 3. This initial increasing SIR trend is a typical characteristic of diffusion controlled cells, which was probably caused by the consumption of electroactive species at electrodes or the liberation of electroactive species from the degraded flux [3][7]. The SIR values at the very beginning of the test varied a lot, from 10^6 to 10^{10} Ohms, depending on which fluxes and cleaning processes were used. Some failed boards, however, showed occasions of intermittent SIR drops or decreased SIR in the later stage, as shown in Figures 4 and 5.

The overall SIRs ranged from 10^8 to 10^{11} Ohms with variations according to different processes. Among all the components, QFP80 and Capacitors always had the highest SIRs (larger than 10^{10} Ohms), while QFP160 and BGA always had lowest SIRs (10^9~10^{10} Ohms). The SIRs of connectors were in the middle or in the lower range of the SIR out of the 5 types. An interesting comparison lied between QFP80 and QFP160. The SIR of QFP80 was always higher than that of QFP160 by one or half one order of magnitude. Capacitors showed the most recurring noise and intermittents throughout the test, seemingly quite sensitive to any perturbation of the system, while the rest 4 types of components were relatively stable with few times of intermittent SIR drops.

Since the overall SIR performance, the occurrences of intermittent drops, and the initial SIR right after the test were the three major factors to evaluate the cleanliness of the manufacturing processes in terms of SIR, these three factors were summarized and shown in Table 2. Based on this information, a ranking to distinguish the 20 boards is given in Table 3.

