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# Protection Performance of Conformal Coatings in Harsh Environments

**Ling Zou and Chris Hunt**

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# Protection Performance of Conformal Coatings in Harsh Environments

L Zou and C Hunt
Engineering and Process Control Division

**ABSTRACT**

Conformal coatings have been widely used to protect electronic circuits from harsh service environments. But relatively little is documented regarding the extent and nature of the protection afforded, especially in very aggressive environments. This work investigated the protection performance of seven different types of coatings (two water-based acrylics, solvent-based acrylic, fluoroacrylate, silicone, polyurethane, and epoxy) in harsh environments using Surface Insulation Resistance (SIR) measurements as the monitoring tool. The results have been correlated with visual assessments of coating coverage. Degradation of the electronics assembly can occur from the presence of a number of contaminants, which include process residues, surfactants, hydraulic fluids, de-icing fluids, marine environments, and gas pollutants ($SO_2$, $NO_2$, HCl). In this work the effect of coating type and coverage on the protection performance against these particular contaminants has been evaluated. The results show that coating type affects the level of protection against certain contaminants i.e. they are contaminant-sensitive. Coating coverage plays an important role, with failure developing at the weakest point of the coating, and all the coatings gave poor protection against hydraulic fluids. An overall summary ranking of protection afforded by the coatings in these tests has been established. In addition the results demonstrate that damp heat testing is a suitable discriminatory tool for coating performance and that the SIR technique is a sensitive tool in detecting coating breakdown.

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authorised by Director, Engineering and Process Control Division

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# 1 INTRODUCTION

Achieving high reliability is the key issue in today's electronics manufacture. Electronics are now being used in a wide range of applications and under increasingly severe conditions, and the challenge is to maintain higher levels of reliability in these hostile environments, particularly in safety critical applications.

Contaminants, either from manufacturing processes or the environment, can cause leakage currents which degrade circuit functionality. When ionic and hydrophilic contaminants reach the circuit board surface (under the coating and with the copper tracks), leakage currents will occur. Furthermore if the contaminants are corrosive and mobile, they can migrate and react with the metals on the circuit board to generate conductive products. These corrosion products may then in turn migrate and further degrade the circuit operation. Catastrophic failure occurs when the corrosion products form a dendrite-like growth of metallic compounds, causing a short circuit between adjacent electrodes. Besides a short-circuit failure, an open circuit failure may also result when there is extensive localised corrosion along a thin conduction line.

To protect the circuit assembly a conformal coating is sometimes applied, which may be one of several polymers, typically applied by dipping or spraying, which may cover all or part of the assembly. They are able to achieve a high degree of protection even in environments that would normally be considered fatal for electronic equipment[1, 2]. On a coated board the effect of the contaminant is dependent on penetration of the coating and the presence of moisture. A valuable tool capable of measuring the resultant leakage current at the substrate interface is the Surface Insulation Resistance (SIR) technique, and this tool is used extensively to verify product reliability.

The protection performance of the coatings is not just based on the coating material, but also the coating coverage. Moreover, manufacturers typically give relatively little guidance on how these materials perform under wide ranging environmental conditions. In this study the protection performances of seven different coating types against six selected contaminants have been evaluated. These contaminants represent the harsh environments in which electronic boards are most likely to operate. The effect of coating coverage on coating protection performance has also been studied by altering the stand-off of BGA components to vary the coating and contaminant penetration.

# 2 EXPERIMENTAL

## 2.1 TEST VEHICLE

Two board designs were used in these experiments; one had no components and was used to investigate the effect of a wide range of contaminants, whilst the second design included two BGA components. The first test coupon design for investigating harsh environments, NPL TB67, is shown in Figure 1. The design comprises four identical combs of dimensions 25 mm x 25 mm with 400 and 200 μm track and gap respectively. The coupon was manufactured from epoxy FR-4 laminate, and had 17μm thick copper track with a AuNi finish.

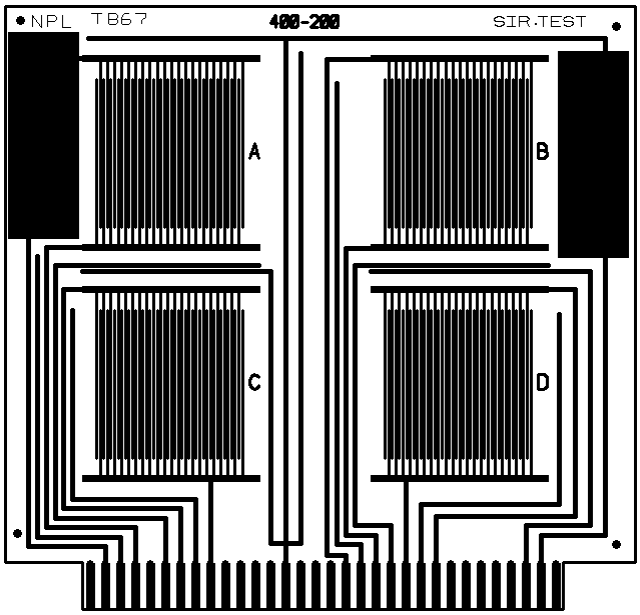



**Figure 1.** Layout of test board TB67

The second test board, NPL TB70, designed for coverage study, is shown in Figure 2. There are four SIR patterns on the board, all having 400 and 200µm track and gap respectively, as shown in Figure 3. The three different comb sizes used were 12 x 7 mm for A and B, 15 x 12 mm for C, and 25 x 25 mm for D. The board was manufactured from epoxy FR-4 laminate, and has 2 oz (70 µm) thick copper tracking with a AuNi finish for A, B and C, and 4 oz (140 µm) copper with a AuNi finish for D.

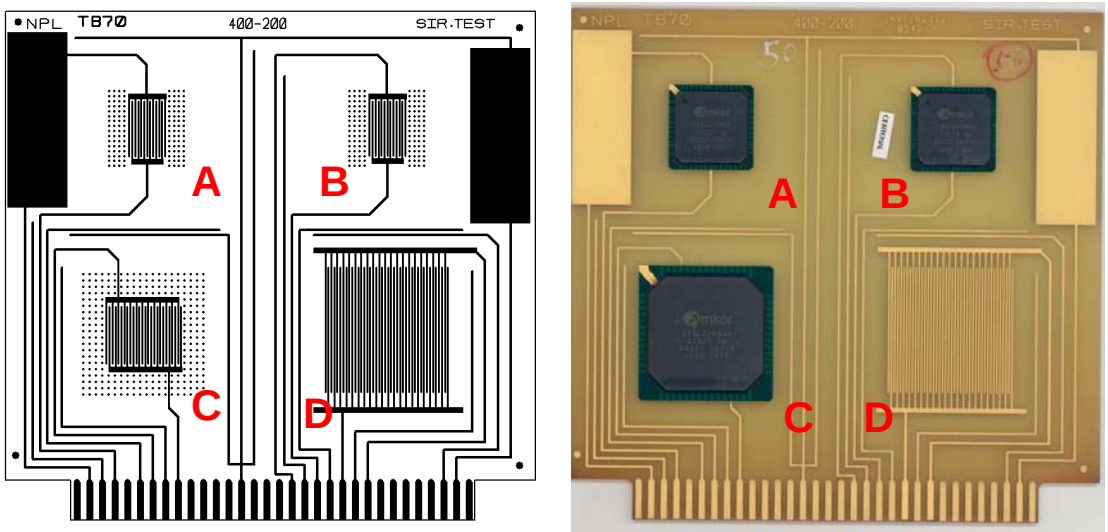
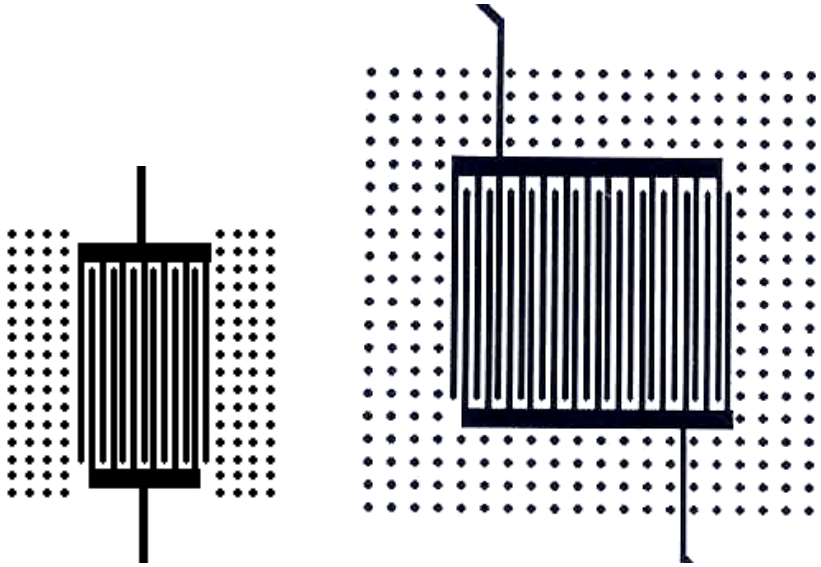



**Figure 2.** Test board TB70

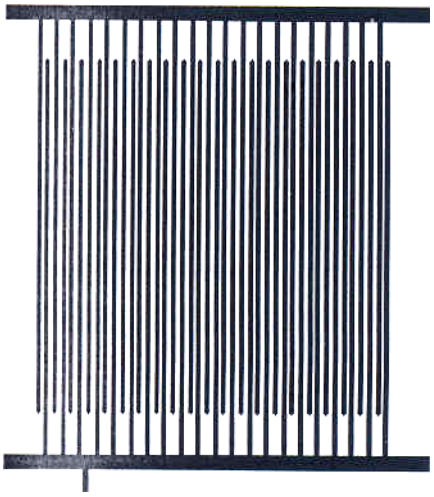
Two BGAs types were used on this board, a BGA 256 component with 1 mm pitch and 0.4 mm ball diameter, and a BGA 256T device with 1.27 mm pitch and 0.75 mm ball diameter. The BGA 256 device was mounted above the A and B patterns after first removing a central strip of balls, and the BGA 256T was mounted on pattern C, as

depicted in Figure 2. Two stencil thicknesses, 150 and 200 µm, were used to assist in achieving different stand-off heights. In Table 1, high stand-off assemblies are coded as high assembly, and normal stand-off assemblies are coded as normal assembly (see also Figure 4). To achieve the high stand-off the components were held at the higher position using shims.

A lead-free water soluble solder paste, (96.5% Sn, 3.0% Ag and 0.5% Cu) was used for assembly, and the boards were cleaned according to the manufacturers' recommendations using a two-stage water wash at 60ºC in a Kerry ultrasonic bath.



**Pattern A & B** **Pattern C**



**Pattern D**

**Figure 3.** The three test pattern types on TB70


**Figure 4.** Gap between board and BGA component

**Table 1.** Gap H for different SIR pattern and assemblies

| Assembly | Pattern | Gap (H) µm |
|---|---|---|
| Normal | A & B | 200 |
| High | A & B | 400 |
| Normal | C | 400 |
| High | C | 500 |

## 2.2 COATING MATERIALS

Seven different coating chemistries from six suppliers were used (two different water-based acrylics, solvent-based acrylic, silicone, polyurethane, fluoroacrylate and epoxy). The test boards were coated by the materials suppliers themselves in accordance with their own recommended standard procedures. The coatings were applied by dipping except for the water-based acrylic (1) coating, which was applied by both dipping and spraying. Two coatings, water-based acrylic (1) and epoxy, were used to investigate the effect of the coating coverage under components having different stand-off heights. The details of test boards with coatings are listed in Table 2.

**Table 2.** Test boards

| Test board | Appl. method | Coating |
|---|---|---|
| TB67 PCB and TB70 normal assembly | Dip | Water-based acrylic (1) |
| | | Water-based acrylic (2) |
| | | Solvent-based acrylic |
| | | Silicone |
| | | Polyurethane |
| | | Epoxy |
| TB70 normal assembly | Dip | Fluoroacrylate |
| | Spray | Water-based acrylic (1) |
| TB70 high assembly | Dip | Water-based acrylic (1) |
| | | Epoxy |

## 2.3 CONTAMINANTS

The reliability of circuitry is of great concern, especially when operated under severe environmental conditions, e.g. marine environments, industrial gas pollution ($SO_2$, $NO_2$, HCl), surfactants, hydraulic fluids and de-icing fluids. The following contaminants were selected to represent these harsh environmental conditions in this study after a survey of industrial partners.

**Sea water:** The ASTM seawater was used as a contaminant to represent marine environments where salt spray/fog dominate. The main constituents of seawater are listed in Table 3.

**Table 3**. ASTM seawater

| Chemical | Concentration (% by weight ) |
|---|---|
| NaCl | 2.46 |
| $NaSO_4$ | 0.41 |
| $MgCl_2.6H_2O$ | 1.11 |
| $CaCl_2.6H_2O$ | 0.23 |
| KCl | 0.07 |
| $NaHCO_3$ | 0.02 |
| Total | 4.30 |

**Industrial pollution gases**: The industrial pollution gases $SO_2$, $NO_2$, HCl will become $H_2SO_4$, $HNO_3$ and HCl acids under high humidity conditions, and thence form acid rain. Acid rain is extremely harmful for electronic boards, and in this work a mixture of these three acids, according to an acid rain formula[3] was employed. For the best discrimination of coating performance the acid rain solution was used at 100 and 1000 times concentration for the contaminants, as listed in Table 4. This approach is also representative of a gas pollution environment, where, in the presence of moisture, the absorbed gas forms acid on the surface.

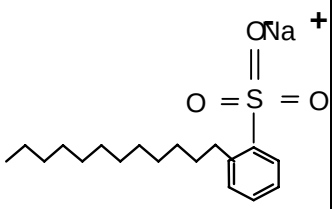
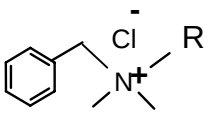
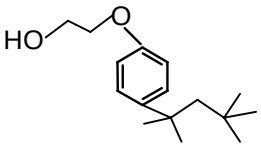
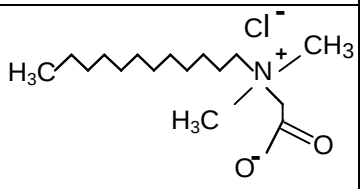
**Table 4**. Three acids in acid rain

| Chemical / Code | $H_2SO_4$ | $HNO_3$ | HCl |
|---|---|---|---|
| | (mg / litre) | | |
| Acid rain | 11 | 7 | 1 |
| 100x Acid rain | 1100 | 700 | 100 |
| 1000x Acid rain | 11000 | 7000 | 1000 |

**Surfactants**: Surfactants are generally water-soluble surface-active agents having a hydrophobic portion. All surfactants possess the common property of lowering surface tension when added to water in small amounts. They can be categorized according to the charge present in the hydrophilic portion of the molecule (after dissociation in an aqueous solution), and they can be anionic, cationic, non-ionic and amphoteric. In this work a representative of each type

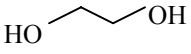
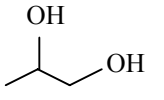
was selected as a contaminant (see Table 5 for coding and structure). In all cases a 1% surfactant concentration was used.

**Table 5**. Four surfactants

| Type | Chemical | Code | Molecular structure |
|---|---|---|---|
| Anionic | Laurylbenzolsulfonsaeure | LABS |  |
| Cationic | Benzalkonium chloride | BC |  |
| Non-ionic | TRITON X-100 | TX |  |
| Amphoteric | Lauryl betaine | LB |  |

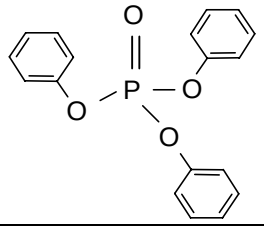
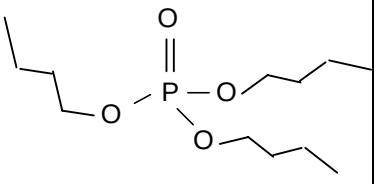
**De-icing fluids:** Ethylene glycol and propylene glycol are commonly used de-icing fluids, and usually comprise 80% of the de-icing fluid. In this work 100% ethylene and propylene glycols were used to contaminate the board. Their chemical names, molecular structures, concentrations and codes are listed in Table 6.