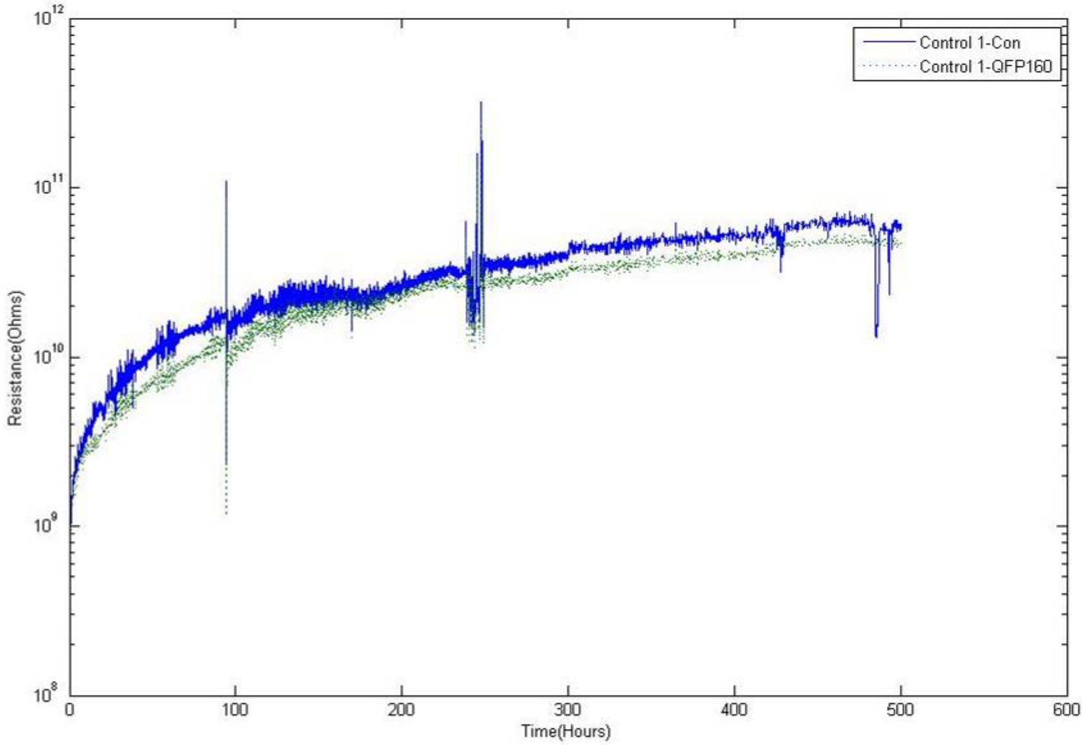

Figure 2: SIR for control board 1

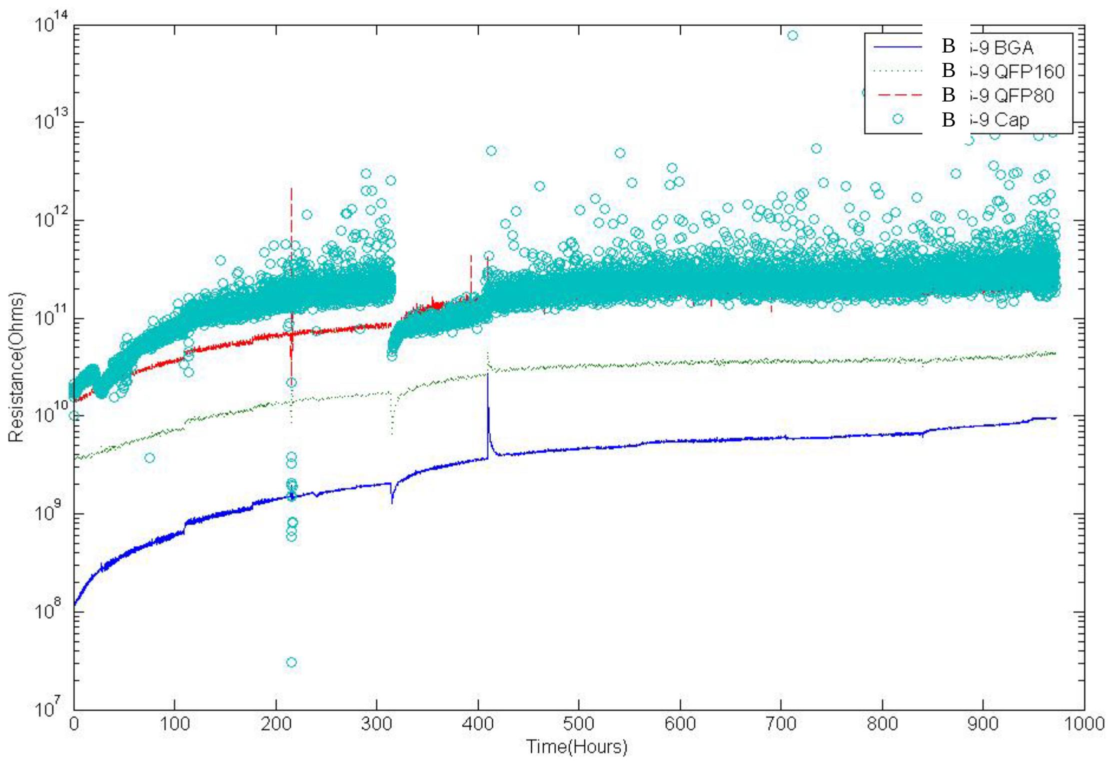

Figure 3: SIR for B-9

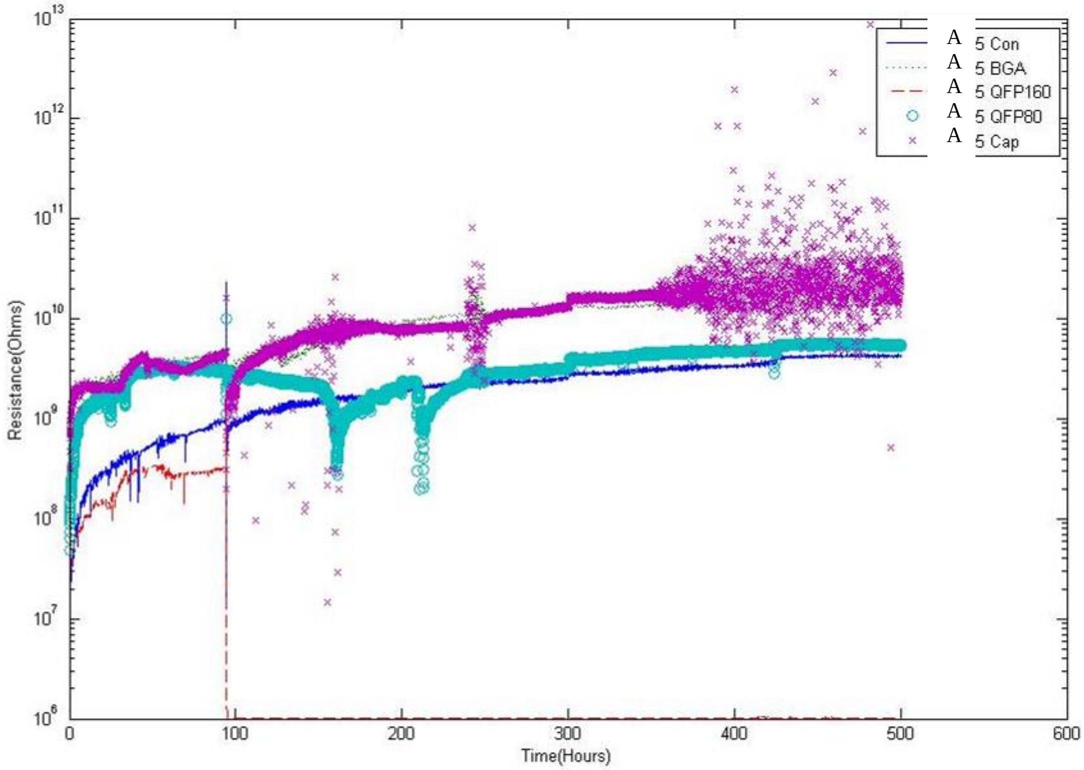

Figure 4: SIR for A-5

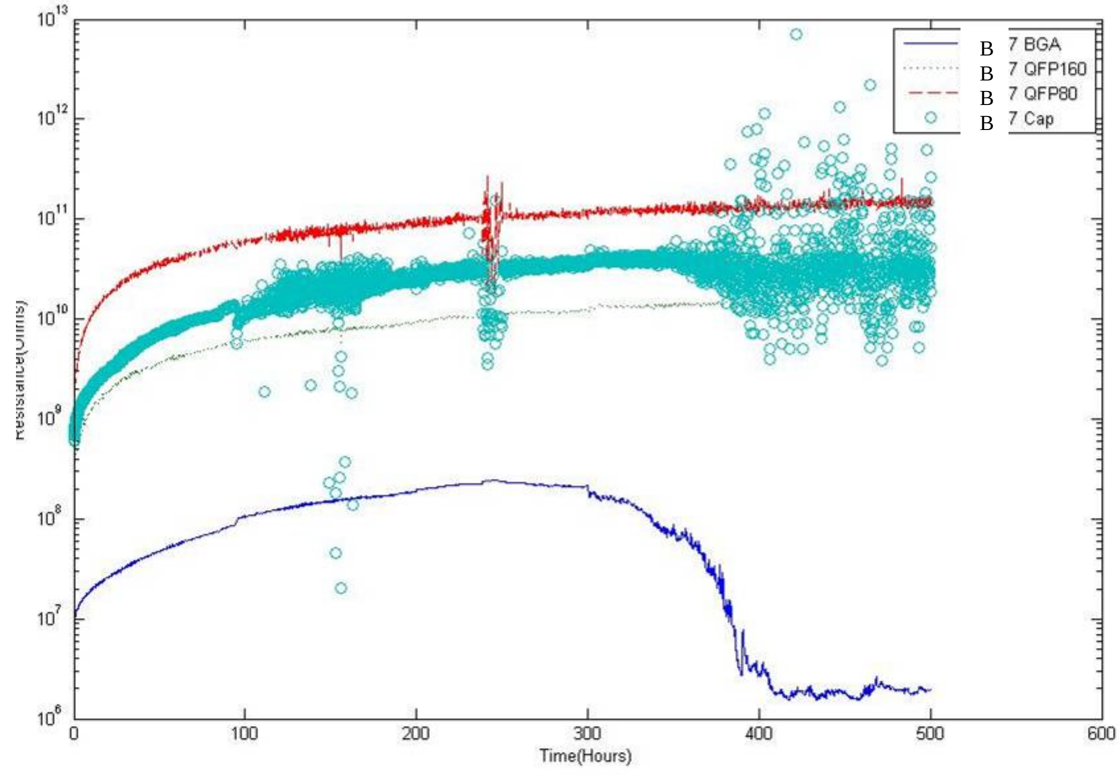

Figure 5: SIR for B-7

Table 2 Intermittent Drops of Individual Components, and Overall and Initial SIR

Board Type	SIR Intermittents of Individual Components					SIR of Boards (Ohms)	
	Conn	**BGA**	**QFP(160)**	**QFP (80)**	**Cap**	**Overall**	**Initial**
Control 1	$4>10^{9}$		$2>10^{9}$			10^{10}~$3x10^{10}$	10^{9}~10^{10}
Control 2		\		$7>10^{8}$	$2>10^{9}$	10^{9}~10^{11}	10^{8}~10^{11}
Control 3	\		$2>10^{9}$			$3x10^{10}$~$4x10^{10}$	10^{9}~10^{10}
Control 4		$20>10^{10}$		$4>10^{10}$	$1>9x10^{9}$	$2x10^{10}$~$2x10^{11}$	$2x10^{9}$~$4x10^{10}$
A-1	\	\	\	\	**$4<10^{8}$**	$3x10^{8}$~$3x10^{10}$	$4x10^{7}$~10^{8}
A-4	$2>10^{9}$		**$1\rightarrow10^{8}$**	$1>10^{9}$	$4>10^{8}$	10^{9}~$2x10^{10}$	$2x10^{8}$~$3x10^{9}$
A-5	$1>10^{8}$	$>10^{9}$	**$<=10^{6}$**	$2>10^{8}$	**$5<10^{8}$**	10^{9}~$2x10^{10}$	$3x10^{7}$~$5x10^{8}$
A-7	$10>10^{8}$		\	$1>10^{9}$	**$3<10^{8}$**	$3x10^{9}$~$2x10^{10}$	10^{8}~10^{9}
A-9	$2>10^{9}$		\	$2>10^{9}$	$4>10^{8}$	10^{10}~$5x10^{10}$	10^{9}~10^{10}
B-1		\	\	\	**$5<10^{8}$**	$4x10^{8}$~$7x10^{10}$	$3x10^{7}$~$4x10^{8}$
B-3	$4>10^{9}$	\	\	$1>10^{9}$	$1>10^{9}$	10^{9}~$3x10^{10}$	$2x10^{8}$~$2x10^{9}$
B-5	$2>10^{9}$	$2>10^{9}$	$10>10^{8}$	$4>10^{9}$	\	$2x10^{9}$~$5x10^{10}$	10^{9}~10^{10}
B-7		**$<=2x10^{6}$**	\	$2>10^{10}$	**$3<10^{8}$**	10^{8}~10^{11}	10^{7}~$3x10^{9}$
B-9		\	\	\	$3>10^{8}$	$2x10^{9}$~$2x10^{11}$	10^{8}~10^{10}
C-1		\	\	\	$3>10^{8}$	10^{9}~10^{11}	$4x10^{7}$~10^{9}
C-3		\	\	\	$1>10^{8}$	$2x10^{9}$~$2x10^{10}$	$7x10^{7}$~10^{9}
C-5		\	$8>10^{8}$	$6>10^{9}$	**$4<10^{8}$**	$3x10^{9}$~$3x10^{10}$	$2x10^{8}$~$2x10^{10}$
C-7	$4>10^{9}$	\	\	\	$4>10^{9}$	10^{9}~$4x10^{10}$	$3x10^{7}$~$3x10^{9}$
C-9	\	\	$1>10^{9}$	$1>10^{9}$	**$5<10^{8}$**	10^{9}~10^{11}	$2x10^{8}$~$2x10^{10}$
D-1		\	\	\	**$5<10^{8}$**	$8x10^{8}$~$2x10^{10}$	$3x10^{7}$~$2x10^{8}$
D-3		\	\	\	$3>10^{8}$	$3x10^{9}$~$3x10^{10}$	$4x10^{7}$~$2x10^{9}$
D-5		\	$2>10^{9}$	$2>10^{10}$	**$3<10^{8}$**	$2x10^{9}$~$2x10^{11}$	10^{8}~$4x10^{10}$
D-7		\	\	$2>=10^{10}$	$5>10^{8}$	$5x10^{9}$~10^{11}	$5x10^{7}$~10^{10}
D-9	**$<=10^{8}$**	\	\	\	$4>10^{8}$	10^{8}~$3x10^{10}$	$4x10^{6}$~10^{10}

Note: red-colored cells indicate failures. Grey colored cells mean the component was not monitored by in-situ SIR measurement. The number "$4>10^{9}$," for example, means 4 occasions of intermittent drops, but they are all above 10^{9} Ohms.

From Table 3, it can seen that cleaning process 3 is the best, cleaning process 9 is also strong though it can give diverse performance, cleaning 5 and 1 are good, and cleaning process 7 is the worst. So the ranking of cleaning process from best to worst is 3>9>1>5>7. As to the fluxes, B can give the best performance although one B board failed. D can give diverse performance, and C occupies the middle of the rankings, while A seems to be the worst.

Another conclusion that can be drawn is, fluxes and cleaning processes have to be paired to demonstrate their effectiveness. For example, B, the best flux in this study, could always give very good SIR performance, but once it was used with cleaning 7, the board failed. Another example, A, the worst flux in the study, could still give strong SIR performance when it was used with a strong cleaning process 9.

Table 3 Relative Ranking of PCBs Based on the SIR Performance

Ranking	Types	Comments
1	B-3	SIR range 10^9~$3x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms
2	A-9	SIR range 10^{10}~$5x10^{10}$ Ohms, 4 occasion of intermittents, all intermittents above 10^8 Ohms
3	B-9	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, possible noise
4	D-7	SIR range $5x10^9$~10^{11} Ohms, 5 occasions of intermittents, all intermittents above 10^8 Ohms
5	D-3	SIR range $3x10^9$~$3x10^{10}$ Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
6	C-3	SIR range $2x10^9$~$2x10^{10}$ Ohms, 1 occasion of intermittents, all intermittent drops above 10^8 Ohms, most of components steady around 10^9 Ohms
7	C-7	SIR range 10^9~$4x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms, most of components had high resistances (10^{10} Ohms)
8	C-1	SIR range 10^9~10^{11} Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
9	D-5	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, a few intermittent drops below 10^8 Ohms
10	C-9	SIR range 10^9~10^{11} Ohms, more than 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
11	B-5	SIR range $2x10^9$~$5x10^{10}$ Ohms, more than 20 occasions of intermittents, all intermittents above 10^8 Ohms
12	A-7	SIR range $3x10^9$~$2x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms
13	C-5	SIR range $3x10^9$~$3x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms, but intermittents happened on more than one component
14	B-1	SIR range $4x10^8$~$7x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
15	A-1	SIR range $3x10^8$~$3x10^{10}$ Ohms, 4 occasions of intermittents, a few intermittent drops below 10^8 Ohms
16	D-1	SIR range $8x10^8$~$2x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
17	A-4	SIR range 10^9~$2x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample showed failing trend after 50 hours but recovered
18	D-9	SIR range 10^8~$3x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample failing from 500 hours
19	B-7	one component failed at about 300 hours
20	A-5	one component failed at about 96 hours, a lot of intermittents

2. ROSE Results

In parallel with the set of boards used for SIR test, another identical set of testing boards were prepared for ROSE and IC tests, based on IPC-TM-650 2.3.25, "Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract (ROSE)," and IPC-TM-650 2.3.28, "Ionic Analysis of Circuit Boards, Ion Chromatography Method". After extracting surface contaminants by IPA and DI water, identical samples were prepared for ROSE and IC. The conductivities of the boards are shown in Table 4.

Note that 3 NaCl solutions with different concentrations were also prepared and their conductivities were measured, in order to build up a calibration curve to obtain equivalent NaCl amounts, as shown in Figure 6.

Table 4 Measured Conductivities of the Boards

Sample	Conductivity (µS)	Sample	Conductivity (µS)
DI water	0.5	D-2	1.1
Control Solution (after hot water bath)	0.5	D-4	0.8
Control Solution (without hot water bath)	0.5	D-6	0.9
Control Board 1	0.7	D-8	1
Control Board 2	0.7	D-10	1
Control Board 3	0.6	C-2	1.1
Control Board 4	0.7	C-4	0.8
0.3 ppm NaCl	**0.7**	C-6	0.9
1.5 ppm NaCl	**1.1**	C-8	1.1
3 ppm NaCl	**1.7**	C-10	0.9
A-2	1.3	B-2	1
A-4	1	B-4	0.8
A-6	1.5	B-6	1
A-8	1.4	B-8	1.4
A-10	1	B-10	0.8

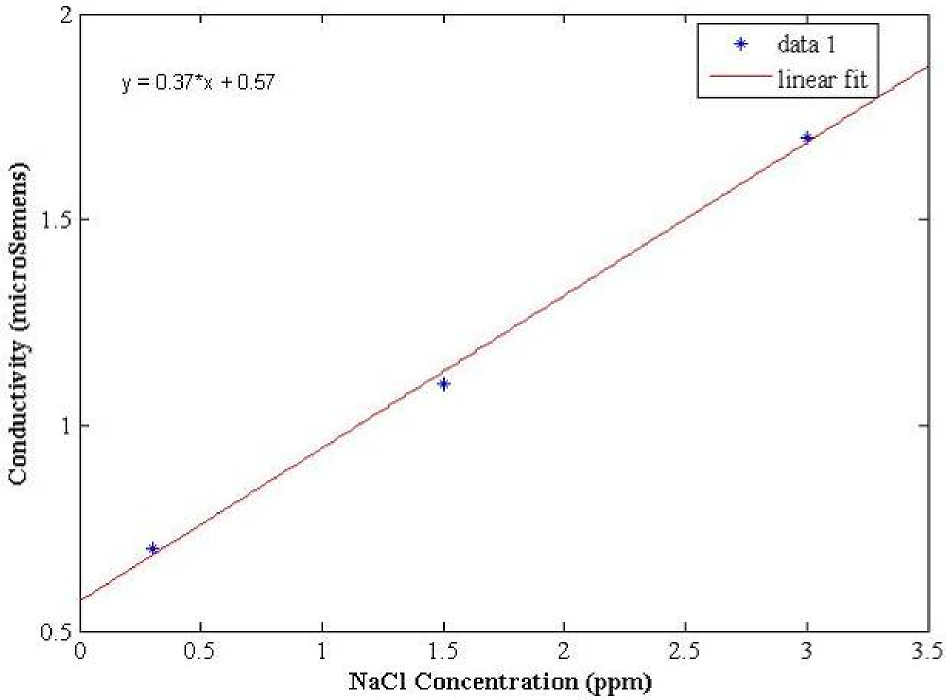

Figure 6: Calibration curve for conductivity measurement

From the volumes of extracted solutions and the area of testing boards (370 cm^2), a ranking of test boards based on overall cleanliness is obtained, as shown in Table 5.

Table 5 Ranking of Test Boards Based Only on ROSE Tests

Ranking	Sample	Surface NaCl Concentration (Equiv. NaCl μg/cm^2)
1	B-10	0.320
2	C-4	0.394
3	B-4	0.399
4	D-4	0.401
5	D-6	0.541
6	C-10	0.560
7	C-6	0.622
8	B-6	0.731
9	D-10	0.747
10	A-10	0.753
11	B-2	0.762
12	A-4	0.766
13	D-8	0.803
14	D-2	0.902
14	C-2	0.902
16	C-8	1.014
17	A-2	1.382
18	B-8	1.463
19	A-6	**1.620**
20	A-8	**1.939**

3. IC Results

IC was then used to identify the individual types of ions, either inorganic or organic, based on the comparison between the sample solutions from the testing boards and the standard solutions. On a chromatograph of IC results, the retention times of different peaks can be used to identify types of the ions using appropriate standards, and the areas below the peaks are used to determine their concentrations. Figures 7 to 9 show two standard solutions and a typical sample solution of testing board A-6. From the calibration curves set by three standard solutions with different concentrations for each type of ions, either organic or inorganic, the concentrations of identified ions in the testing board solutions were obtained and converted as amounts of contaminants on the board surface, as shown in Table 6.

4. Correspondence between SIR, ROSE and IC

As shown in Table 5, the top 5 ranked boards with green areas and the bottom 4 ranked boards with red color were the ones which had close match among their ROSE, IC and SIR performance. B-10, for example, the cleanest board in terms of ROSE, bore the least amount of inorganic ions, although it had some amount of organic anions. Its SIR was high (10^9~10^{11} Ohms) with few intermittents. So these three aspects showed consistency to each other. This consistency was also shown among the worst ones. B-8, in the bottom red region, is among the "dirtiest" ones in terms of ROSE, which bore a large amount of fluoride and fair amount of sulphate. Its SIR had a lot of intermittent drops, and its BGA component failed after 300 hours.

In the middle gray region of Table 5, their overall cleanliness was in the middle range in terms of ROSE, and most of them bore fair or small amounts of fluoride and small amounts of sulphate, corresponding to their mid-range ROSE results. But their SIR performances varied a lot. Some of them had much worse SIR performance than what they were expected to be based on their cleanliness, such as D-10, but some had better SIR performance than that expected by their cleanliness, such as A-10. This implies that in the middle range of cleanliness of the testing boards, the cleanliness may not be the dominant factor to affect their SIR anymore, thus allowing SIR to bear more random nature. But the close match among ROSE, IC and SIR shown from very clean ones (green region) and very dirty ones (red region) suggests that their cleanliness influences more and almost dominates their SIR performances.

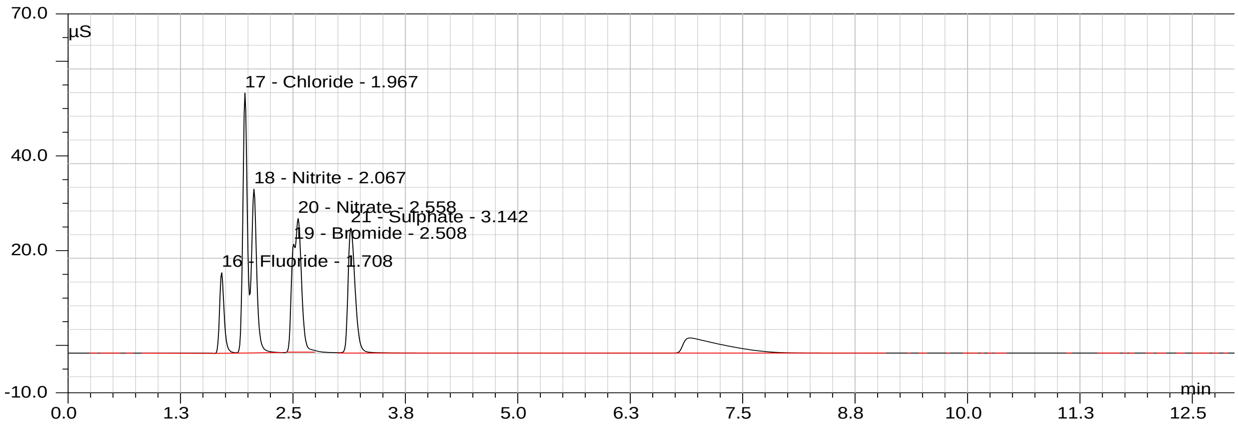

Figure 7: IC test diagram for 7-anion standard (20ppm)

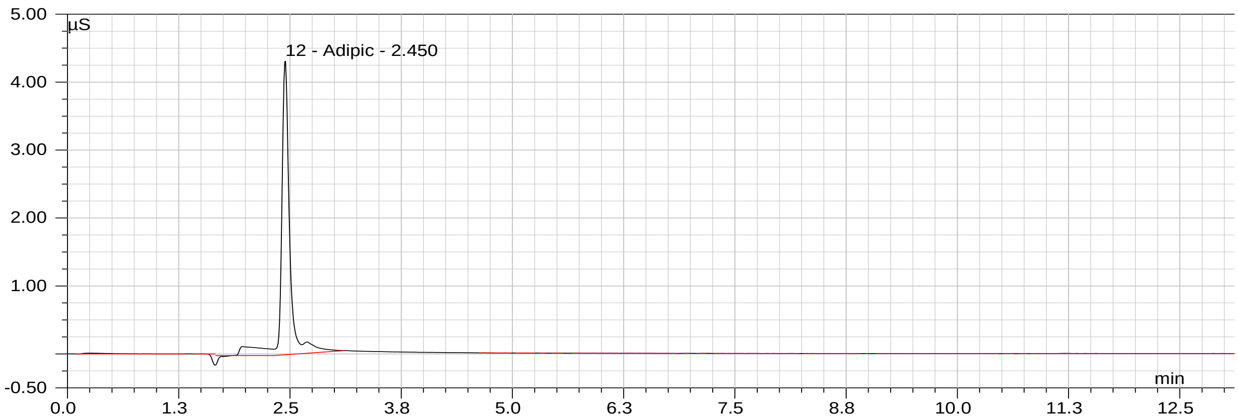

Figure 8: IC test diagram for adipic acid standard (10ppm)

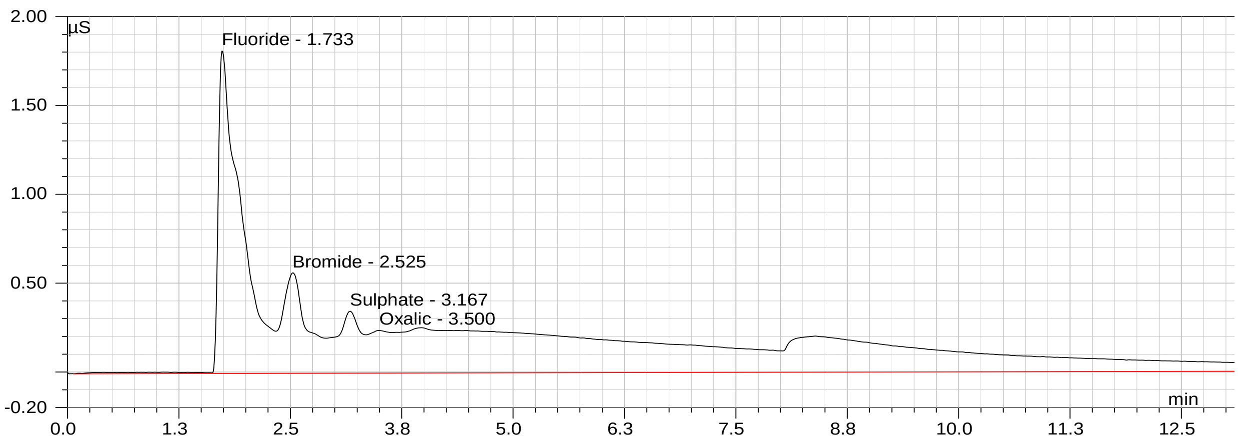

Figure 9: IC test diagram for A-6

Table 6 Ion Types and Concentrations on the Test Boards

	Ion Types and Amounts (μg/cm^2)									
	Fluoride	**Succinic**	**Chloride**	**Nitrite**	**Glutaric**	**Bromide**	**Malic**	**Nitrate**	**Sulphate**	**Oxalic**
Control Board 1	0.216			0.006					0.595	
Control Board 2	0.073		0.093						0.391	
Control Board 3	0.002		0.022						0.379	
Control Board 4	0.055			0.077					0.392	
A-2	1.982					0.001			0.466	0.027
A-4	2.194								0.023	0.007
A-6	1.375					**2.199**			0.636	0.014
A-8	0.252		**1.436**					0.009	0.540	0.006
A-10	1.151						0.010		0.015	
B-2	1.040								0.424	0.009
B-4	1.133					0.002			0.508	
B-6		3.582					1.245		0.445	0.013
B-8	1.412								0.493	0.011
B-10		3.829			0.245				0.000	
C-2	0.692							0.009	0.029	
C-4	0.656								0.035	
C-6	0.317			0.183			1.079		0.501	0.346
C-8				0.128					0.371	
C-10	0.603						0.021		0.000	
D-2	0.464								0.037	
D-4		5.075		0.085					0.379	
D-6								0.282	0.380	
D-8	0.621								0.425	0.342
D-10	0.454								0.018	

Another observation is that inorganic ions contribute more to the conductivity, correspond more to ROSE results and tend to exacerbate the SIR performance, especially the existence of chloride and bromide. A-6 and A-8, for instance, bore 2.199 µg/cm^2 bromide and 1.436 µg/cm^2 chloride, respectively. Based on the criteria set by the national defense center for environmental excellence (NDCEE) which establishes the maximum acceptable contamination level of bromide as 2.33 µg/cm^2 and chloride as 0.39 µg/cm^2, A-6 was close to the failure criterion for bromide and A-8 had exceeded the criterion for chloride. In addition, according to IPC/EIA J-STD-001C for ROSE, the maximum acceptable ionic contamination level for PCBs is 1.56 µg/cm^2 NaCl equivalent. Since A-6 and A-8 had 1.62 µg/cm^2 and 1.939 µg/cm^2 NaCl equivalents respectively, both failed in light of ROSE criteria. Since A-6 also had a large amount of fluoride and sulphate, it is reasonable that it had a large equivalent NaCl (1.62 µg/cm^2), and thus failed.

5. Optical Inspection and Final Ranking

Optical inspection was performed to identify any observable problems on the PCBs which may be associated with the manufacturing process. The major problems were divided into 5 groups: white residue and debris, plastic fibers and brown residues, falling off of components, bridging of pins of QFPs, and breaks in solder mask. Typical ones are shown in Figures 10 and 11.