**Table 6**. De-icing fluids

| Chemical | Code | Molecular structure | Concentration |
|---|---|---|---|
| Ethylene glycol | EG |  | 100% |
| Propylene glycol | PG |  | |

**Hydraulic fluids:** Hydraulic fluids are a large group of liquids with a wide range of constituents. Triphenyl phosphate and tributyl phosphate are two of the main components of organophosphate ester hydraulic fluid[4], and hence 100% triphenyl and tributyl phosphates were used as the contaminants to represent this group of chemicals. Details of the phosphates are listed in Table 7.

**Table 7**. Hydraulic fluids

| Chemical | Code | Molecular structures | Concentration |
|---|---|---|---|
| Triphenyl phosphate | TP |  | 100% |
| Tributyl phosphate | TB |  | |

**Fluxes:** Fluxes are widely used for electronics assemblies, and their residues may cause reliability issues for the electronic circuits. A solvent-based flux, which was used in previous work, was chosen for the study[5] of coating coverage. The composition of the flux is given in Table 8.

**Table 8**. Solvent flux

| Adipic acid | Succinic acid | Glutaric acid | Rosin | IPA |
|---|---|---|---|---|
| (% by weight) | | | | |
| 1.7 | 1.7 | 1.7 | 1.7 | 93.2 |

## 2.4 TEST BOARD CONTAMINATION

### 2.4.1 Test board TB67 PCB

For all the contaminants 50 µl were slowly applied as a number of drops, initially onto the centre of the comb pattern, and then to ensure a uniform coverage, by dispensing further drops in areas of low coverage. The aim was to achieve a uniform thickness of the contaminant over the SIR pattern, and to avoid the contamination spreading outside the pattern. However some conformal coatings had high surface energy, and the contaminants did not wet very well, so small drops of contaminants were dispersed on the SIR test pattern, as shown in Figure 5. Boards contaminated with seawater, acid rain and surfactant were left to air dry for up to two hours before SIR testing. In the cases of the de-icing fluids and hydraulic fluids, the SIR testing was started immediately after contamination. In addition, since hydraulic fluid TP is solid at room temperature, (melting point of 48°C), it was heated to about 60°C, and then applied to the comb.

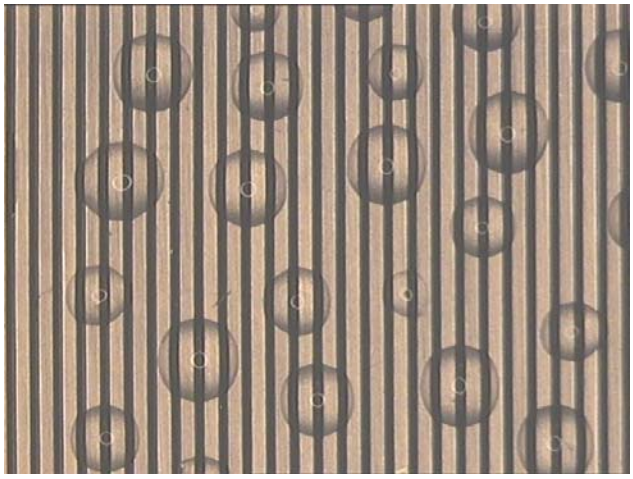


**Figure 5.** Contaminant on high surface energy conformally-coated board

### 2.4.2 Test board TB70 assembly

For the TB70 assembly, 25 µl of contaminants were applied to either side of each BGA component for patterns A and B (50 µl in total), as shown in Figure 6. For comb C, 50µl were applied to each side, whilst 50 µl of contaminants were applied uniformly to cover pattern D. Contaminated assemblies were left to air dry for up to two hours before SIR testing.

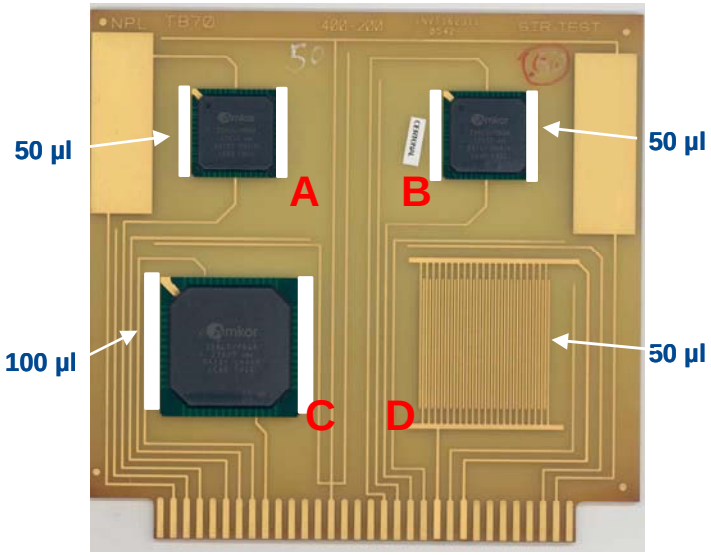



**Figure 6.** Contaminant on high surface energy conformally-coated board

## 2.5 SURFACE INSULATION RESISTANCE MEASUREMENTS

A Gen3 Auto SIR that has a current sensitivity of 1 x $10^{-11}$A was used to monitor the SIR values. The SIR measurements were performed under constant temperature and humidity conditions. A DC bias voltage was continuously applied across the comb

patterns during the test period of 72 hours, and the SIR was measured every 10 minutes. The instrument includes a $10^6$ Ω resistor on each test channel to protect any dendrite that forms, so the minimum SIR measurement value of the system is $10^6$ Ω.

Generally two sets of test parameters were used to investigate the effect of test conditions on coating performance; 40°C/93% RH with 5V bias, and 85°C/85% RH with 50V bias,. The de-icing fluids EG, PG, and hydraulic fluid TB, were volatile at high temperatures, and hence were only used under the 40°C/93% RH with 5V bias test. Moreover, the hydraulic fluid TB was only used under the 85°C/85% RH with 50V bias test, since it is solid below 48°C.

The SIR test matrix is summarised in Table 9. Since one board for each combination of contaminant and coating was measured for test board TB67, the results are the averages of four SIR measurements. For the TB70 test board, two boards for each combination of contaminant and coating were measured, so the SIR results are the averages of two measurements for each test pattern.

**Table 9.** Matrix for SIR testing (X indicates test omitted)

<table>
<tr><th rowspan="2">Test board</th><th rowspan="2">Contaminant</th><th rowspan="2">Concentration</th><th colspan="2">SIR test</th></tr>
<tr><th>40°C/93% RH<br>5V</th><th>85°C/85% RH<br>50V</th></tr>
<tr><td rowspan="12">TB67<br>PCB</td><td>Sea water</td><td>100%</td><td rowspan="5">✔</td><td rowspan="5">✔</td></tr>
<tr><td>LABS</td><td rowspan="4">1%</td></tr>
<tr><td>BC</td></tr>
<tr><td>TX</td></tr>
<tr><td>LB</td></tr>
<tr><td>EG</td><td rowspan="2">100%</td><td>✔</td><td>X</td></tr>
<tr><td>PG</td><td>✔</td><td>X</td></tr>
<tr><td>Acid rain</td><td>100X</td><td>✔</td><td>X</td></tr>
<tr><td>Acid rain</td><td>1000X</td><td>✔</td><td>✔</td></tr>
<tr><td>TP</td><td rowspan="2">100%</td><td>✔</td><td>X</td></tr>
<tr><td>TB</td><td>X</td><td>✔</td></tr>
<tr><td rowspan="2">TB70<br>Assembly</td><td>LABS</td><td>1%</td><td>X</td><td>✔</td></tr>
<tr><td>Flux</td><td>100%</td><td>X</td><td>✔</td></tr>
</table>

## 3 RESULTS AND DISCUSSION

### 3.1 COATING PROTECTION FROM CONTAMINANTS

The values of SIR with time on coated boards contaminated with seawater tested under two conditions are presented in Figure 7, and the final SIR results from the two conditions are summarised and compared in Figure 8. Similarly, the results for the four surfactants are presented in Figures 9 and 10, the acid rain in Figures 11, 12 and 13, the de-icing fluids in Figures 14 and 15,and for hydraulic fluids are in Figures 16 and 17.

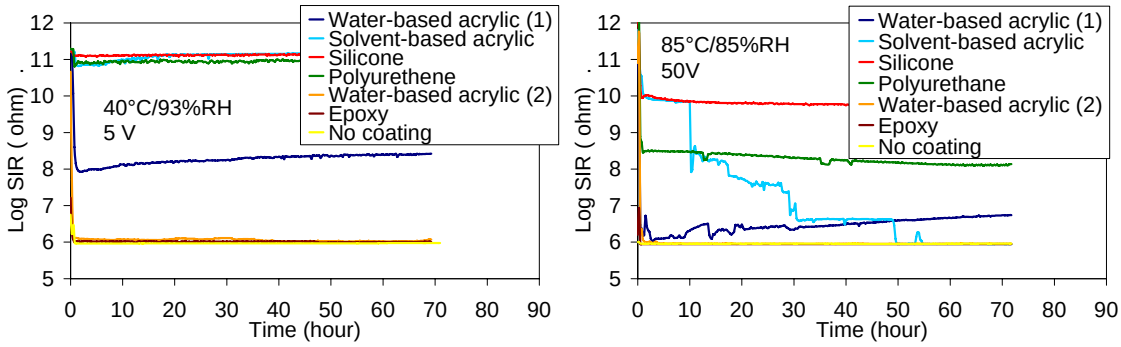



**Figure 7.** SIR plots for different coatings with seawater

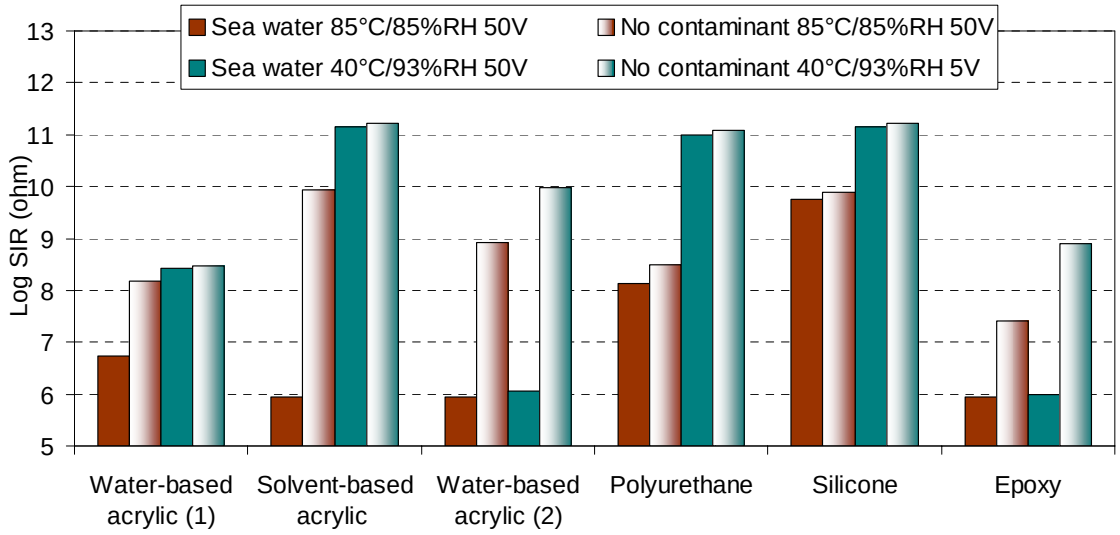
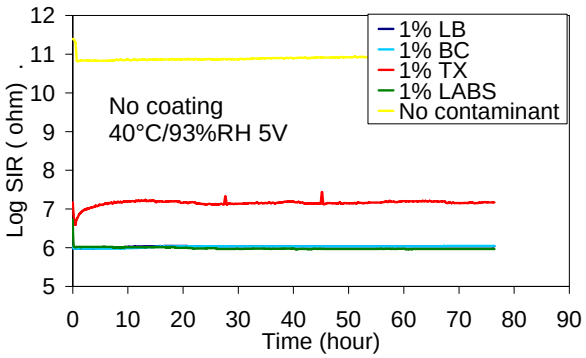
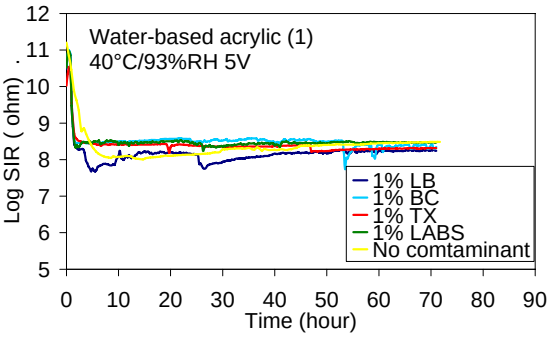
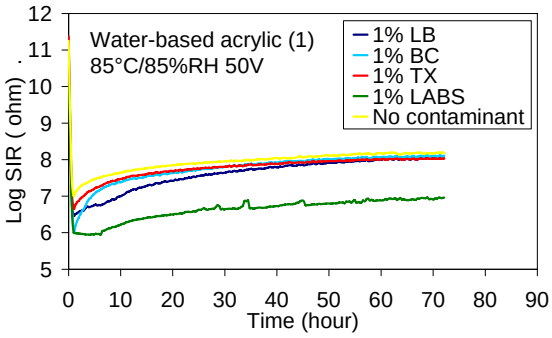
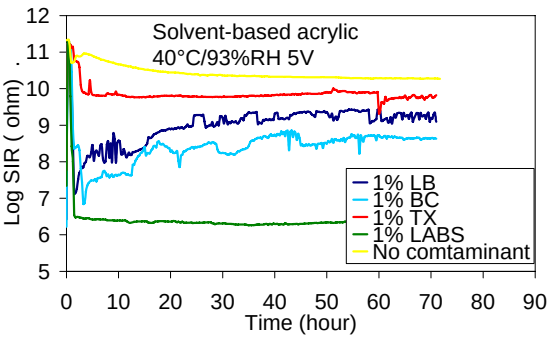


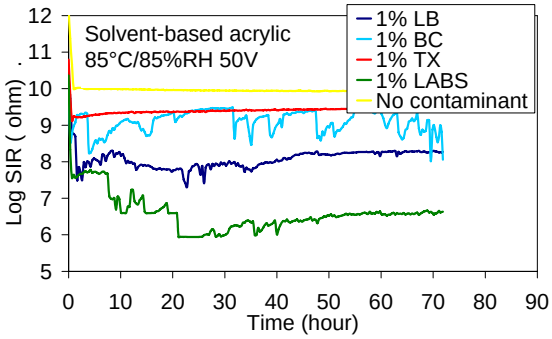

**Figure 8.** Final SIR values using different conformal coating with seawater

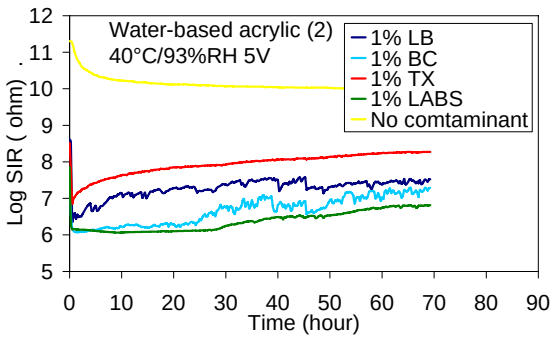


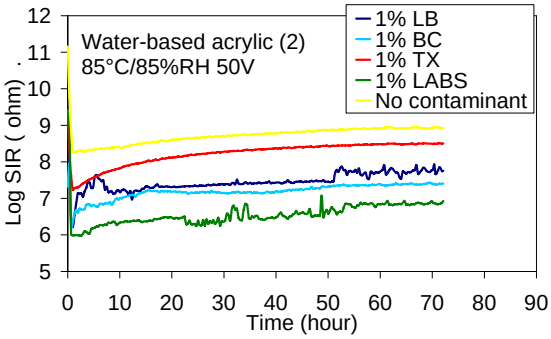

Water-based acrylic (1)
40°C/93%RH 5V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No comtaminant