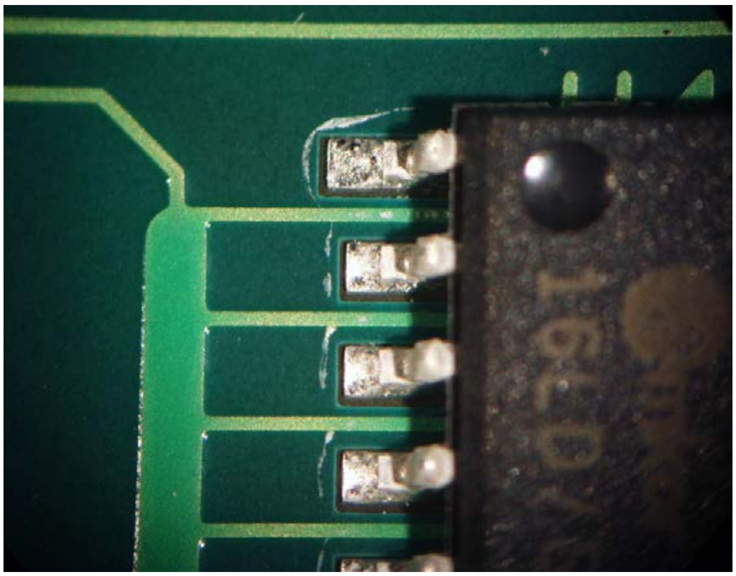

Figure 10: An optical micrograph from B-10: white residue

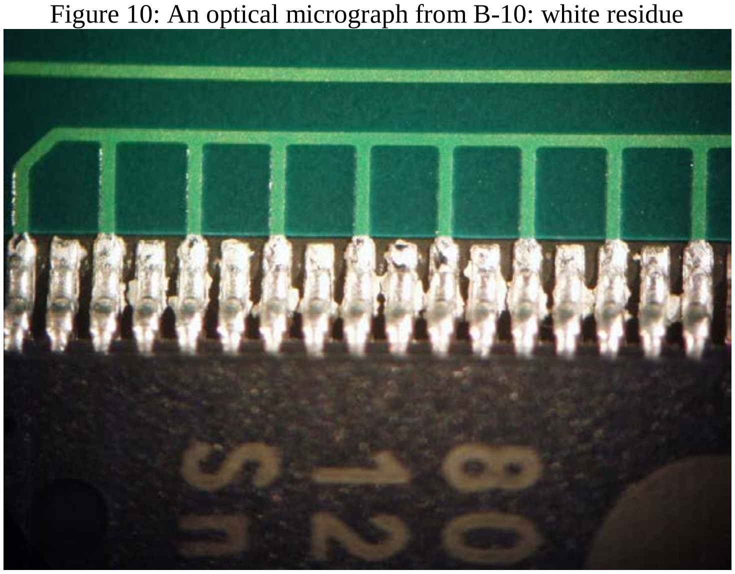

Figure 11: An optical micrograph from C-10: bridging of pins

Overall ranking was finalized based on all the 4 methods, shown in Table 7.

Table 7 Overall Ranking of Test Boards Based on SIR Performance, ROSE, IC Data and Optical Inspection

Ranking	Types	Comments
1	B-3	SIR range 10^9~$3x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms
2	A-9	SIR range 10^{10}~$5x10^{10}$ Ohms, 4 occasion of intermittents, all intermittents above 10^8 Ohms
3	B-9	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, possible noise
4	C-3	SIR range $2x10^9$~$2x10^{10}$ Ohms, 1 occasion of intermittents, all intermittent drops above 10^8 Ohms, most of components steady around 10^9 Ohms
5	D-3	SIR range $3x10^9$~$3x10^{10}$ Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
6	D-7	SIR range $5x10^9$~10^{11} Ohms, 5 occasions of intermittents, all intermittents above 10^8 Ohms
7	C-7	SIR range 10^9~$4x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms, most of components had high resistances (10^{10} Ohms)
8	NC-1	SIR range 10^9~10^{11} Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
9	D-5	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, a few intermittent drops below 10^8 Ohms
10	B-5	SIR range $2x10^9$~$5x10^{10}$ Ohms, more than 20 occasions of intermittents, all intermittents above 10^8 Ohms
11	C-9	SIR range 10^9~10^{11} Ohms, more than 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
12	B-1	SIR range $4x10^8$~$7x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
13	C-5	SIR range $3x10^9$~$3x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms, but intermittents happened on more than one component
14	D-1	SIR range $8x10^8$~$2x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
15	A-1	SIR range $3x10^8$~$3x10^{10}$ Ohms, 4 occasions of intermittents, a few intermittent drops below 10^8 Ohms
16	A-7	SIR range $3x10^9$~$2x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms
17	A-4	SIR range 10^9~$2x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample showed failing trend after 50 hours but recovered
18	D-9	SIR range 10^8~$3x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample failing from 500 hours
19	B-7	one component failed at about 300 hours
20	A-5	one component failed at about 96 hours, a lot of intermittents

Key to table:
Green (1-5): good
Yellow (6-15): questionable
Magenta (16-20): unacceptable

6. Proper Pairs of Cleaning Process and Flux

6.1. One current process, which uses B -10 cleaning, is a good combination which is strongly recommended, and can continue to be used.

B -10 exhibited good SIR performance, produced the best ROSE results and good IC results, although it did exhibit some white residue. Its SIR for combs underneath components and capacitors was steady from 10^9 to 10^{11} Ohms throughout the test. IC analysis showed that it contained hardly any inorganic ions, although it did have an appreciable amount of organic ions. This combination ranks 3rd among all the combinations.

6.2. Another current process, C-8 cleaning, gave acceptable results and can continue to be used, but it was on the borderline for cleanliness.

C-8 is acceptable (it did not fail any test requirements), but is not strongly recommended. This combination had fairly high amounts of contaminants, mostly inorganic ions, and also exhibited contamination that was visible in the optical microscope. Its SIR performance was generally good, although it exhibited 4 occasions of intermittent SIR drops on connectors and capacitors, none of which fell below the failure threshold. This combination ranks 7th overall among all the process combinations tested, but on the low end of the scale for cleanliness. C-8 is not as good as B-10 in terms of board cleanliness and SIR performance.

6.3. A third current flux D, was a good choice when cleaned with 4, and can be recommended.

D was an acceptable but not strongly recommended choice when cleaned with 8: it did not fail any test requirements but did not have good cleanliness. The use of D-10 is strongly discouraged due to SIR failures. The remaining cleaning processes (2 and 6) with D are not recommended.

6.4. Cleaning 4 is the recommended cleaner for automated cleaning processes. Even though 10 is a good choice for use with B, better performances are expected by switching to 4. Cleaning 4 is the best cleaning agent for automated assembly with automated cleaning. Therefore cleaning 4 would be strongly recommended as a future choice for automated cleaning processes.

6.5. Manual soldering with A in combination with cleaning 10 is strongly recommended, while A gave unacceptably poor results with all the other cleaning agents tested.

6.6. Perhaps one of the most significant conclusions of this study is that a good solder/flux combination must be paired with the correct cleaning process in order to be successful.

Conclusions

IPC-B-52 populated boards have been used to test the reliability of assemblies processed with 4 types of fluxes and 6 cleaning processes. SIR, ROSE, and IC tests and optical inspection were employed to assess the reliability and the overall cleanliness of the boards.

Although B-52 board design was still in the finalizing stage as a process qualification test vehicle for industrial consensus review at the end of 2010, it has been used to qualify and differentiate the cleaning processes and flux agents in this work. B-52 design proves to be effective in generating differentiable test results and establishing the ranking of surface cleanliness and its impact on reliability issues. However, the super sensitive nature to pick up random noises manifested by capacitors due to possible system perturbations in the design may compromise its SIR testing in some way, thus requiring further measures to stabilize them.

Aside from B-52, the combination of these 4 methods, SIR testing, ROSE, IC, and optical inspection can effectively distinguish the advantages and disadvantages of the processes and establish the ranking metrics. Only SIR testing cannot know the source of contaminants, only ROSE cannot know the effects of the overall contaminants, and only IC cannot know which types of ions have the most impact on the reliability of PCBs associated with surface cleanliness. Although optical inspection can catch bridging, white residue or component fall-off, it cannot tell the differences of the rest boards about their cleanliness. But these 4 methods together can work well to tell the severity of cleanliness and its effect on reliability issues. Not all the boards show close correspondence between their ROSE, IC and SIR, especially in the mid-level contamination boards, but the close correspondence between the “very clean” and “very dirty” boards does show the strength of the synthesis of these four methods.

The most important finding of this work is that fluxing systems must be combined with appropriate cleaning processes in order to be successful. Although nearly half of the fluxes or cleaning processes showed a clustering trend from the standpoint of view of checking either fluxing or cleaning independently, the rest of them varied a lot in the ranking due to their different combinations with each other. This requires a careful choosing of combinations of flux and cleaning processes for manufactures even if some individual flux or cleaning process works fine independently.

Finally, the different impacts of organic and inorganic ions on the board performances are worth mentioning. The existence of relatively large amounts of inorganic ions such as chloride, bromide, and fluoride have led to the failure of the boards, whereas the large amounts of organic ions such as succinic acid and malic acid have not resulted in the failure of the boards. Although a few failure industrial standards exist for chloride and bromide, there are no standards for fluoride. From this work, 1.4 $\mu g/cm^2$ of fluoride may be used as the failure threshold for future consideration for fluoride only. Yet other types of organic acids have to be investigated to confirm the general industrial statement that weak organic acids bring little harm to the boards in term of cleanliness related reliability and corrosion issues.

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An Evaluation of the Insulation Resistance and Surface Contamination of Printed Circuit Board Assemblies

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Objective:

- Evaluate compatibility of solder fluxes and cleaning processes using a combination of techniques: surface insulation resistance (SIR) measurement, resistivity of solvent extract (ROSE), ion chromatography (IC), and optical inspection.

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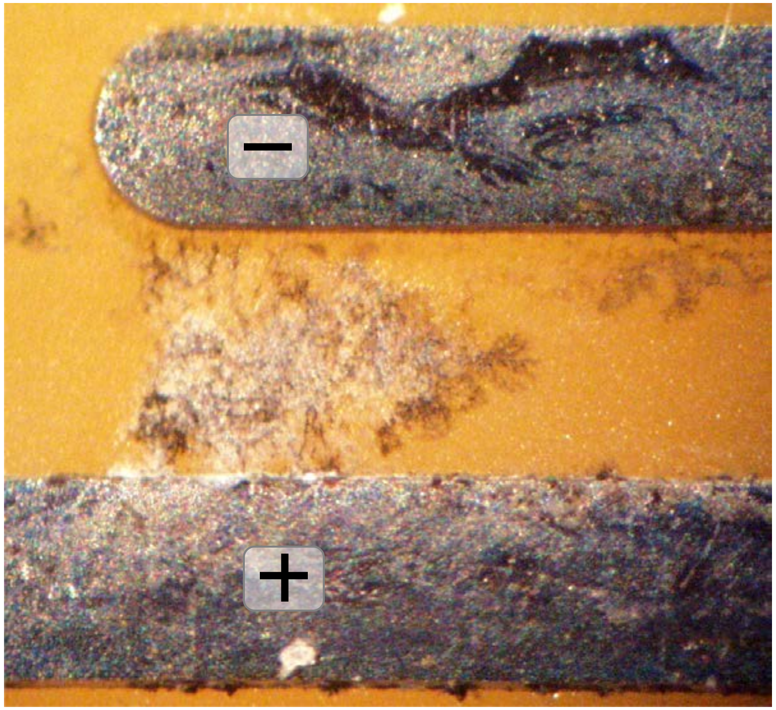
Problem Statement

- A variety of flux chemistries are available for use in the solder assembly process, including no clean flux, aqueous-based water soluble flux and rosin-based flux systems. No clean processes offer the potential to reduce environmental impact, lower operating costs and simplify manufacturing processes [1].
- A poorly designed solder assembly process can risk the development of electrical leakage currents due to electrochemical migration (ECM) [2][3].
- To reduce the risk of ECM associated with surface contamination due to flux residues, an evaluation was performed of the compatibility of several flux systems and cleaning processes.