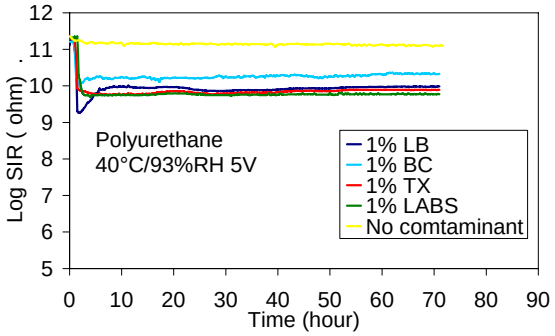

Water-based acrylic (1)
85°C/85%RH 50V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No contaminant

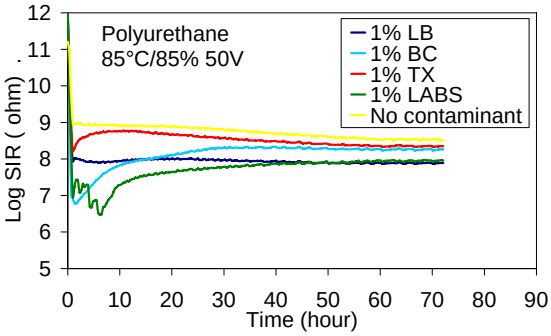

Solvent-based acrylic
40°C/93%RH 5V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No comtaminant

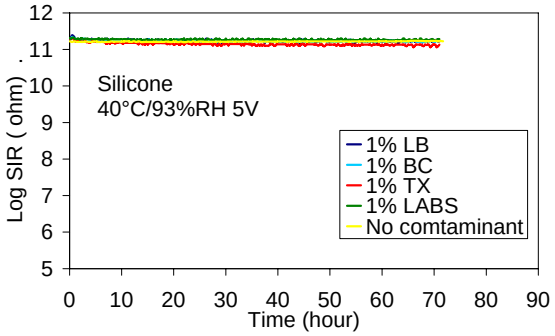

Solvent-based acrylic
85°C/85%RH 50V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No contaminant

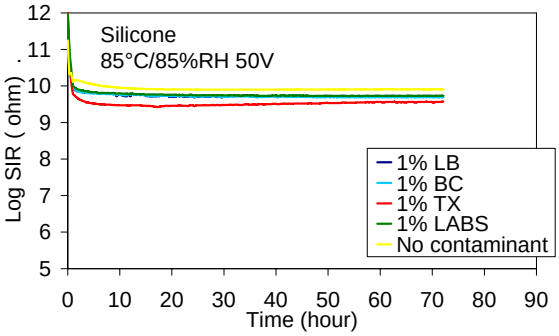

Water-based acrylic (2)
40°C/93%RH 5V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No comtaminant


Water-based acrylic (2)
85°C/85%RH 50V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No contaminant


Polyurethane
40°C/93%RH 5V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No comtaminant


Polyurethane
85°C/85% 50V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No contaminant


Silicone
40°C/93%RH 5V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No comtaminant


Silicone
85°C/85%RH 50V
Log SIR ( ohm)
Time (hour)
1% LB
1% BC
1% TX
1% LABS
No contaminant

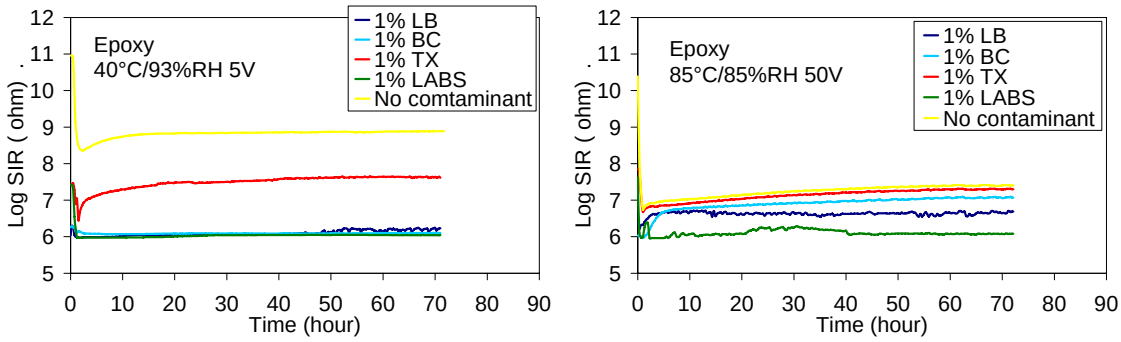



**Figure 9.** SIR plots for different coatings with four types of surfactant

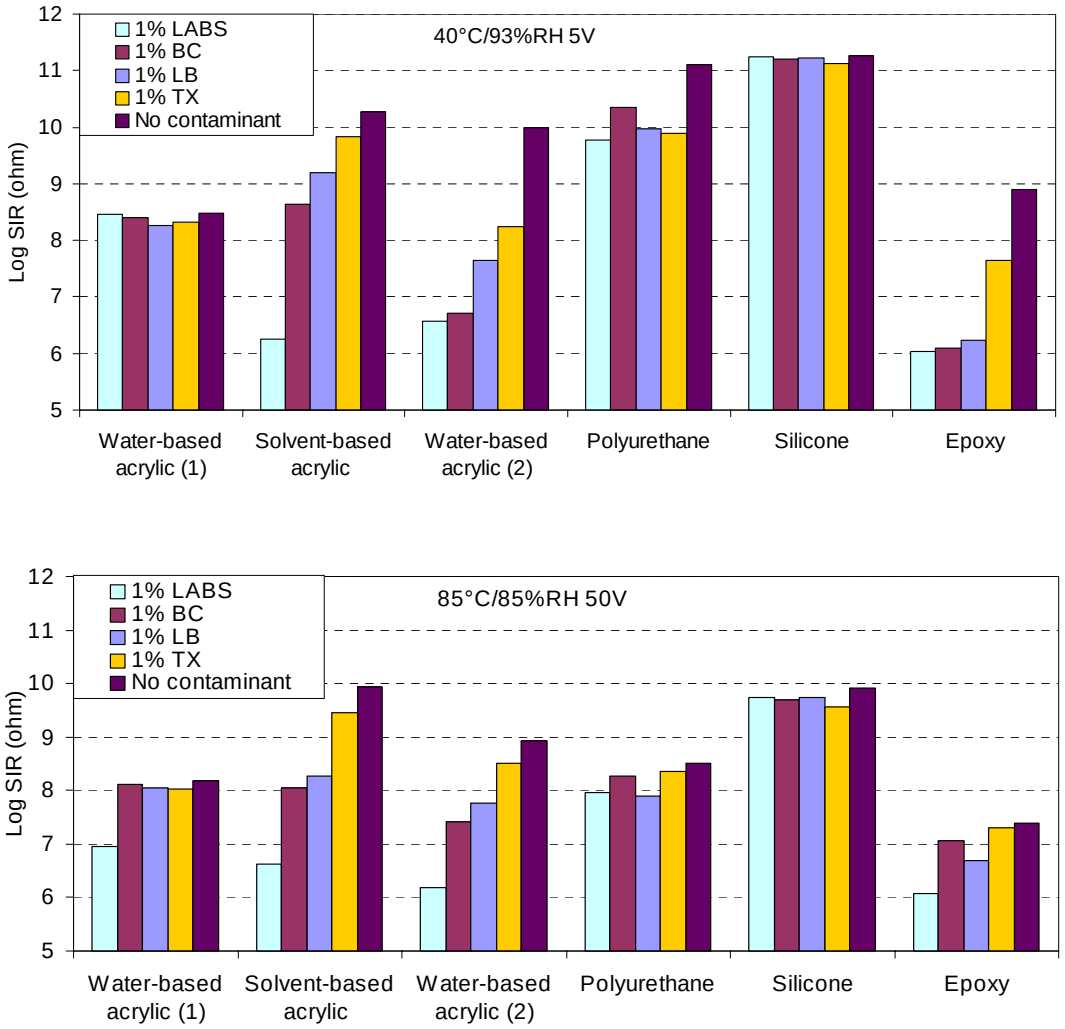



**Figure 10.** Final SIR values for different conformal coatings with four types of surfactant

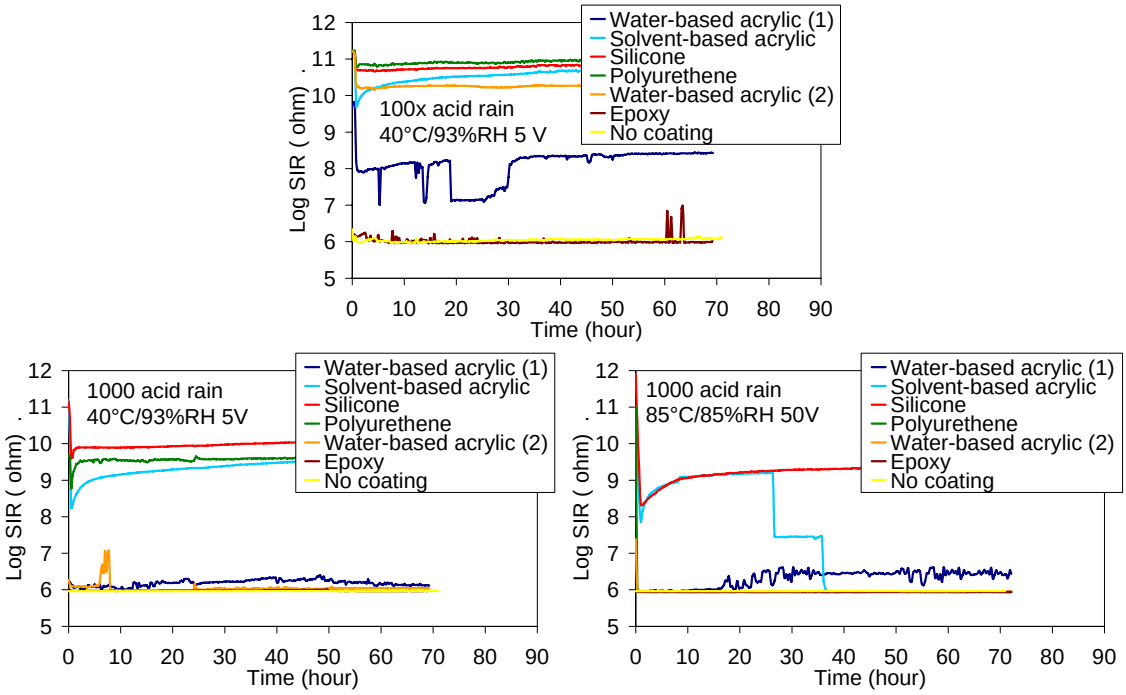



**Figure 11.** SIR plots for different coatings with different concentrations of acid rain

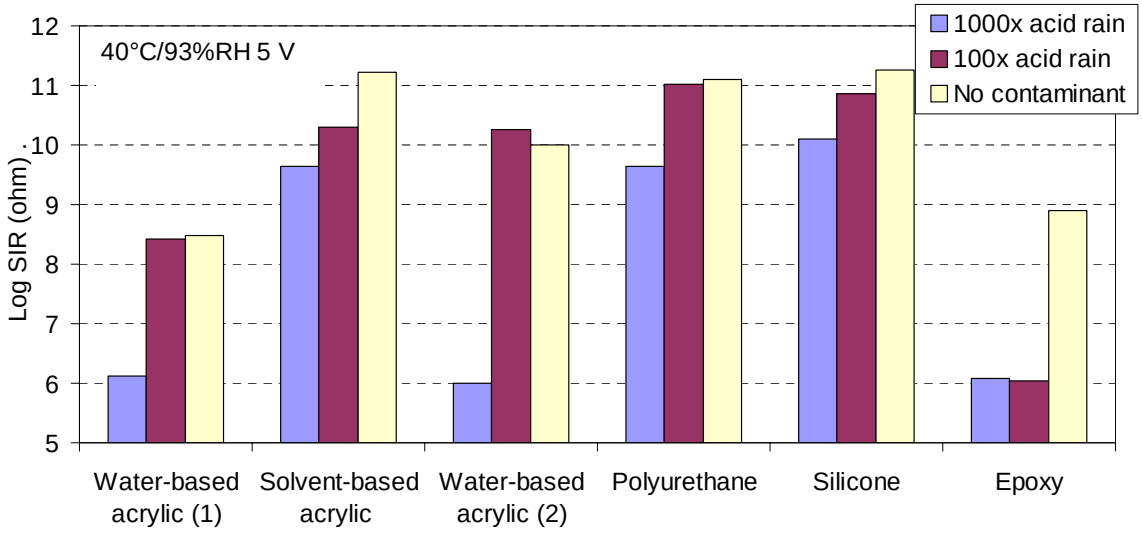



**Figure 12.** Final SIR values for different conformal coatings with different concentrations of acid rain

There are several salient points from these results:

- Different coatings offered different levels of protection for the underlying electronic circuit.
- All the coatings protected the boards from selected contaminants, except for the hydraulic fluids, which were damaging to the structures of all coatings.
- The epoxy coating performed poorly in these tests for all contaminants, which is a surprising result that will be discussed later.

- The coatings did act as physical barriers, with the permeation of contaminants dependent on coating material (molecular chemistry), and the concentration of the contaminant. For example in Figure 12 the SIR value decreased with an increase in acid rain concentration for all coatings. *This implies that organic coatings will not be completely impermeable to the wide range of contaminants tested here*; the more concentrated the contaminant, the greater the penetration, leading to a reduction in the SIR values.
- The effect of the same contaminant on the SIR performance of different coatings can be explained by the different permeabilities of different coatings.
- Sufficient protection to electronic boards is typically achieved with the silicone, polyurethane and solvent-based acrylic coatings, but even with these coatings the SIR values decreased compared with the uncontaminated boards, but were typically still above $10^9\,\Omega$.
- In general, silicone coatings gave the best protection against all contaminants under both test conditions, and the epoxy the worst. Considering all the results from all the tests the ranking for all the coatings in terms of protection performance from best to worst was

*silicone > polyurethane > solvent based acrylic > water based acrylic(1) > water based acrylic (2) > epoxy.*

- The surfactant results presented in Figures 9 and 10 reveal that the surfactant *type* is very significant (the concentration was the same for all types). The anionic surfactant gave the lowest SIR value and was the most aggressive, whilst the non-ionic surfactant gave the highest SIR value with all the coatings, and was the least aggressive.

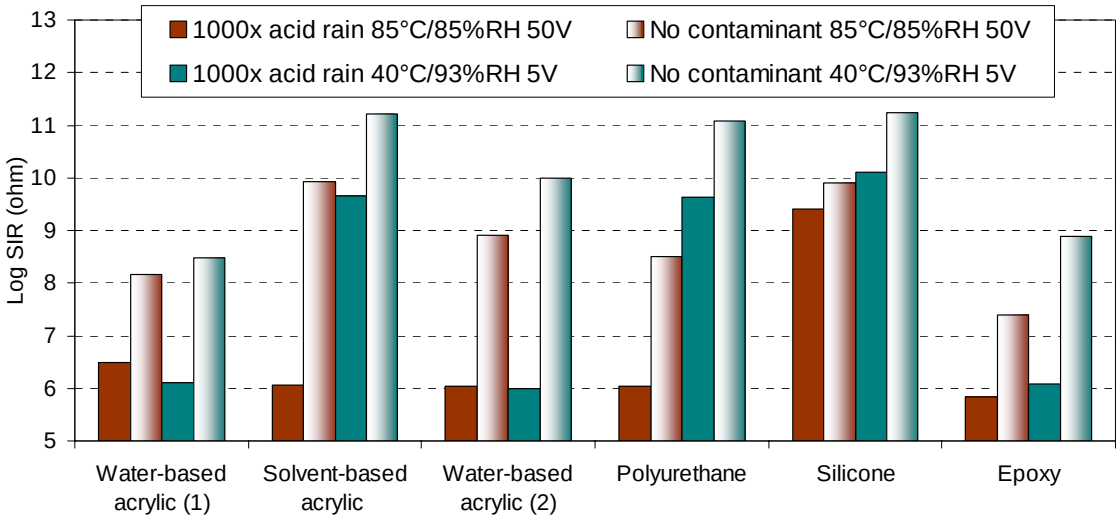



**Figure 13.** Final SIR values for different conformal coatings with different Concentrations of acid rains for both test conditions

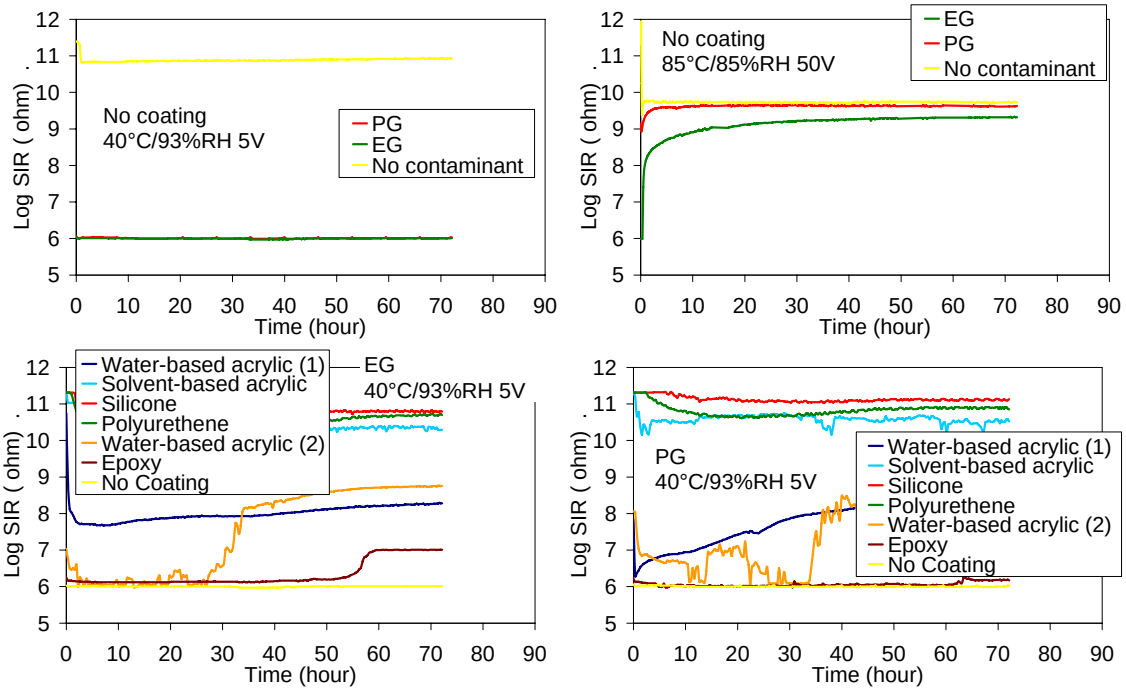



**Figure 14.** SIR plots for different coatings with de-icing fluids

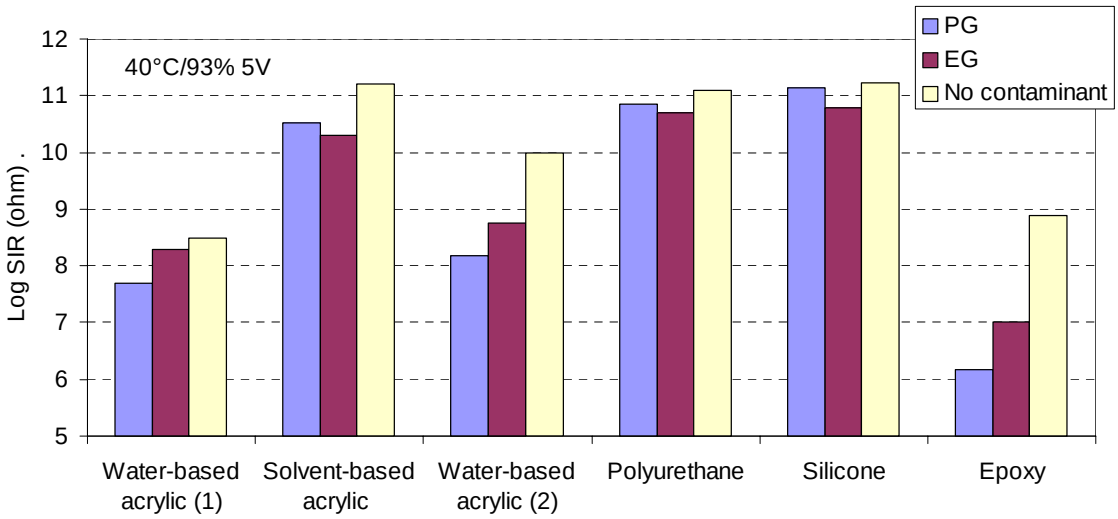



**Figure 15.** Final SIR values for different conformal coatings with de-icing fluids

- The hydraulic fluids were found to be very harmful to the coatings, as demonstrated in Figures 16 and 17 in which the SIR performance dramatically fell for all coatings. This is because hydraulic fluids damage the coatings, as shown in Figure 18. Clearly, contaminants that can dissolve or blister the coating should be avoided as they completely undermine the coating protection[6].

- Two environmental stress screening test conditions were used, 40°C/93% RH with 5V bias, and 85°C/85% RH with 50V bias, and this did have an impact on the SIR values for all the coatings, even when there was no contamination on the boards. Not surprisingly the 85°C/85% RH with 50V bias test condition was the more severe test, giving lower SIR values, than the 40°C/93% RH with 5V bias test for all contaminants. A comparison of the two data sets reveals that there is not always a similar scaling in severity between each condition. For the seawater and acid rain results the 85°C/85% RH condition had a huge impact, reducing the SIR to the minimum limit $10^6\Omega$, except for the silicone material. However, the surfactant results show a more measured decrease in SIR. The higher temperature 85ºC condition can also cause volatilisation of the contaminant, as observed with the glycols.

- It is important to note that for the uncontaminated boards with the silicone, polyurethane and solvent-based acrylic materials the SIR measurement equipment was used at its sensitivity limit. So *the recommended experimental approach is to use the 85°C/85% RH with 50V test initially, but if the effect is dramatic then the environmental condition can be relaxed to 40°C/93% RH with 5V bias test*.

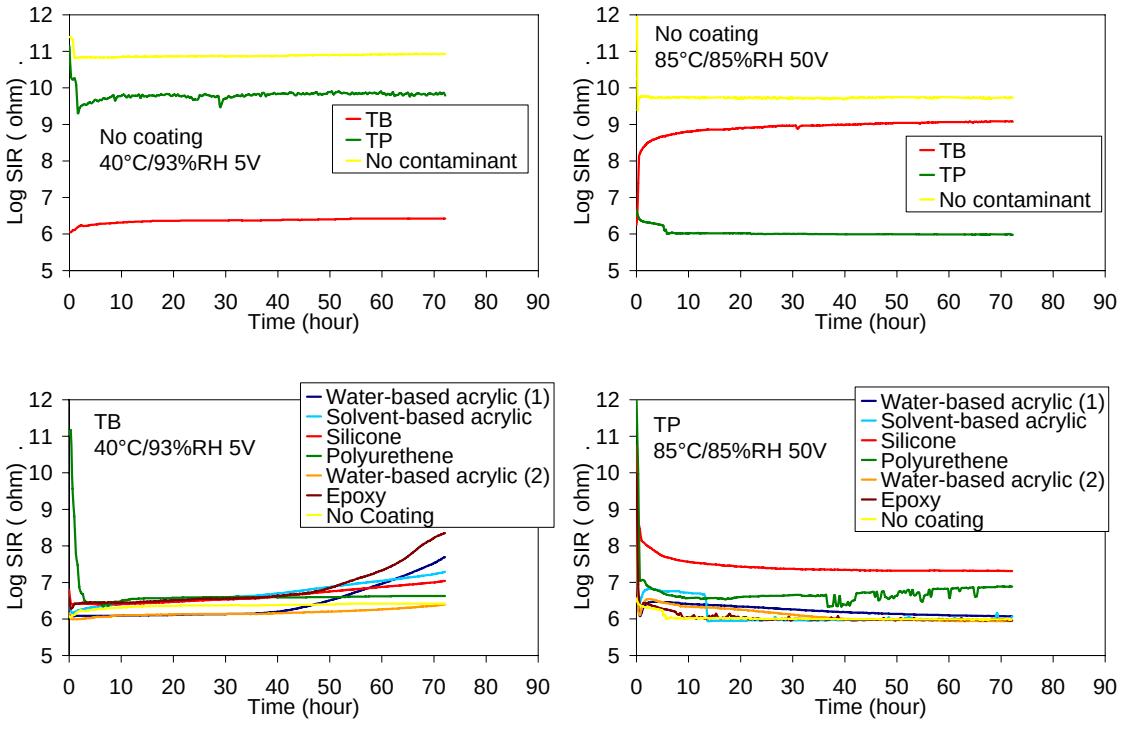



**Figure 16.** SIR plots for different coatings with hydraulic fluids

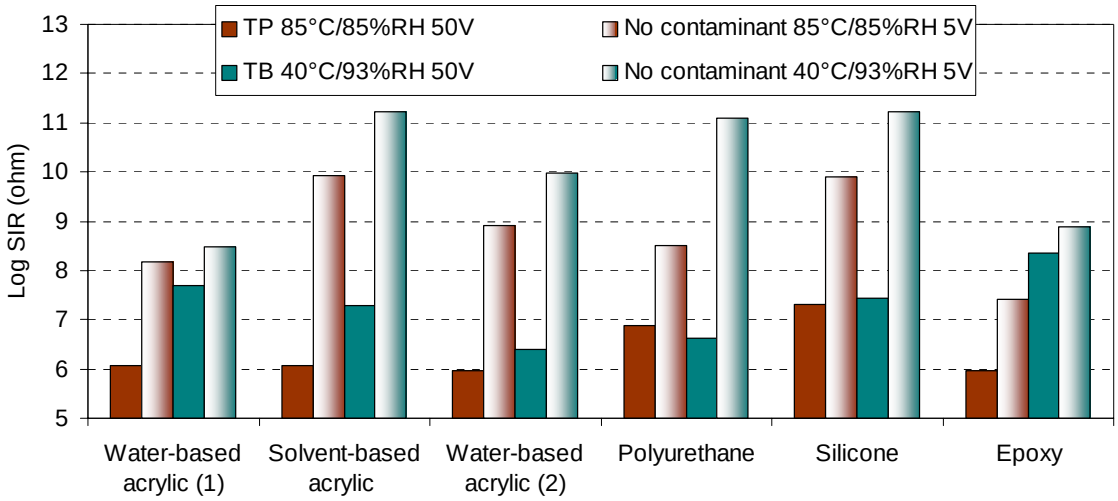



**Figure 17.** Final SIR values for different conformal coatings with hydraulic fluids

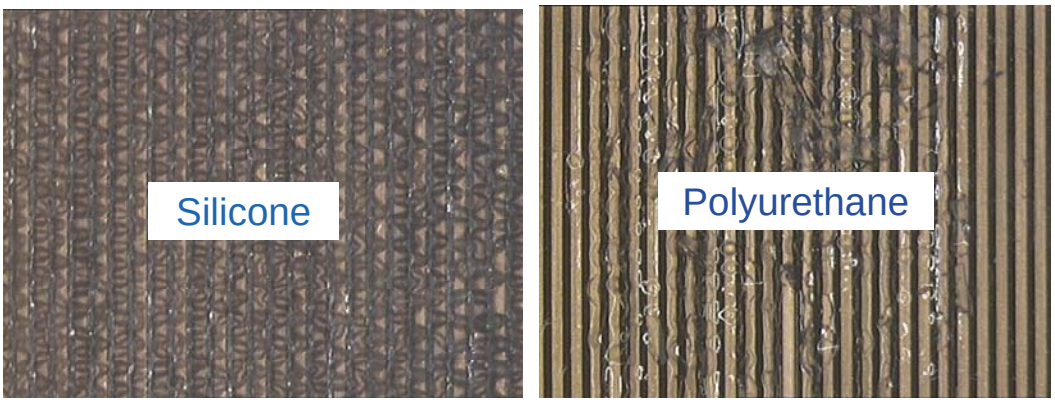



**Figure 18.** Coating blistering caused by hydraulic fluids

## 3.2 VISUAL INSPECTION OF SIR TEST BOARDS

The test boards were all inspected after SIR testing, and significant differences in corrosion were observed, dependent on the specific combination of coating and contaminant. The ranking from least to most corroded for different contaminants is presented shown in Figures 19 to 22. This visual inspection ranking agreed with that obtained from the SIR results, and hence the visual inspection results can be useful in discriminating between the protection performances of coatings. However, it is important to remember that only the SIR results reflect the reliability of the electronics assembly directly.