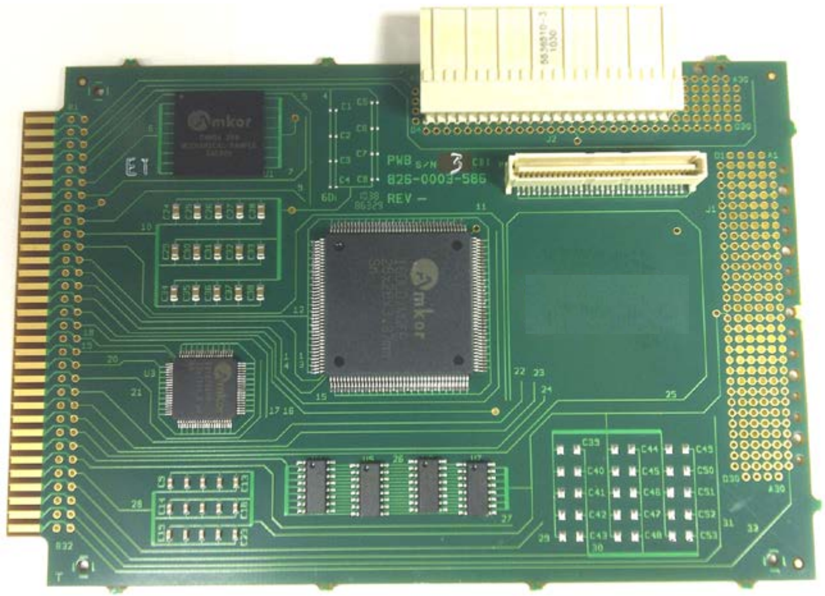


Overview of Evaluation Techniques

- Surface Insulation Resistance (SIR) Measurement during Temperature-Humidity-Bias Testing
  - An indicator of combined effects of ionic and non-ionic contaminants
  - Greatly affected by adsorbed surface moisture, contaminant species and levels, ionic mobility
  - Monitored continuously to detect dendrite growth
- Resistivity of Solvent Extract (ROSE) Test
  - An overall measure of ionic contaminants on the surface
  - Cannot identify the species of ions
- Ion Chromatography (IC)
  - Can identify the individual species of ions
- Optical Inspection
  - Visual assessment of post-manufacturing issues, such as bridging, white residue, defects in solder mask, etc.

Experimental Setup (SIR)

- **IPC-B-52 Boards**
  - CON: Connector-Through Hole-Horizontal
  - BGA: 256 I/O, full 16x16 array, 1.0 mm pitch, 17 mm body size
  - QFP160: Interdigitated comb structure under quad flat pack with 160 I/O, 28 mm square body, with a 0.65 mm pitch.
  - QFP80: Interdigitated comb structure under quad flat pack with 80 I/O, 12 mm square body, with 0.5 mm pitch and a 2 mm lead footprint
  - Cap: Array of 15 0603 surface mount ceramic capacitors-10.0pF
- **SIR Test System**
  - Agilent 4349B high resistance meter, multiplexed over 48 channels; 1 MOhm resistor in series. 5 V bias.
- **Temperature-humidity conditions:** 40C, 93%RH (per IPC TM 650-2.6.3.7).
- **Failure Criteria**: <100 MOhms (based on IPC J-STD-004A method 3.4.5.1 and IPC-9201).



Experimental Setup (ROSE, IC & Optical)

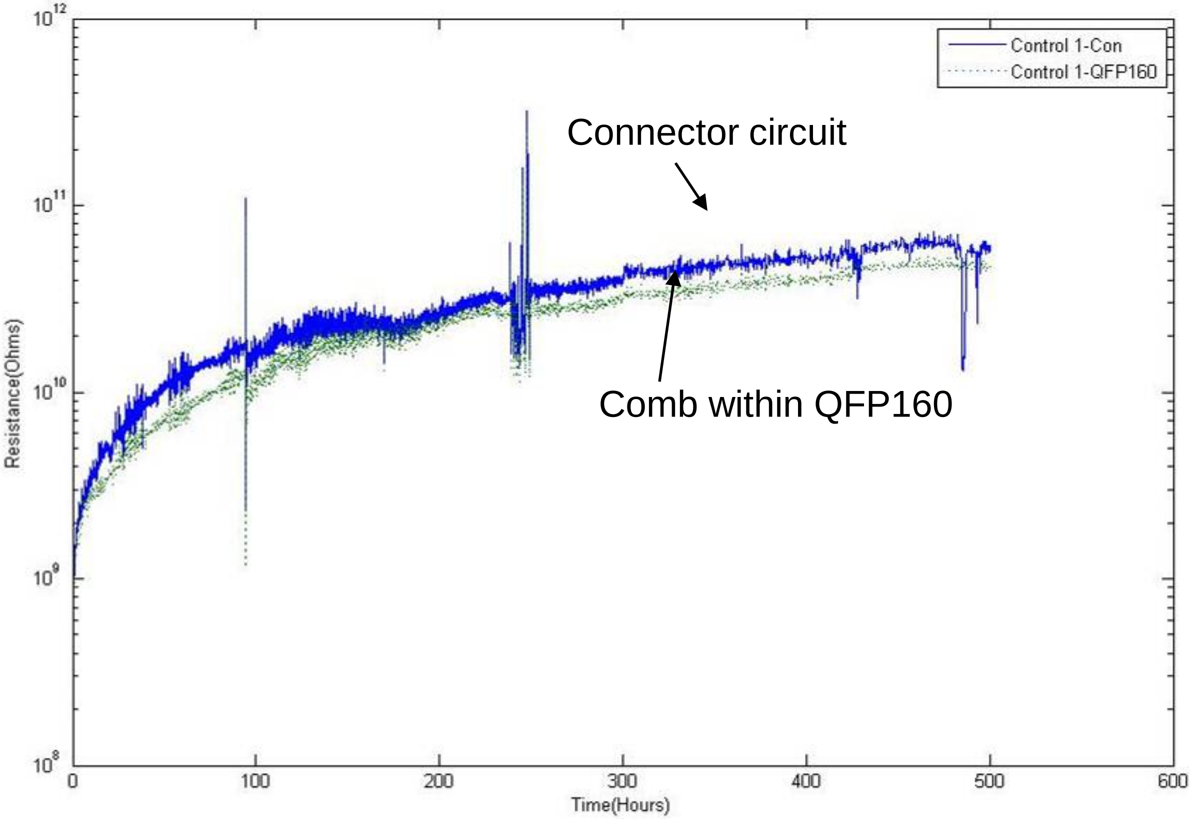
- ROSE
  - Omega conductivity meter, 0.1 µS/cm resolution
  - Solution (75% isopropanol and 25% DI water)
  - Immersion of boards in solution with a 80C hot water bath to extract surface contaminants (consistent with IPC method 2.3.28 on IC).
  - Generation of identical samples for both ROSE and IC.
- IC
  - DIONEX-600 System for liquid ion-exchange chromatography
  - Same extract samples as produced for ROSE
- Optical microscope
  - Nikon SMZ-2T microscope, up to 63x magnification

Flux Systems and Cleaning Processes

- **Four fluxes:** Flux A and B are rosin-based mildly activated fluxes; C and D are no-clean and water soluble fluxes, respectively.
- **Six Cleaning processes**: Either water based or solvent based processes.
- 20 Combinations in total (a few combinations were excluded).
  - Every pair of odd and even numbers, such as 1 and 2, or 3 and 4 is from the same cleaning process.
- 4 control boards (unpopulated) for SIR, and 4 controls for cleanliness.

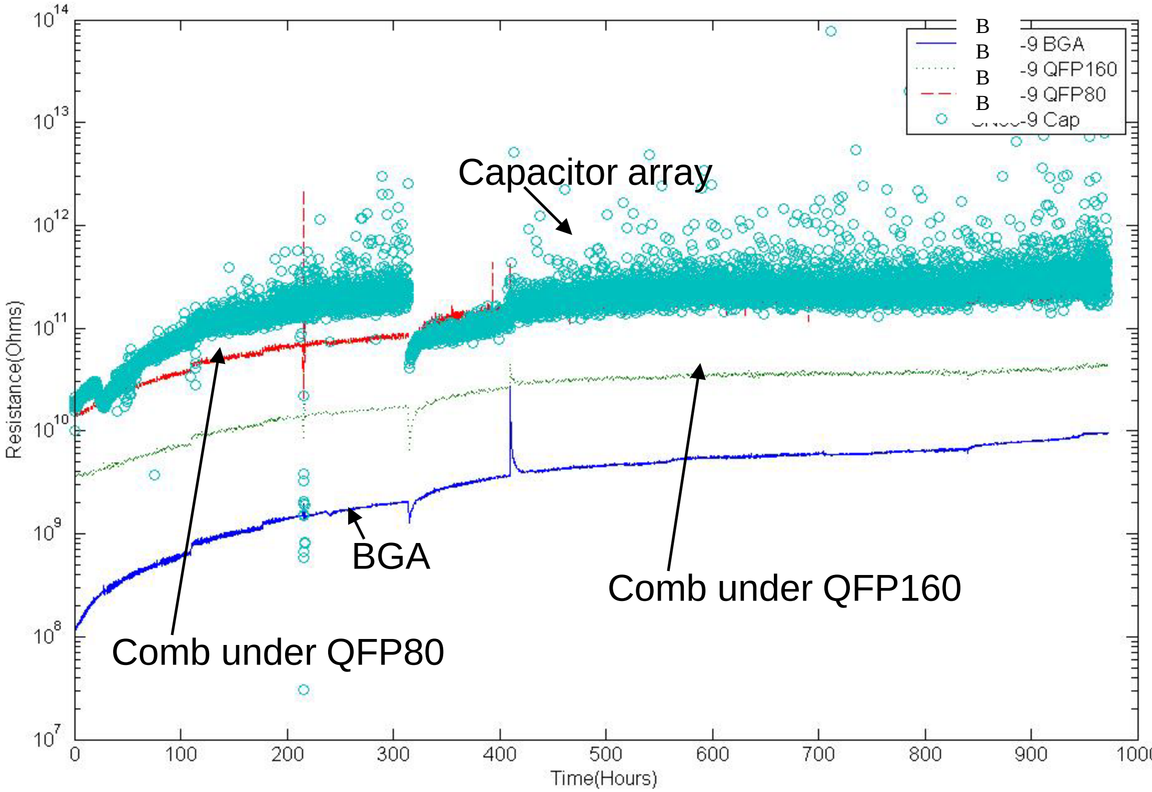
A -1	**A -3**	**A -5**	**A -7**	**A -9**	**n/a**
A -2	**A -4**	**A -6**	**A -8**	**A -10**	**n/a**
B -1	**B -3**	**B -5**	**B -7**	**B -9**	**n/a**
B -2	**B -4**	**B -6**	**B -8**	**B -10**	**n/a**
C-1	**C-3**	**C-5**	**C-7**	**C-9**	**n/a**
C-2	**C-4**	**C-6**	**C-8**	**C-10**	**n/a**
D-1	**D-3**	**n/a**	**D-7**	**D-9**	**D-11**
D-2	**D-4**	**n/a**	**D-8**	**D-10**	**D-12**