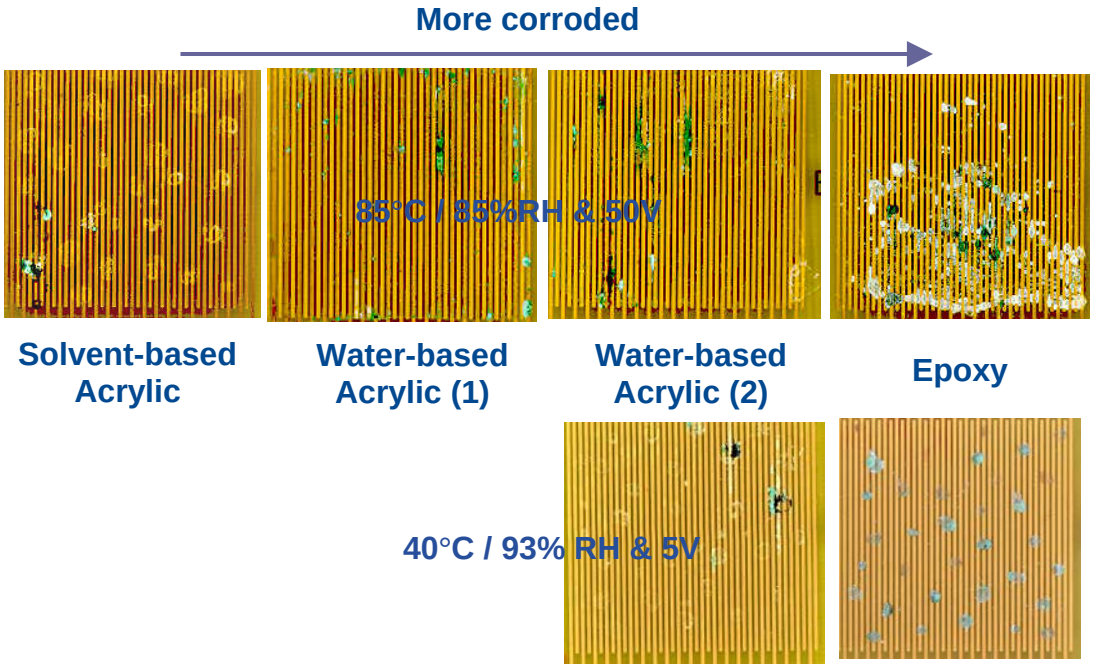



**Figure 19.** Appearance of SIR test boards after testing with seawater at both test conditions

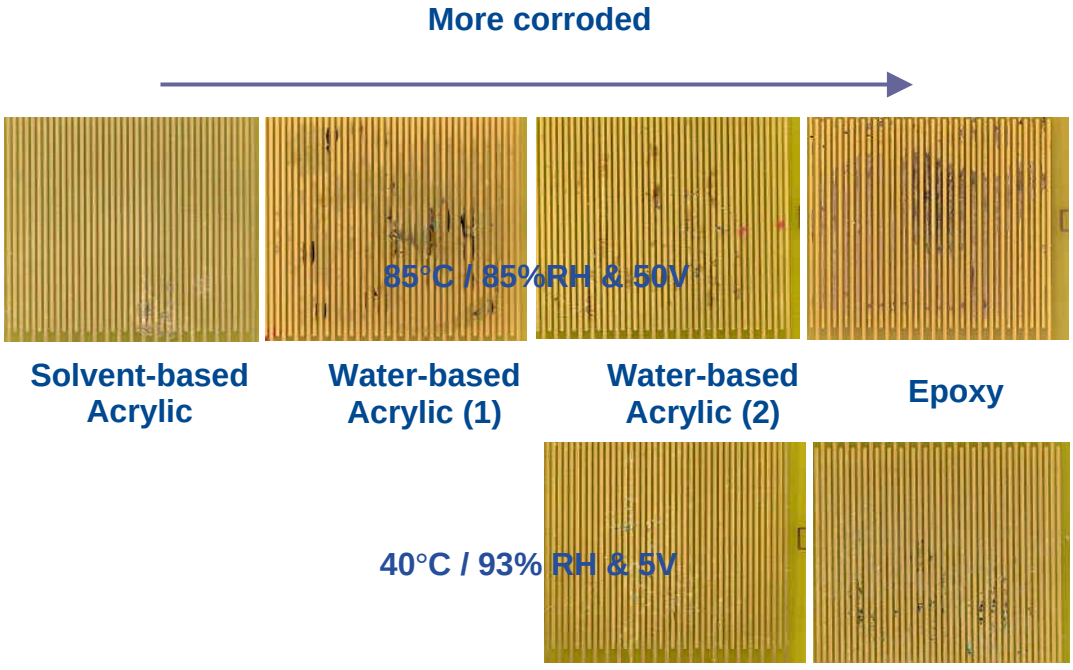



**Figure 20.** Appearance of SIR test boards after testing with anionic surfactant at both test conditions

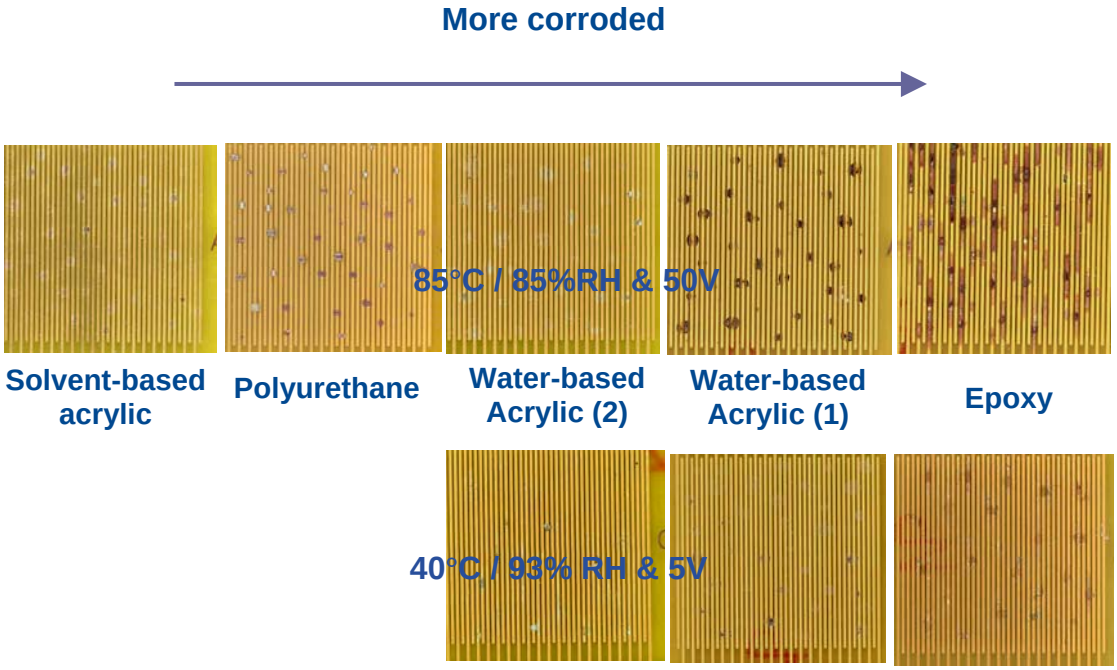



**Figure 21.** Appearance of SIR test boards after testing with 1000x acid rain at both test conditions

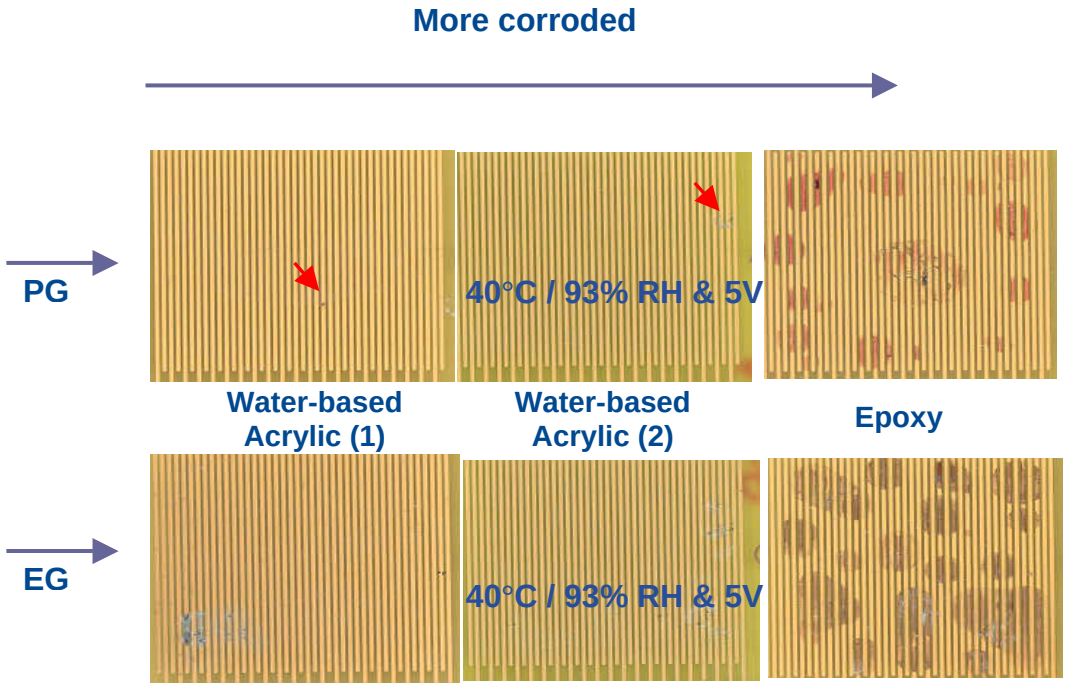



**Figure 22.** Appearance of SIR test boards after testing with de-icing fluids

## 3.3 COATING THICKNESS ON TB67 PCB

In order to determine the coating thickness, coated boards were sectioned on a line through the comb patterns, by first guillotining and then grinding back with silicon carbide paper. The thicknesses of coatings are illustrated in Figure 23, and clearly show that the coating thickness varied with different coatings. The silicone coating was much thicker than the others, and in the case of the epoxy material there was hardly any coating on top of the metal track. The thickness of coating, which affects the protection performance, will be discussed further in Section 3.5.

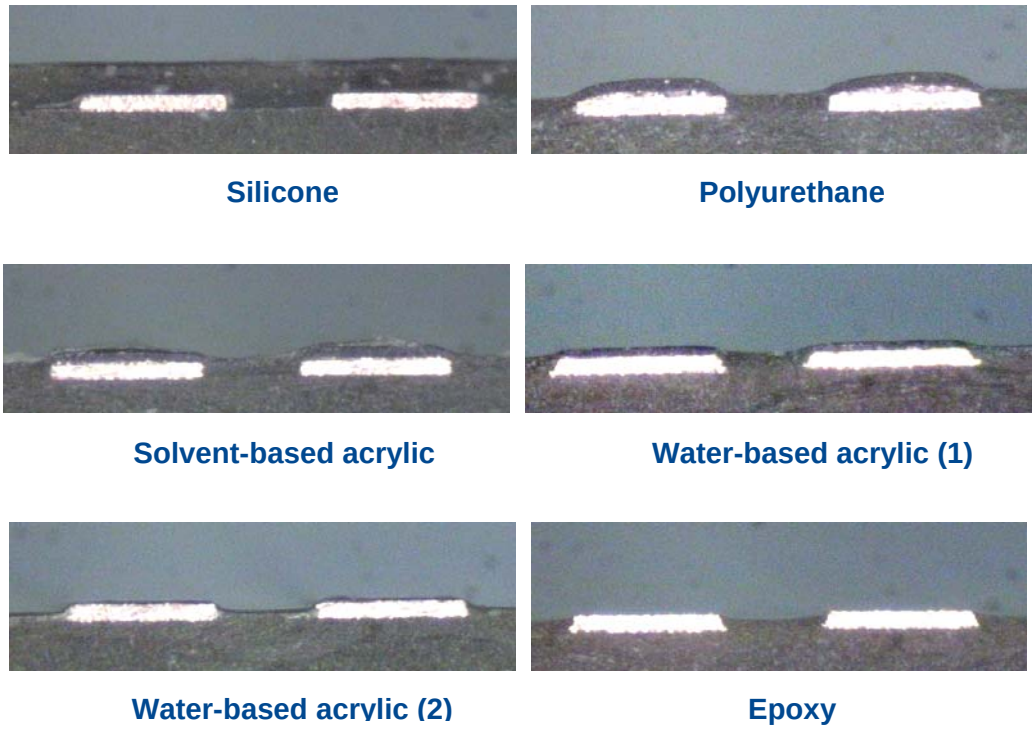



**Figure 23.** Coating thicknesses on TB67 PCB

## 3.4 COATING COVERAGE ON TB70 ASSEMBLIES

Assessing the coating coverage is not an easy task due to the transparency of the coating. However, it is possible to estimate the coating coverage under the BGA component by observing the colour change from the back side of the boards, as shown in Figure 24.

The coverage results for the eight coatings on normal assemblies are presented schematically in Figure 25, and for the two coatings with the higher stand-off assemblies, in Figure 26.

There is no clear relationship between component stand-off and coating penetration. For the water-based acrylic (1) coating and the A and B patterns, the coating penetrated and

fully covered the comb for the high stand-off components, but only partially for the normal stand-off. With the A and B patterns the epoxy coating partial coverage was achieved for the high-stand off component, and full coverage for the normal stand-off, the opposite to the behaviour of the water-based acrylic(1). However, with the epoxy coating only ~50% coverage of the SIR pattern on the C location was achieved for both stand-off conditions

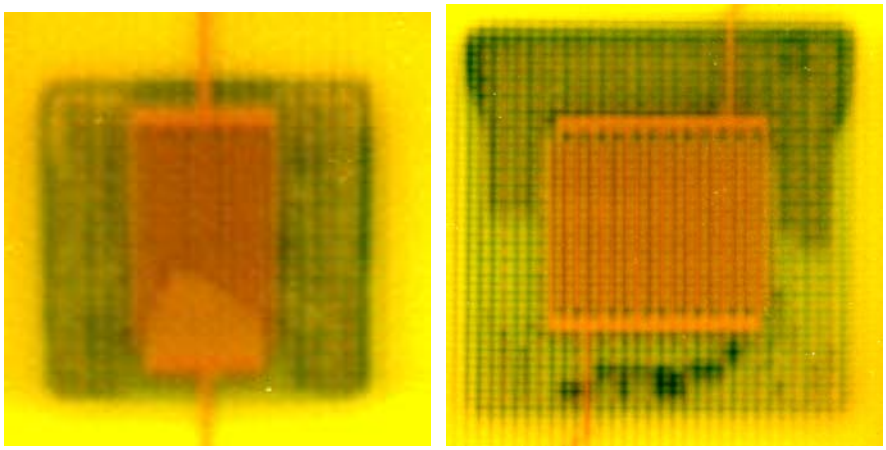


**Figure 24.** The images show the level of epoxy coating penetration under the component. The left image is for the A and B patterns, and the right is for the C pattern for TB70.

The coating penetration did show some differences with stand-off, component size, and coating material, but a larger study is required to allow definitive conclusions. There is a trade off between the wetting (capillarity) force, the coating viscosity and energy of the surface; these factors vary and interact with the process.

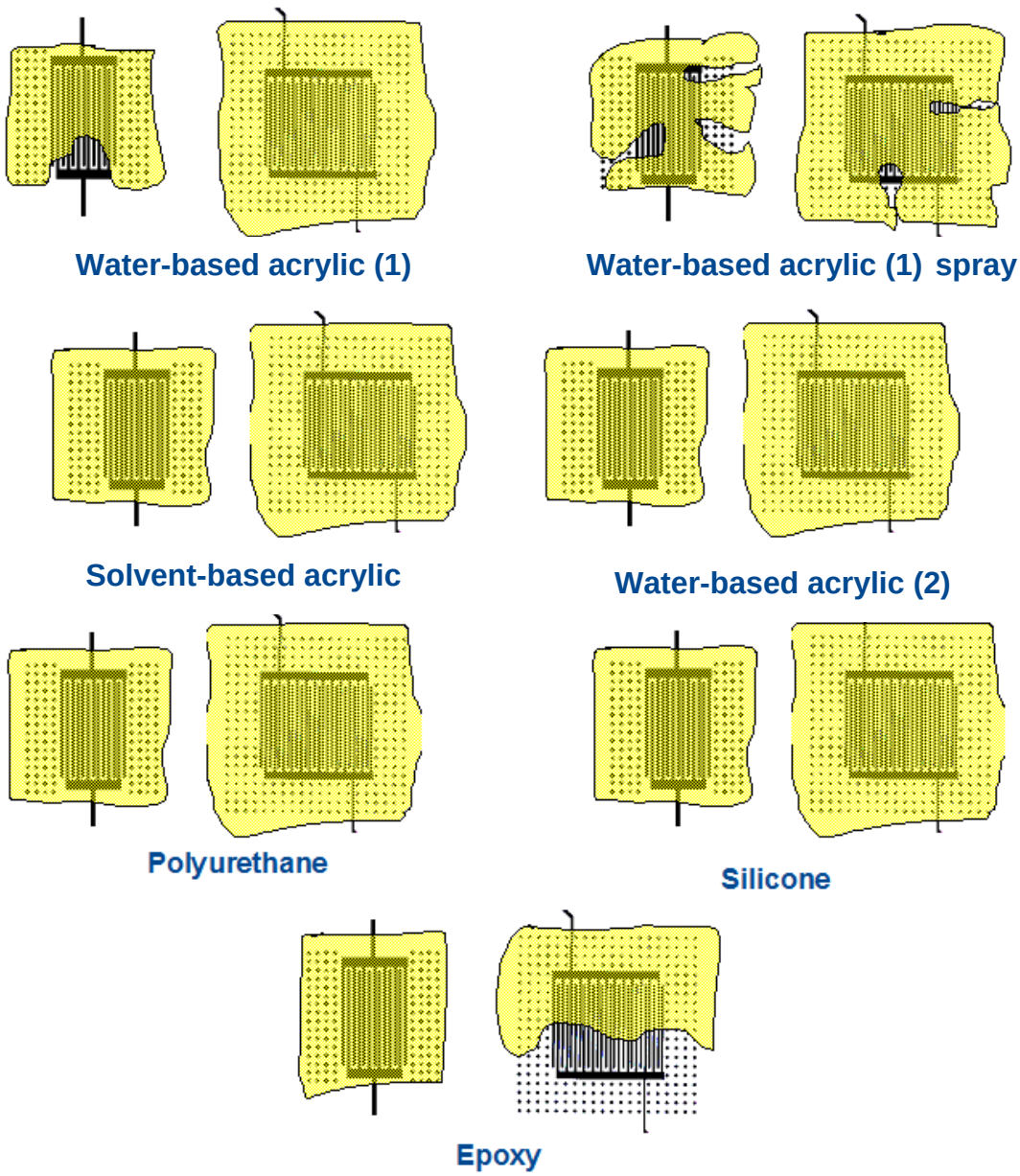



**Figure 25.** Coating coverage for assemblies having normal stand-off heights. In each case the left is for the A and B patterns, and the right is for the C pattern.

The above procedure provided information on where the coating had penetrated, but not on the level of coating thickness. Therefore, the BGA components were removed, and combs A, B, C and D, were sectioned to evaluate the coating thickness. Typical coating thicknesses achieved on these test patterns are illustrated in Figure 27. Since the fluoroacrylate coating was ~1µm thick it is not included in the Figure. It is important to note that the copper had been plated up to 70µm thick for patterns A, B, and C, and up to 140µm for pattern D, and this compares to 17µm on TB67. The sections demonstrate that for the dipped coatings, the coated material is much thinner than observed in Figure 23. The spray coated water-based acrylic(1) showed much thicker coverage on comb D, but further investigation revealed the coating was not uniform. These results illustrate

that *there can be a coverage problem when thicker copper tracking is used, especially under components*.

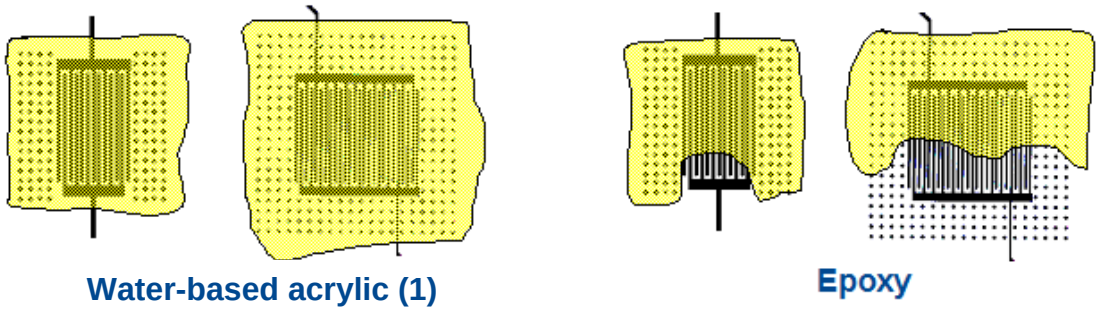
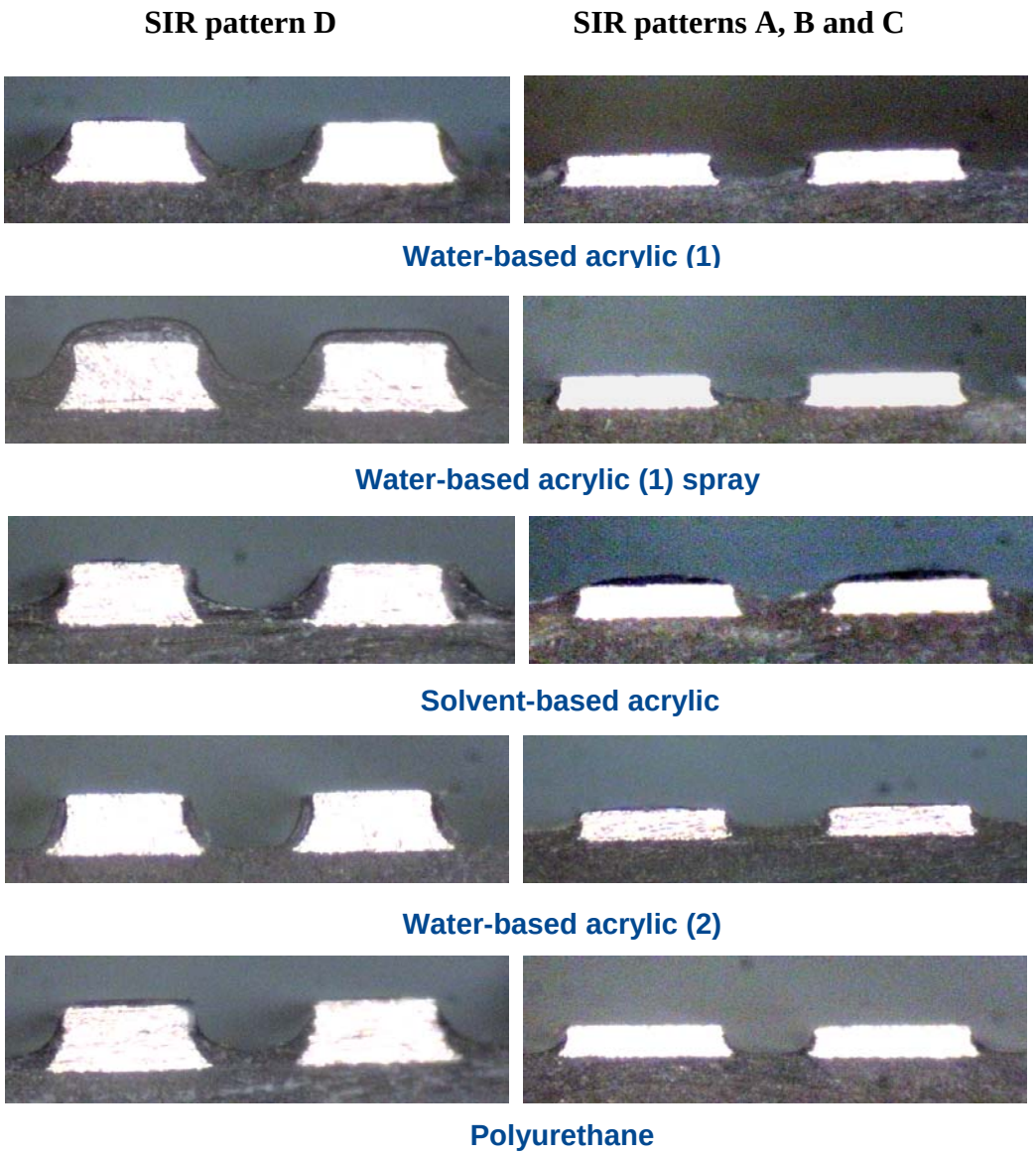



**Figure 26.** Coating coverage for higher stand-off assemblies



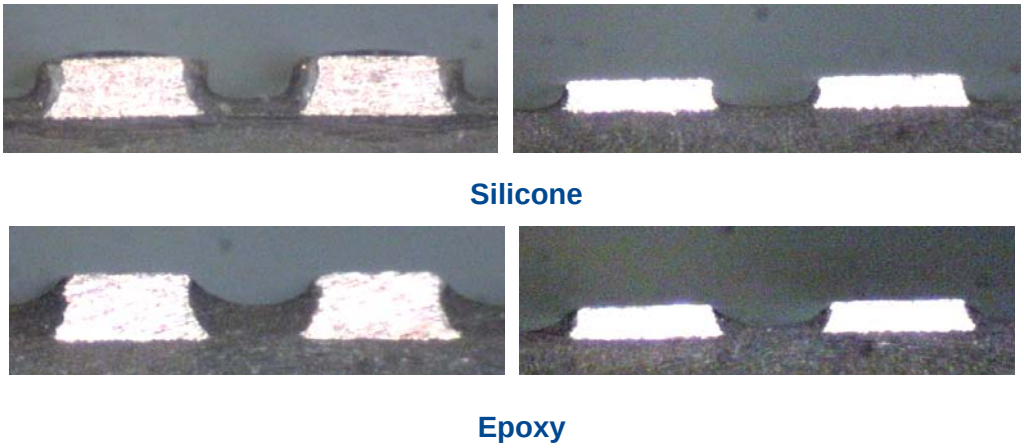



**Figure 27.** Thicknesses of the coatings on comb for TB70

## 3.5 EFFECT OF COATING COVERAGE ON SIR

Two contaminants, LABS and flux, were used to characterise the protection performance of different coatings on the TB70 assembly. The components were mounted "normally" i.e. without modifying the stand-off or artificially increasing the standoff. In Figures 28 to 36 the SIR results are compared between the two contaminants and an uncontaminated test vehicle. Figure 28 is useful in demonstrating the dramatic effect of the contamination on the SIR behaviour of uncoated boards.

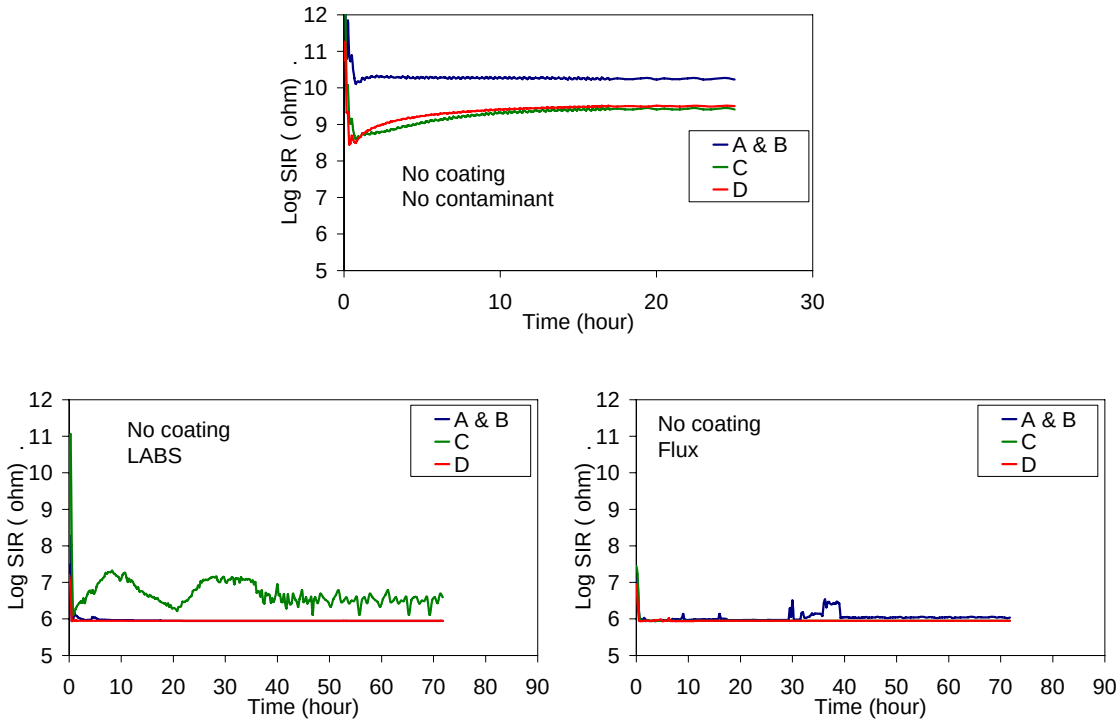



**Figure 28.** SIR plots from TB70 normal assembly with and without two contaminants

The following Figures 29 to 35 highlight the varying degrees of protection given by the coatings.

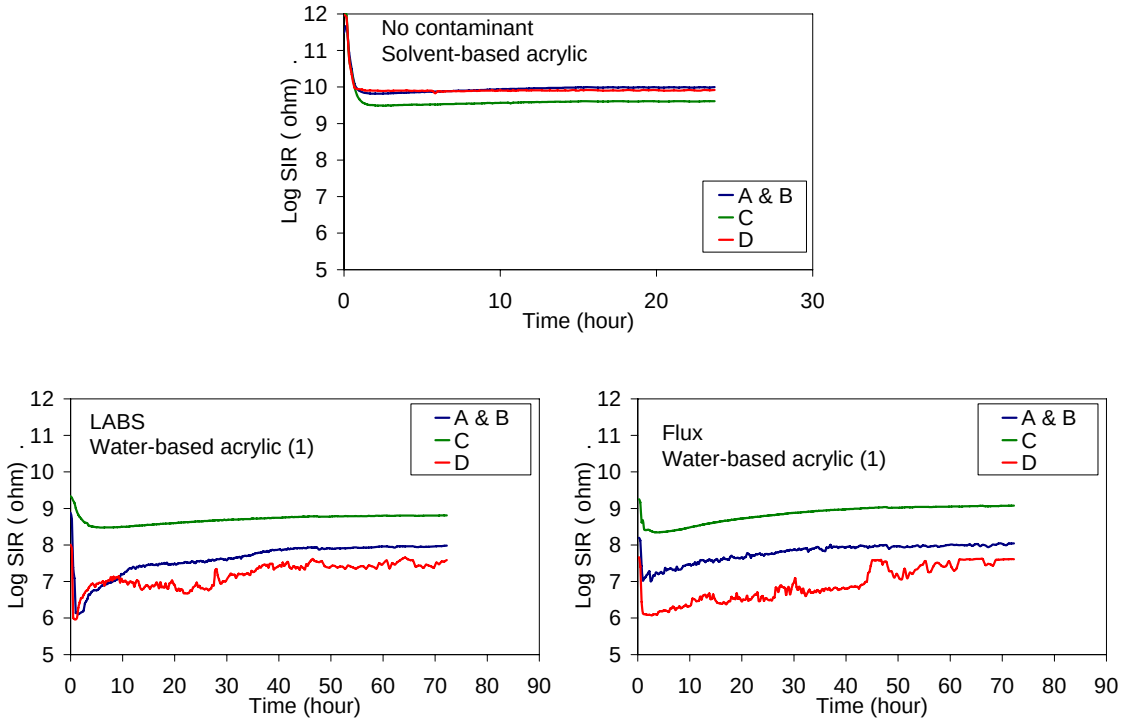



**Figure 29.** SIR plots from TB70 normal assembly with **water-based acrylic(1)** coating with and without two contaminants

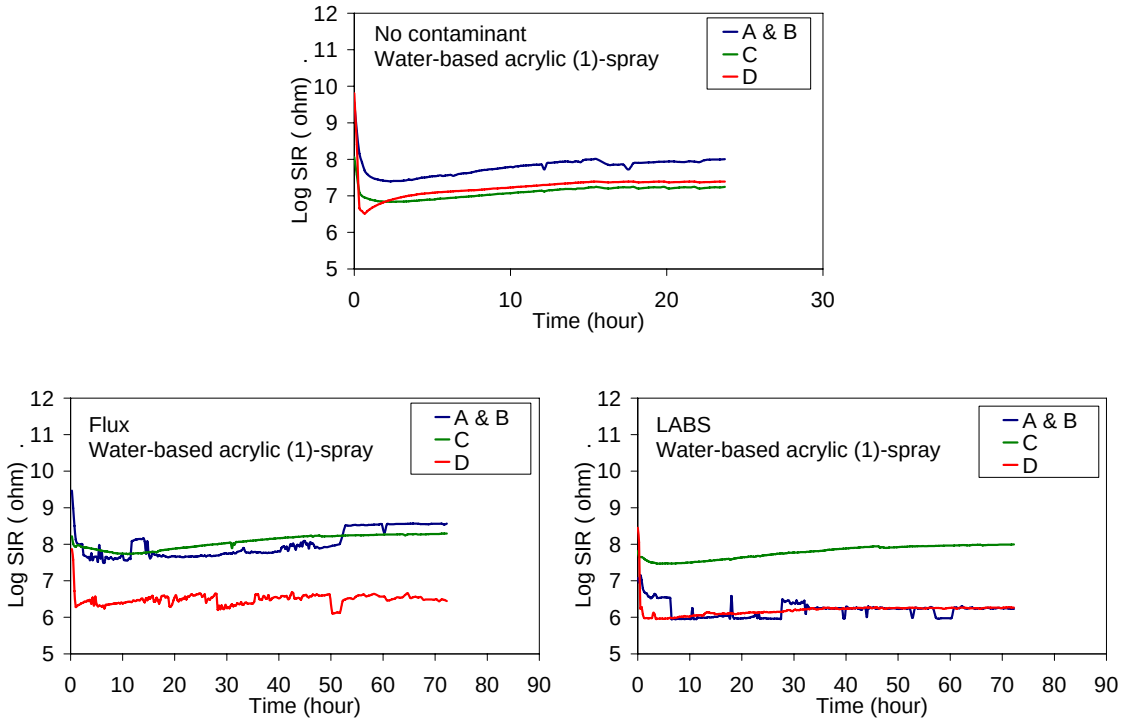



**Figure 30.** SIR plots from TB70 normal assembly with **water-based acrylic (1),** *but spray coated*, with and without two contaminants