SIR Test Results of Control Boards



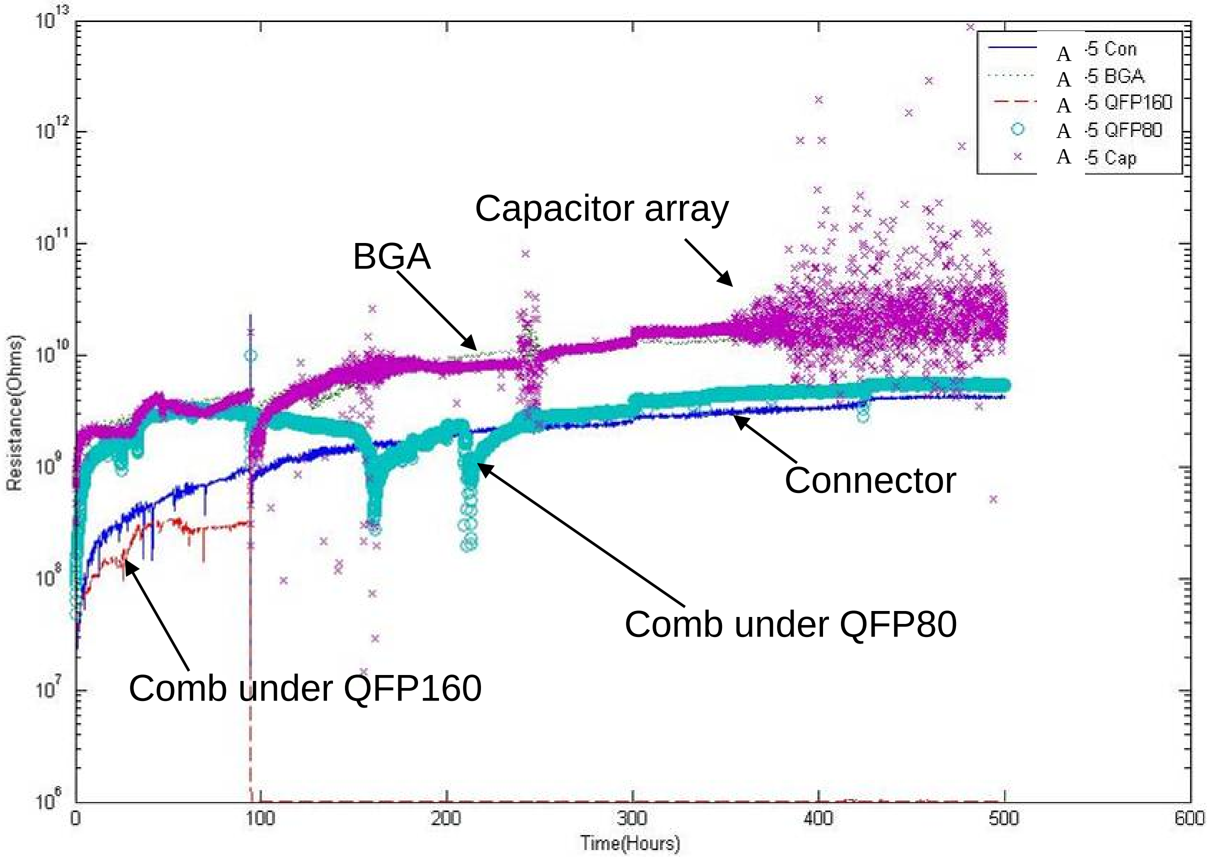
- The SIR of one control board showed an general increase followed by a leveling off. The remaining 3 controls showed similar trends.
- This initial increasing SIR trend is characteristic of diffusion controlled cells, which may have been caused by the consumption of electroactive species at electrodes [3][4].

SIR Test Result: Board B-9 (Survived)



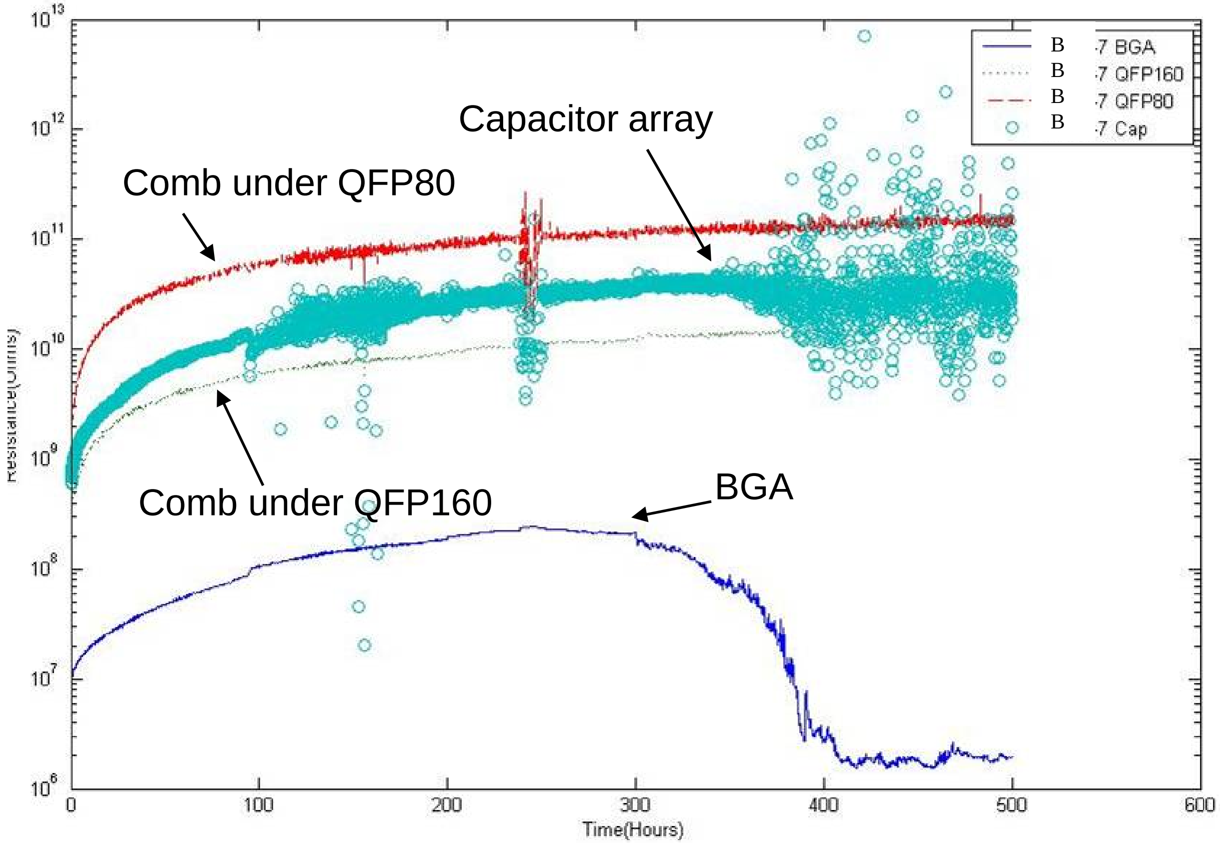
- The general trend of increasing SIR is observed here.
- The capacitors exhibit more variation than other components.
- SIR of the capacitor array and QFP80 was generally higher than that of the BGA and QFP160.

SIR Test Result: Board A-5 (Failed)



- The QFP160 comb failed at around 100 hours.
- Similar increasing SIR trend, similar capacitor array variation.

SIR Test Result: Board B-7 (Failed)



- The BGA failed after 300 hours (would have passed a 168 hour test).
- Similar general SIR increase for the remaining components, similar capacitor variation.

Intermittent Drops of Individual Components, and Overall and Initial SIR

Board Type	SIR Intermittents of Individual Components					SIR of Boards (Ohms)	
	Conn	BGA	QFP(160)	QFP (80)	Cap	Overall	Initial
Control 1	$4>10^9$		$2>10^9$			$10^{10}\sim3x10^{10}$	$10^9\sim10^{10}$
Control 2		\		$7>10^8$	$2>10^9$	$10^9\sim10^{11}$	$10^8\sim10^{11}$
Control 3	\		$2>10^9$			$3x10^{10}\sim4x10^{10}$	$10^9\sim10^{10}$
Control 4		$20>10^{10}$		$4>10^{10}$	$1>9x10^9$	$2x10^{10}\sim2x10^{11}$	$2x10^9\sim4x10^{10}$
A-1	\	\	\	\	**$4<10^8$**	$3x10^8\sim3x10^{10}$	$4x10^7\sim10^8$
A-4	$2>10^9$		**$1\rightarrow10^8$**	$1>10^9$	$4>10^8$	$10^9\sim2x10^{10}$	$2x10^8\sim3x10^9$
A-5	$1>10^8$	$>10^9$	**$<=10^6$**	$2>10^8$	**$5<10^8$**	$10^9\sim2x10^{10}$	$3x10^7\sim5x10^8$
A-7	$10>10^8$		\	$1>10^9$	**$3<10^8$**	$3x10^9\sim2x10^{10}$	$10^8\sim10^9$
A-9	$2>10^9$		\	$2>10^9$	$4>10^8$	$10^{10}\sim5x10^{10}$	$10^9\sim10^{10}$
B-1		\	\	\	**$5<10^8$**	$4x10^8\sim7x10^{10}$	$3x10^7\sim4x10^8$
B-3	$4>10^9$	\	\	$1>10^9$	$1>10^9$	$10^9\sim3x10^{10}$	$2x10^8\sim2x10^9$
B-5	$2>10^9$	$2>10^9$	$10>10^8$	$4>10^9$	\	$2x10^9\sim5x10^{10}$	$10^9\sim10^{10}$
B-7		**$<=2x10^6$**	\	$2>10^{10}$	**$3<10^8$**	$10^8\sim10^{11}$	$10^7\sim3x10^9$
B-9		\	\	\	$3>10^8$	$2x10^9\sim2x10^{11}$	$10^8\sim10^{10}$
C-1		\	\	\	$3>10^8$	$10^9\sim10^{11}$	$4x10^7\sim10^9$
C-3		\	\	\	$1>10^8$	$2x10^9\sim2x10^{10}$	$7x10^7\sim10^9$
C-5		\	$8>10^8$	$6>10^9$	**$4<10^8$**	$3x10^9\sim3x10^{10}$	$2x10^8\sim2x10^{10}$
C-7	$4>10^9$	\	\	\	$4>10^9$	$10^9\sim4x10^{10}$	$3x10^7\sim3x10^9$
C-9	\	\	$1>10^9$	$1>10^9$	**$5<10^8$**	$10^9\sim10^{11}$	$2x10^8\sim2x10^{10}$
D-1		\	\	\	**$5<10^8$**	$8x10^8\sim2x10^{10}$	$3x10^7\sim2x10^8$
D-3		\	\	\	$3>10^8$	$3x10^9\sim3x10^{10}$	$4x10^7\sim2x10^9$
D-11		\	$2>10^9$	$2>10^{10}$	**$3<10^8$**	$2x10^9\sim2x10^{11}$	$10^8\sim4x10^{10}$
D-7		\	\	$2>=10^{10}$	$5>10^8$	$5x10^9\sim10^{11}$	$5x10^7\sim10^{10}$
D-9	**$<=10^8$**	\	\	\	$4>10^8$	$10^8\sim3x10^{10}$	$4x10^6\sim10^{10}$