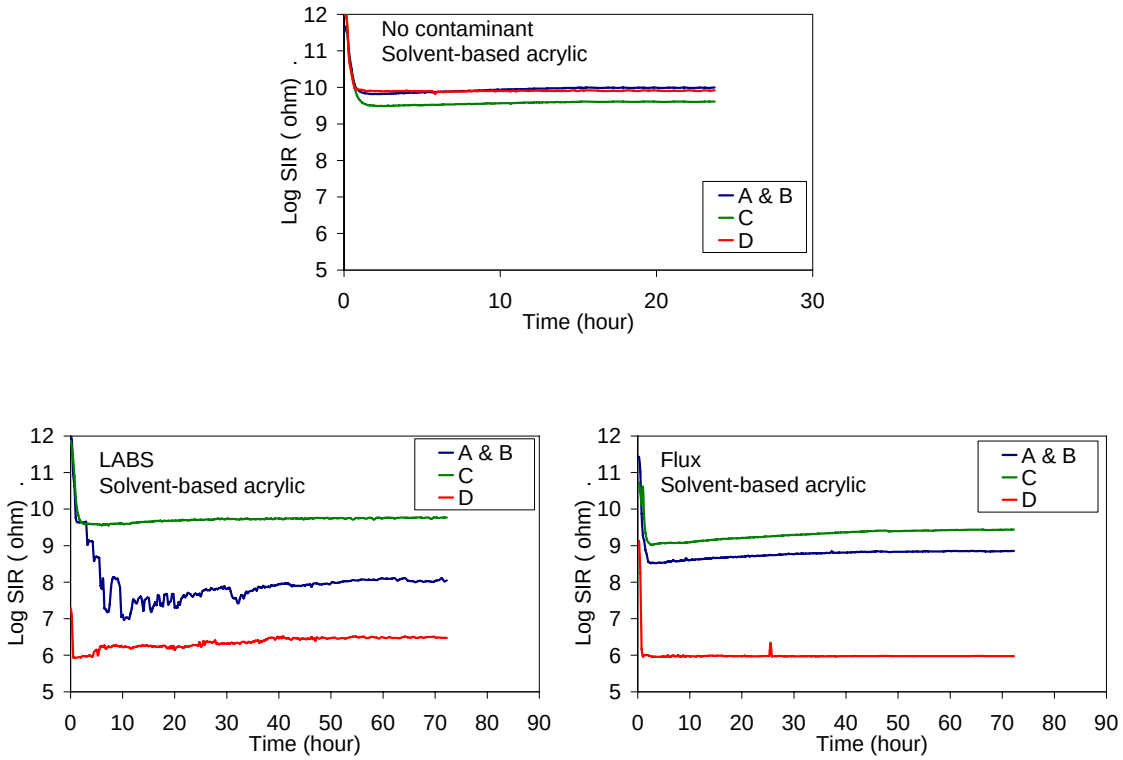



**Figure 31.** SIR plots from TB70 normal assembly with **solvent-based acrylic** coating with and without two contaminants

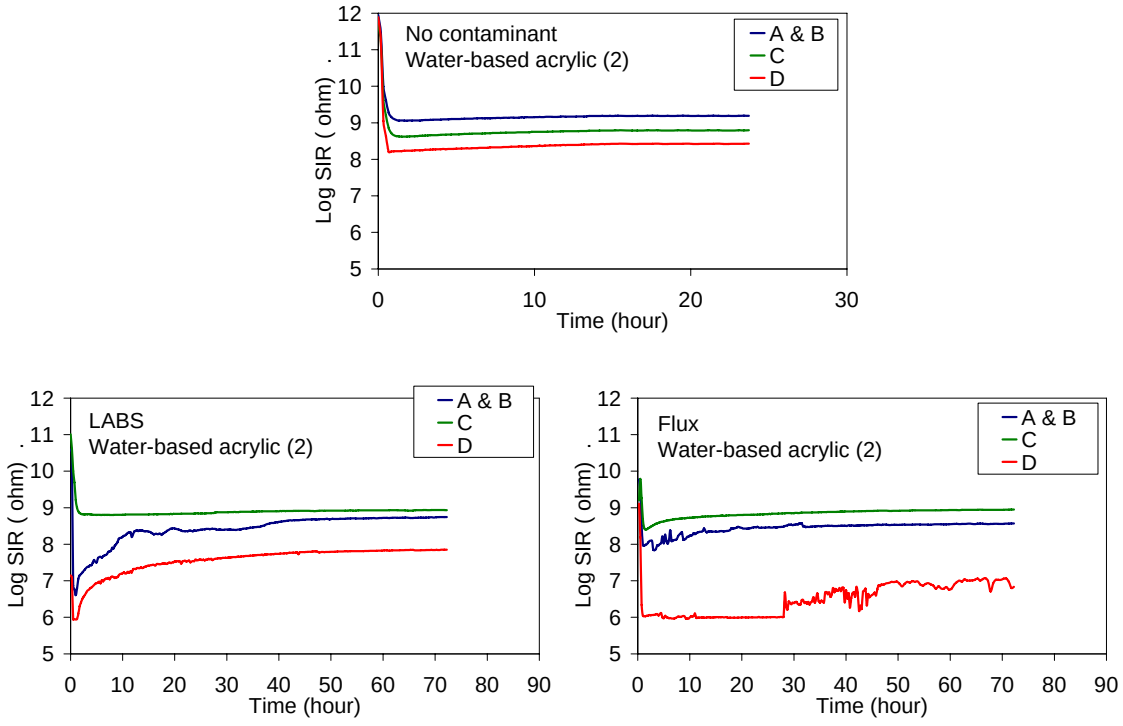



**Figure 32.** SIR plots from TB70 normal assembly with **water-based acrylic (2)** coating with and without two contaminants

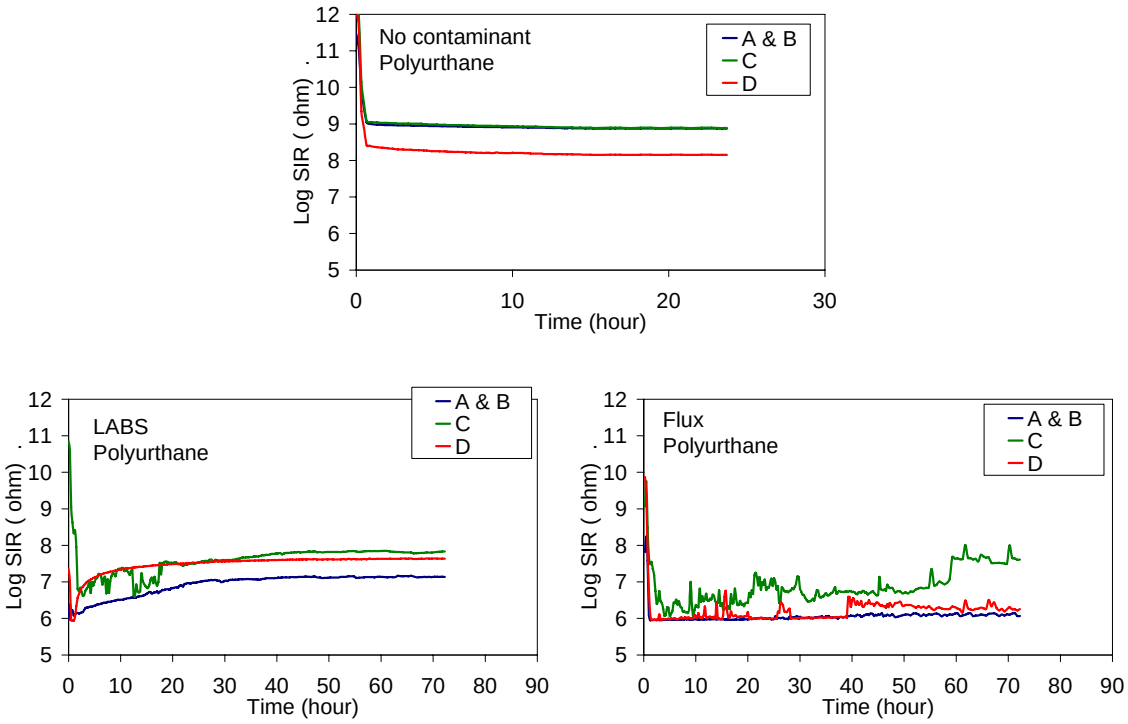



**Figure 33.** SIR plots from TB70 normal assembly with **polyurethane** coating with and without two contaminants

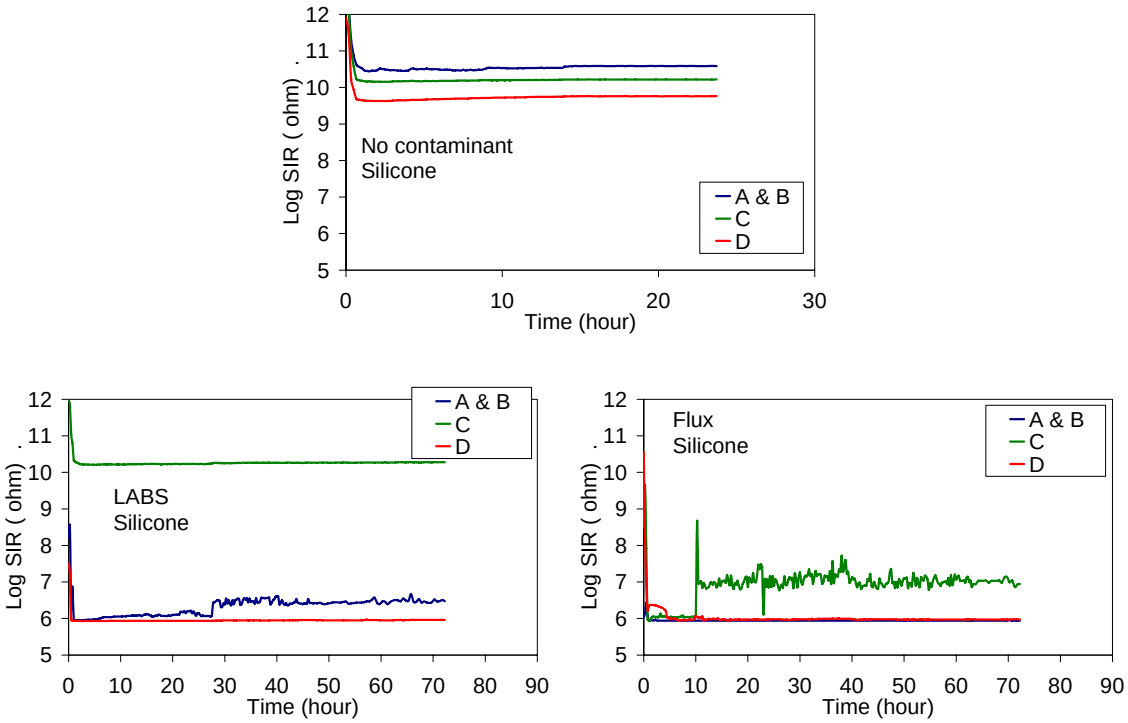



**Figure 34.** SIR plots from TB70 normal assembly with **silicone** coating with and without two contaminants

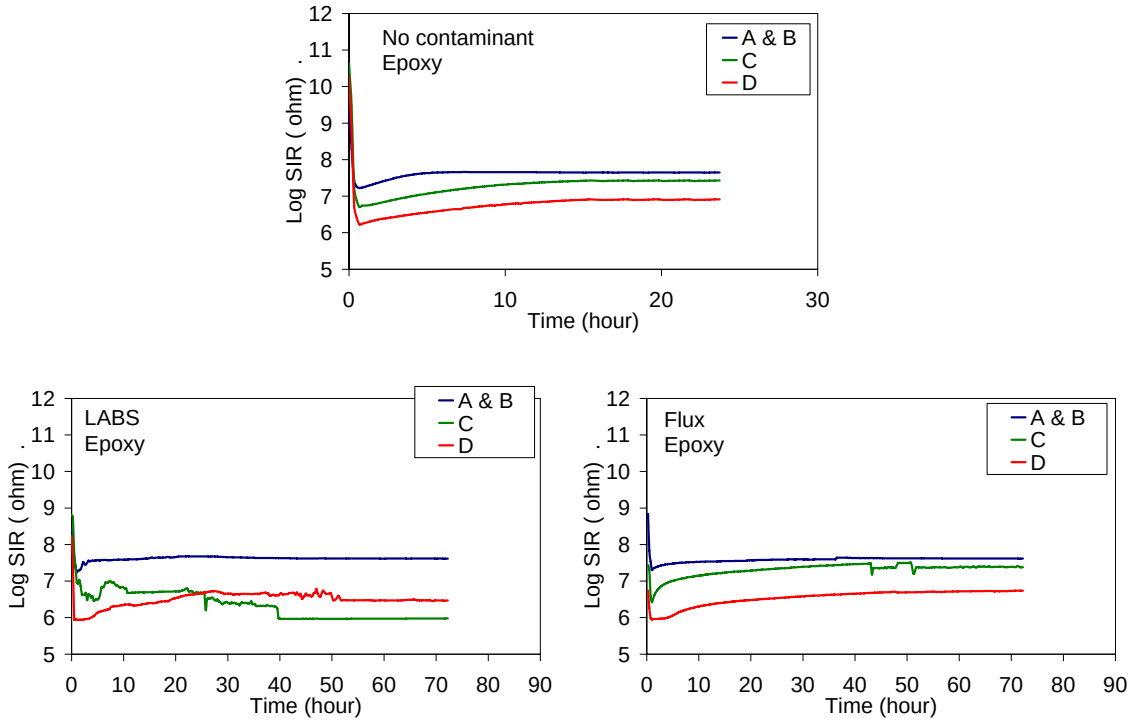



**Figure 35.** SIR plots from TB70 normal assembly with **epoxy** coating with and without two contaminants

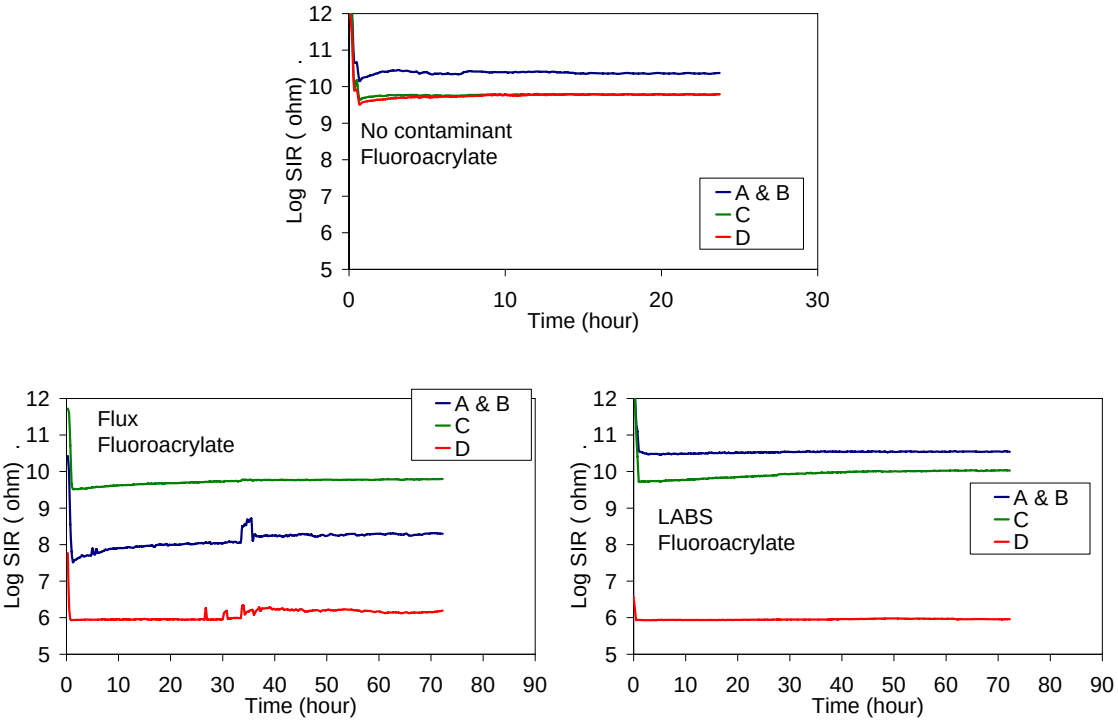



**Figure 36.** SIR plots from TB70 normal assembly with **fluoroacrylate** coating with and without two contaminants

The SIR performances for the high stand-off assemblies protected with water-based acrylic(1) or epoxy coatings are presented in Figures 37 and 38. The effects on overall SIR behaviours of two contaminants and different coatings are summarised and compared in Figures 39 and 40. A similar comparison between the results from normal and high assemblies for two contaminants is given in Figure 41. Finally, the effect on SIR performance of two contaminants on thick SIR pattern (140µm copper) are compared with those from a normal SIR pattern (17µm copper) in Figure 42.