Relative Ranking of PCBs Based on the SIR Performance

Ranking	Types	Comments
1	B-3	SIR range 10^9~$3x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms
2	A-9	SIR range 10^{10}~$5x10^{10}$ Ohms, 4 occasion of intermittents, all intermittents above 10^8 Ohms
3	B-9	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, possible noise
4	D-7	SIR range $5x10^9$~10^{11} Ohms, 5 occasions of intermittents, all intermittents above 10^8 Ohms
5	D-3	SIR range $3x10^9$~$3x10^{10}$ Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
6	C-3	SIR range $2x10^9$~$2x10^{10}$ Ohms, 1 occasion of intermittents, all intermittent drops above 10^8 Ohms, most of components steady around 10^9 Ohms
7	C-7	SIR range 10^9~$4x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms, most of components had high resistances (10^{10} Ohms)
8	C-1	SIR range 10^9~10^{11} Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
9	D-11	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, a few intermittent drops below 10^8 Ohms
10	C-9	SIR range 10^9~10^{11} Ohms, more than 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
11	B-5	SIR range $2x10^9$~$5x10^{10}$ Ohms, more than 20 occasions of intermittents, all intermittents above 10^8 Ohms
12	A-7	SIR range $3x10^9$~$2x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms
13	C-5	SIR range $3x10^9$~$3x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms, but intermittents on more than one component
14	B-1	SIR range $4x10^8$~$7x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
15	A-1	SIR range $3x10^8$~$3x10^{10}$ Ohms, 4 occasions of intermittents, a few intermittent drops below 10^8 Ohms
16	D-1	SIR range $8x10^8$~$2x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
17	A-4	SIR range 10^9~$2x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample showed failing trend after 50 hours but recovered
18	D-9	SIR range 10^8~$3x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample failing from 500 hours
19	B-7	one component failed at about 300 hours
20	A-5	one component failed at about 96 hours, a lot of intermittents

Conclusions from SIR Testing

- Three major factors used to evaluate SIR: overall SIR performance, the occurrences of intermittent drops, and the initial SIR right after the test began.
- The ranking of cleaning process from best to worst is 3>9>1>5>7. Cleaning process 11 is third best overall, but can only be paired with flux D.
- Flux B produces the best overall results, although one B board failed. C and D are varied and occupy the middle of the rankings, while results for A are mostly quite poor.
- Fluxes and cleaning processes have to be paired to demonstrate their effectiveness: compatibility is important.

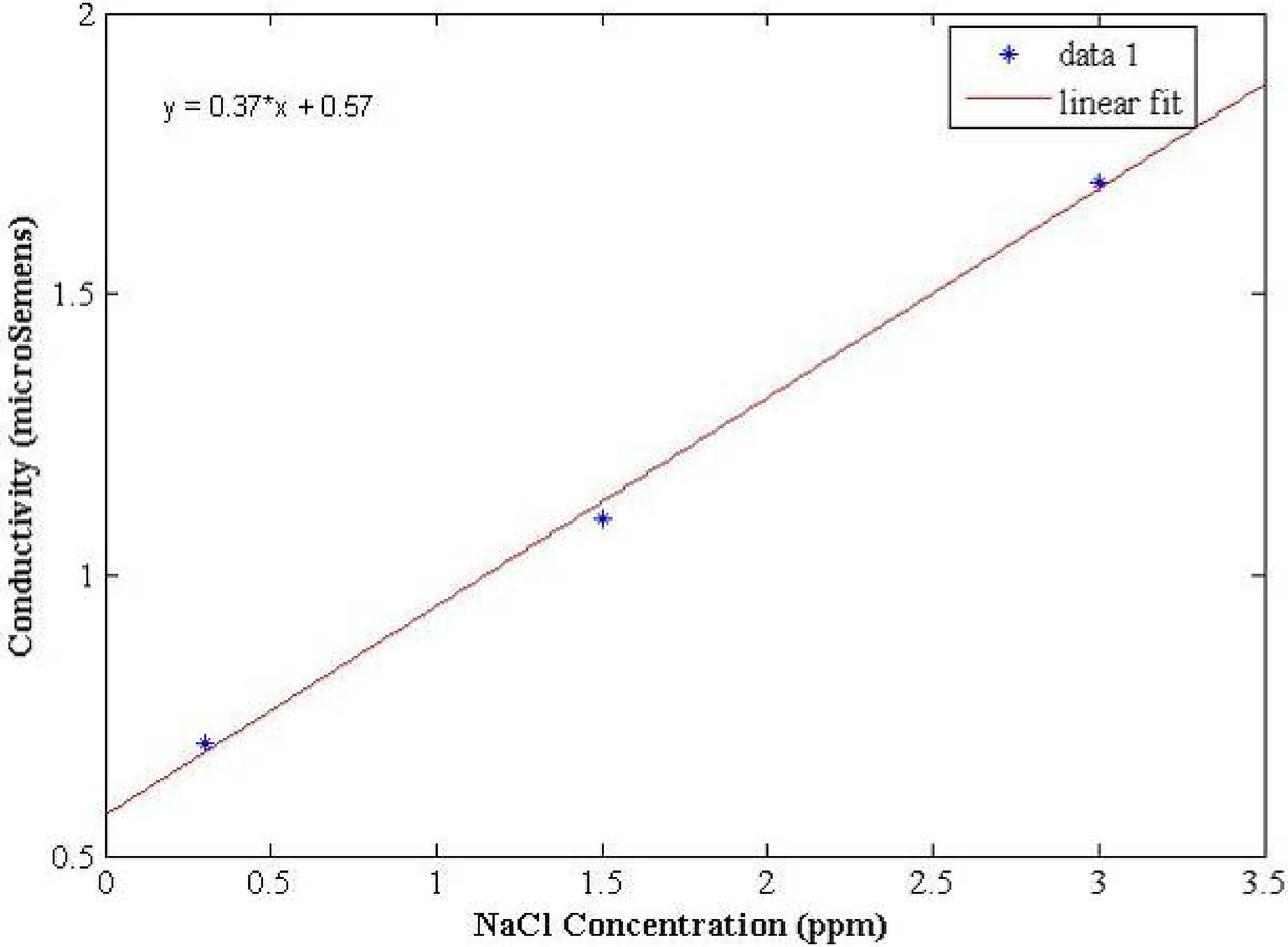
ROSE Procedure

- Based on IPC-TM-650 2.3.25, “Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract (ROSE),” and IPC-TM-650 2.3.28, “Ionic Analysis of Circuit Boards, Ion Chromatography Method”, the samples were prepared.
- The detailed procedure is the following:
  - **Record area of PCBs**.
  - Use clean gloves to handle the PCB and place it in a KAPAK 500 series extraction bag.
  - Prepare **75/25 IPA/DI water solution**.
  - Add 250 ml solution to the extraction bag to cover the PCB.
  - Heat seal the extraction bag and **place in the 80C water bath for an hour**. A small hole should be cut to vent evaporated gases.
  - Prepare 1 control solution without adding any board.
  - **Measure solution volume after extraction**.
  - Pour the solution into two 10-mL vials to make 2 identical samples and allow them to cool to room temperature.
  - Dissolve 0.06g dry NaCl crystal in one liter of 75/25 IPA/DI water solution to **make the standard 0.06g/L NaCl solution**.
  - Place 500 mL 75/25 IPA/DI water test solution in a glass beaker, add 2.5 mL standard 0.06g/L NaCl solution. Stir and measure the conductivity. The concentration of NaCl is 0.3 ppm.
  - Add additional 10 mL of the standard 0.06g/L NaCl solution to the 500 mL test solution, stir and measure the conductivity. The concentration of NaCl is now 1.5 ppm.
  - Add additional 12.5 mL of the standard 0.06g/L NaCl solution to the 500 mL test solution, stir and measure the conductivity. The concentration of NaCl is now 3 ppm.
  - **Plot a three point calibration curve of Conductivity vs. Concentration of NaCl**.
  - **Measure the conductivity of the 25 samples** (20 test boards, 4 control boards, 1 control solution) **and convert them into equivalent NaCl concentrations**.

Measured Conductivities of the Boards

Sample	Conductivity (µS)	Sample	Conductivity (µS)
DI water	0.5	D-2	1.1
Control Solution (after hot water bath)	0.5	D-4	0.8
Control Solution (without hot water bath)	0.5	D-12	0.9
Control Board 1	0.7	D-8	1
Control Board 2	0.7	D-10	1
Control Board 3	0.6	C-2	1.1
Control Board 4	0.7	C-4	0.8
0.3 ppm NaCl	**0.7**	C-6	0.9
1.5 ppm NaCl	**1.1**	C-8	1.1
3 ppm NaCl	**1.7**	C-10	0.9
A-2	1.3	B-2	1
A-4	1	B-4	0.8
A-6	1.5	B-6	1
A-8	1.4	B-8	1.4
A-10	1	B-10	0.8

Calibration Curve for Conductivity Measurement

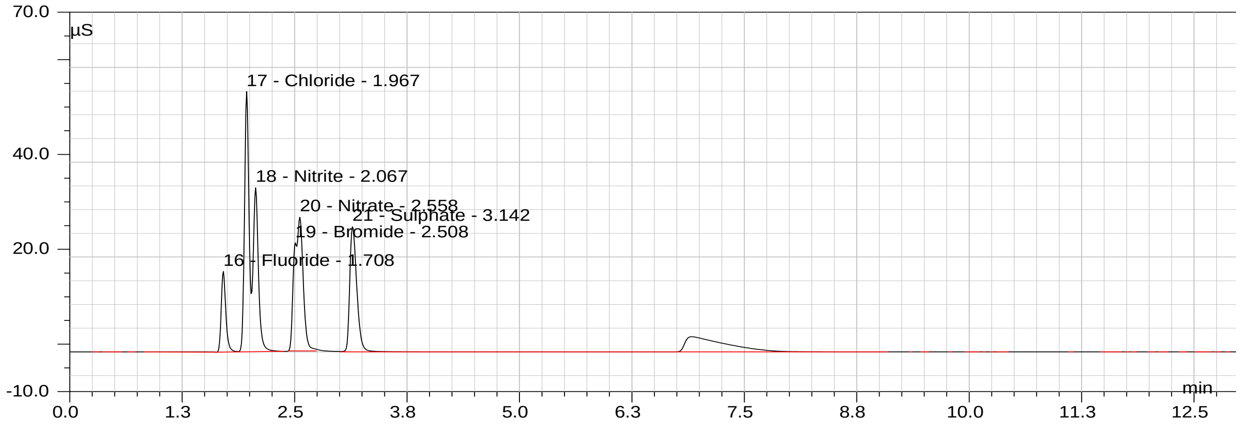


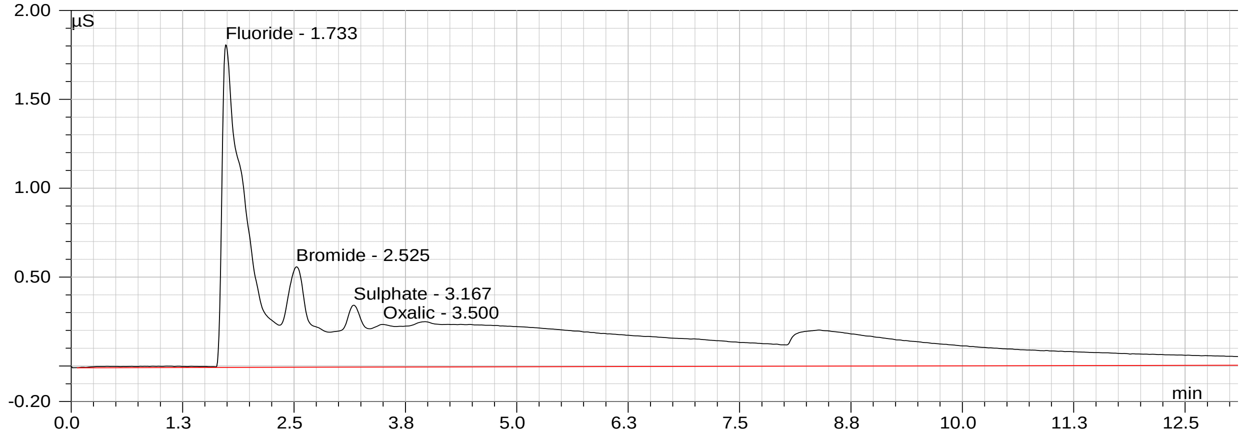
Contamination of Test Boards

Ranking	Sample	Surface Contamination of Equiv. NaCl Concentration ($\mu g/cm^2$)
1	B-10	0.320
2	C-4	0.394
3	B-4	0.399
4	D-4	0.401
5	D-12	0.541
6	C-10	0.560
7	C-6	0.622
8	B-6	0.731
9	D-10	0.747
10	A-10	0.753
11	B-2	0.762
12	A-4	0.766
13	D-8	0.803
14	D-2	0.902
14	C-2	0.902
16	C-8	1.014
17	A-2	1.382
18	B-8	1.463
19	A-6	**1.620**
20	A-8	**1.939**

Ion Chromatography

- IC was used to identify the species types of ions, based on a comparison between the sample solutions and the standard solutions.
- On a chromatograph of IC results,
  - the retention times of different peaks can be used to identify types of the ions using appropriate standards
  - and the areas below the peaks are used to determine their concentrations.





Ion Types and Concentrations on the Test Boards

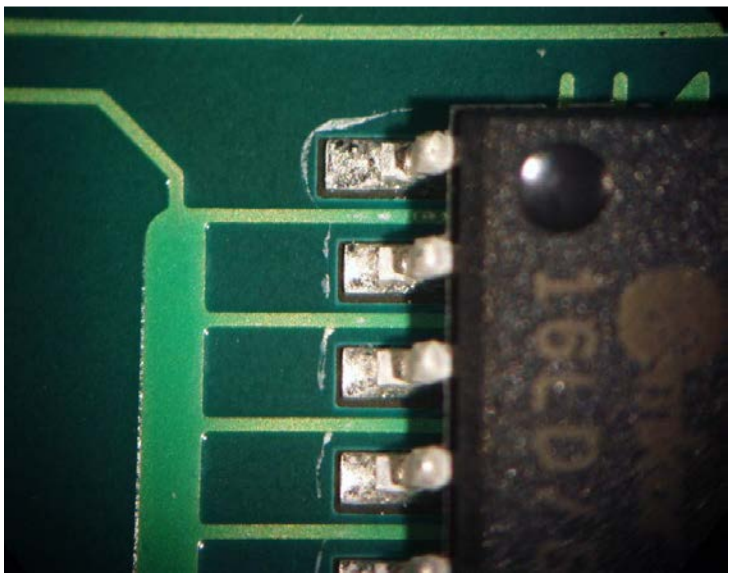
	Ion Types and Amounts (μg/cm²)									
	Fluoride	Succinic	Chloride	Nitrite	Glutaric	Bromide	Malic	Nitrate	Sulphate	Oxalic
Control Board 1	0.216			0.006					0.595	
Control Board 2	0.073		0.093						0.391	
Control Board 3	0.002		0.022						0.379	
Control Board 4	0.055			0.077					0.392	
A-2	**1.982**					**0.001**			**0.466**	**0.027**
A-4	2.194								0.023	0.007
A-6	**1.375**					**2.199**			**0.636**	**0.014**
A-8	**0.252**		**1.436**					**0.009**	**0.540**	**0.006**
A-10	1.151						0.010		0.015	
B-2	1.040								0.424	0.009
B-4	**1.133**					**0.002**			**0.508**	
B-6		3.582					1.245		0.445	0.013
B-8	**1.412**								**0.493**	**0.011**
B-10		**3.829**			**0.245**				**0.000**	
C-2	0.692							0.009	0.029	
C-4	**0.656**								**0.035**	
C-6	0.317			0.183			1.079		0.501	0.346
C-8				0.128					0.371	
C-10	0.603						0.021		0.000	
D-2	0.464								0.037	
D-4		**5.075**		**0.085**					**0.379**	
D-12								**0.282**	**0.380**	
D-8	0.621								0.425	0.342
D-10	0.454								0.018	

Correspondence between SIR, ROSE and IC

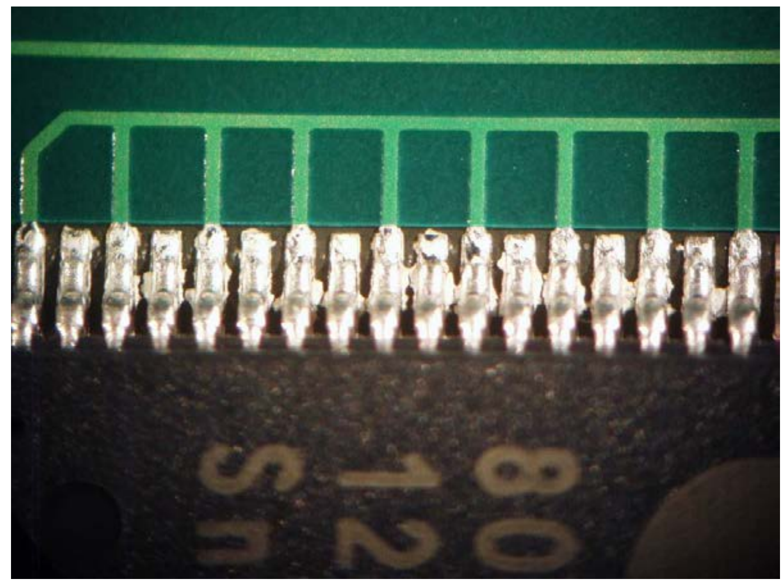
- The "cleanest" and "most contaminated" boards had a close match among their ROSE, IC and SIR performance.
  - The "cleanest" boards in terms of ROSE, bore the least amount of inorganic ions, and had relatively high SIRs (10^9~10^{11} Ohms) with few intermittents.
  - The "most contaminated" boards in terms of ROSE, bore large amounts of inorganic ions, and had relatively low SIRs (10^8~10^{10} Ohms) with a lot of intermittents.
- The boards between the "cleanest" and the "most contaminated," whose cleanliness was in the mid-range in terms of ROSE, bore fair or small amounts of fluoride and small amounts of sulphate, but their SIR performances varied a lot.
- Inorganic ions contribute more to the conductivity, correspond more to ROSE results and tend to exacerbate the SIR performance, especially the existence of chloride and bromide.
  - A-6 had 2.20 µg/cm^2 bromide, close to failure (2.33 µg/cm^2, NDCEE)
  - A-6 had 1.62 µg/cm^2 NaCl equivalent, exceeded failure criterion (1.56 µg/cm^2 NaCl equivalent, IPC/EIA J-STD-001C)
  - A-8 had 1.44 µg/cm^2 chloride, exceeded failure criteria (0.39 µg/cm^2, NDCEE)
  - A-8 had 1.94 µg/cm^2 NaCl equivalent, exceeded failure (1.56 µg/cm^2 NaCl equivalent, IPC/EIA J-STD-001C)

Optical Inspection

- Optical inspection was performed to identify any observable problems on the PCBs which may be associated with the manufacturing process.
- The major problems were divided into 5 groups: white residue and debris, plastic fibers and brown residues, poor attachment of components, bridging of pins of QFPs, and breaks in solder mask.



An optical micrograph from B-10: white residue



An optical micrograph from C-10: bridging of pins

Final Ranking

Ranking	Types	Comments
1	B-3	SIR range 10^9~$3x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms
2	A-9	SIR range 10^{10}~$5x10^{10}$ Ohms, 4 occasion of intermittents, all intermittents above 10^8 Ohms
3	B-9	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, possible noise
4	C-3	SIR range $2x10^9$~$2x10^{10}$ Ohms, 1 occasion of intermittents, all intermittent drops above 10^8 Ohms, most of components steady around 10^9 Ohms
5	D-3	SIR range $3x10^9$~$3x10^{10}$ Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
6	D-7	SIR range $5x10^9$~10^{11} Ohms, 5 occasions of intermittents, all intermittents above 10^8 Ohms
7	C-7	SIR range 10^9~$4x10^{10}$ Ohms, 4 occasions of intermittents, all intermittents above 10^8 Ohms, most of components had high resistances (10^{10} Ohms)
8	C-1	SIR range 10^9~10^{11} Ohms, 3 occasions of intermittents, all intermittents above 10^8 Ohms
9	D-11	SIR range $2x10^9$~$2x10^{11}$ Ohms, 3 occasions of intermittents, a few intermittent drops below 10^8 Ohms
10	B-5	SIR range $2x10^9$~$5x10^{10}$ Ohms, more than 20 occasions of intermittents, all intermittents above 10^8 Ohms
11	C-9	SIR range 10^9~10^{11} Ohms, more than 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
12	B-1	SIR range $4x10^8$~$7x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
13	C-5	SIR range $3x10^9$~$3x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms, but intermittents on more than one component
14	D-1	SIR range $8x10^8$~$2x10^{10}$ Ohms, 5 occasions of intermittents, a few intermittent drops below 10^8 Ohms
15	A-1	SIR range $3x10^8$~$3x10^{10}$ Ohms, 4 occasions of intermittents, a few intermittent drops below 10^8 Ohms
16	A-7	SIR range $3x10^9$~$2x10^{10}$ Ohms, more than 20 occasions of intermittents, a few intermittent drops below 10^8 Ohms
17	A-4	SIR range 10^9~$2x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample showed failing trend after 50 hours but recovered
18	D-9	SIR range 10^8~$3x10^{10}$ Ohms, more than 4 occasions of intermittents, 1 intermittent drop below 10^8 Ohms, one sample failing from 500 hours
19	B-7	one component failed at about 300 hours
20	A-5	one component failed at about 96 hours, a lot of intermittents

Conclusions

- The IPC-B-52 design proves to be effective in generating differentiable test results and establishing the ranking of surface cleanliness and its impact on reliability.
  - The capacitor array exhibited a lot of SIR variation, which may compromise its value to some extent. This warrants further investigation.
- The combination of these 4 methods, SIR testing, ROSE, IC, and optical inspection, is effective for distinguishing the advantages and disadvantages of the processes and establishing ranking metrics.
- The close correspondence between ROSE, IC and SIR for the “cleanest” and “most contaminated” boards shows the strength of the synthesis of these four methods. Those with mid-level contamination exhibited less correspondence.
- Fluxing systems must be combined with appropriate cleaning processes in order to be successful.
- High levels of inorganic ions such as chloride, bromide, and fluoride correlate with SIR failures, whereas large amounts of organic ions did not result in the failure of those boards.

References

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