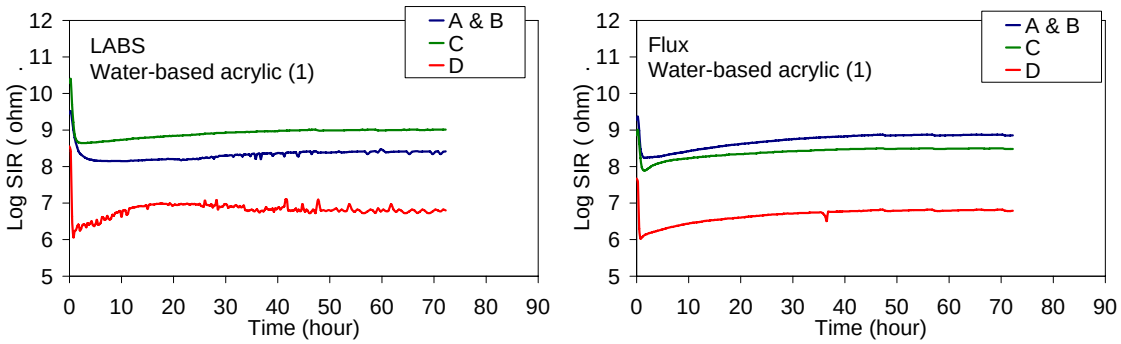



**Figure 37.** SIR plots from of TB70 high assembly with water-based acrylic (1) coating with and without two contaminants

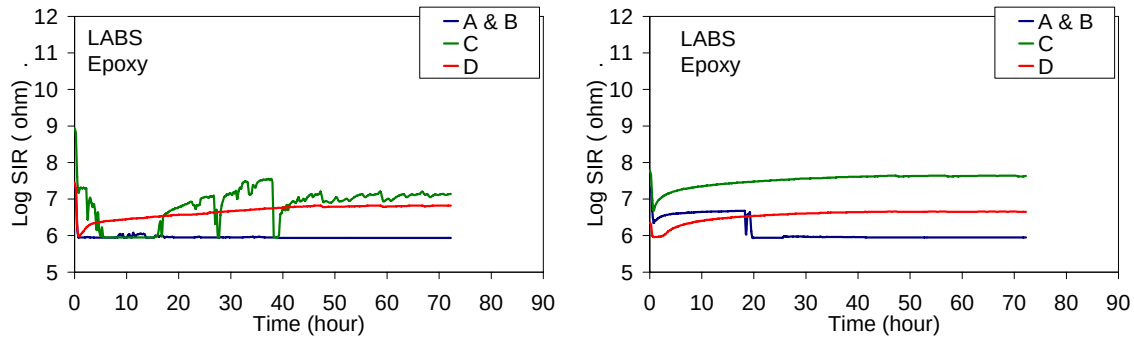



**Figure 38.** SIR plots from TB70 high assembly with epoxy coating with and without two contaminants

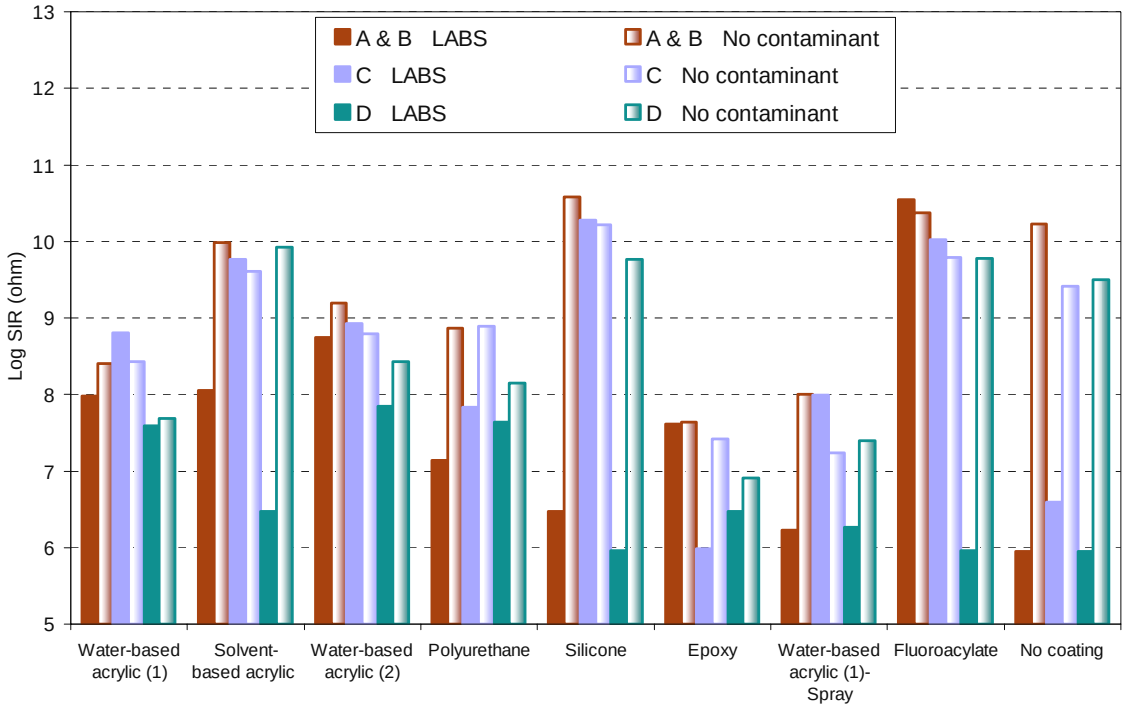



**Figure 39.** Summarised SIR values using TB70 with different conformal coatings and contaminated with LABS

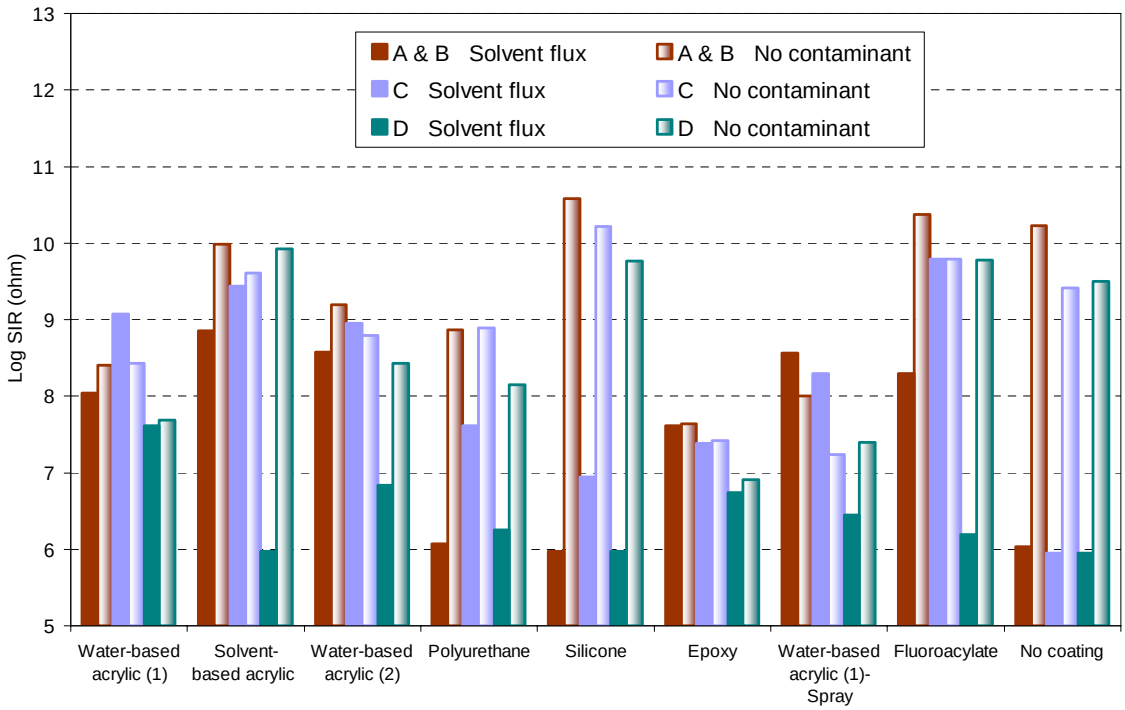



**Figure 40.** Summarised SIR values of different conformal coatings contaminated with flux

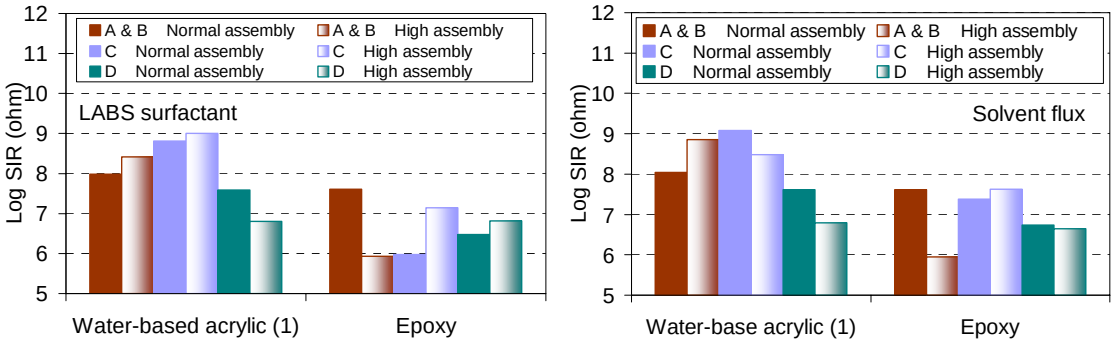



**Figure 41.** Comparison of overall SIR values of normal and high stand-off components on TB70

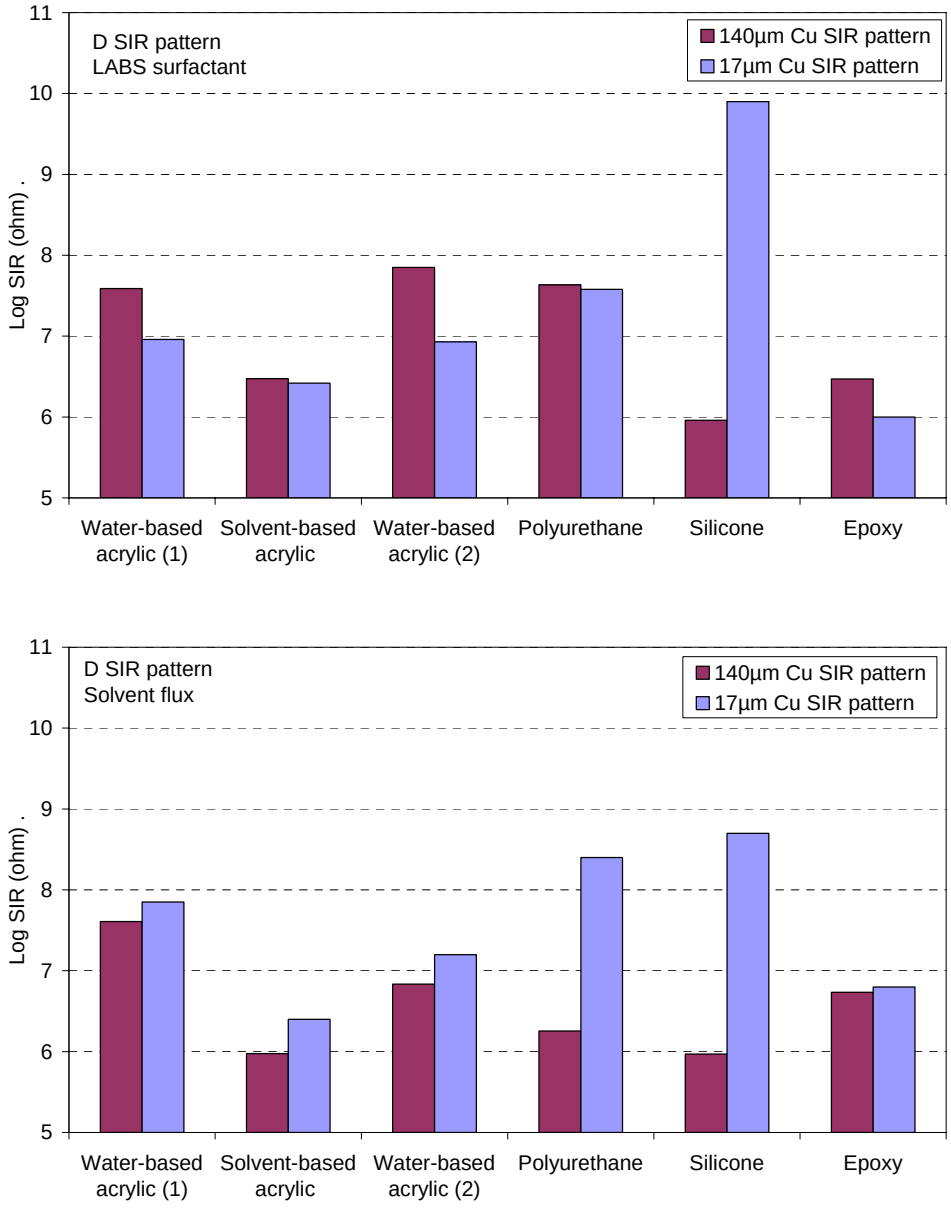



**Figure 42.** Comparison of overall SIR values with SIR patterns of different thickness

### 3.5.1 Coating of Thick SIR (D) Patterns on TB70

There are some interesting points to note from these results. For both contaminants (LABS and flux) as shown in Figures 39 and 40, the protection afforded by all the coatings was not full, leading to significantly reduced SIR values. Even the silicone and polyurethane coatings did not perform well in this test - normally these two coatings produce high SIR results on patterns made with 17µm copper, as shown in Figure 42. The poorer SIR results from assemblies having thick copper pads (D) can be attributed to a thinner coating, compared to that on TB67, for example see Figures 23 and 27.

On TB70 it is interesting that there is a large mount of coating between the tracks. The SIR test boards were inspected on a microscope using a backlight, and some examples are shown in Figure 43. It can be seen that, on uncoated boards, the corrosion was initiated at the bottom of the metal track, and dendrites formed on top of the FR4 laminate. However, on coated boards, the corrosion was initiated from the top edge of the metal tracks, and the dendrite formed on top of the coating. This confirms that the *corrosion always initiates from the thinnest point of the coating, and hence the uniformity of the coating is very important in achieving good protection*.

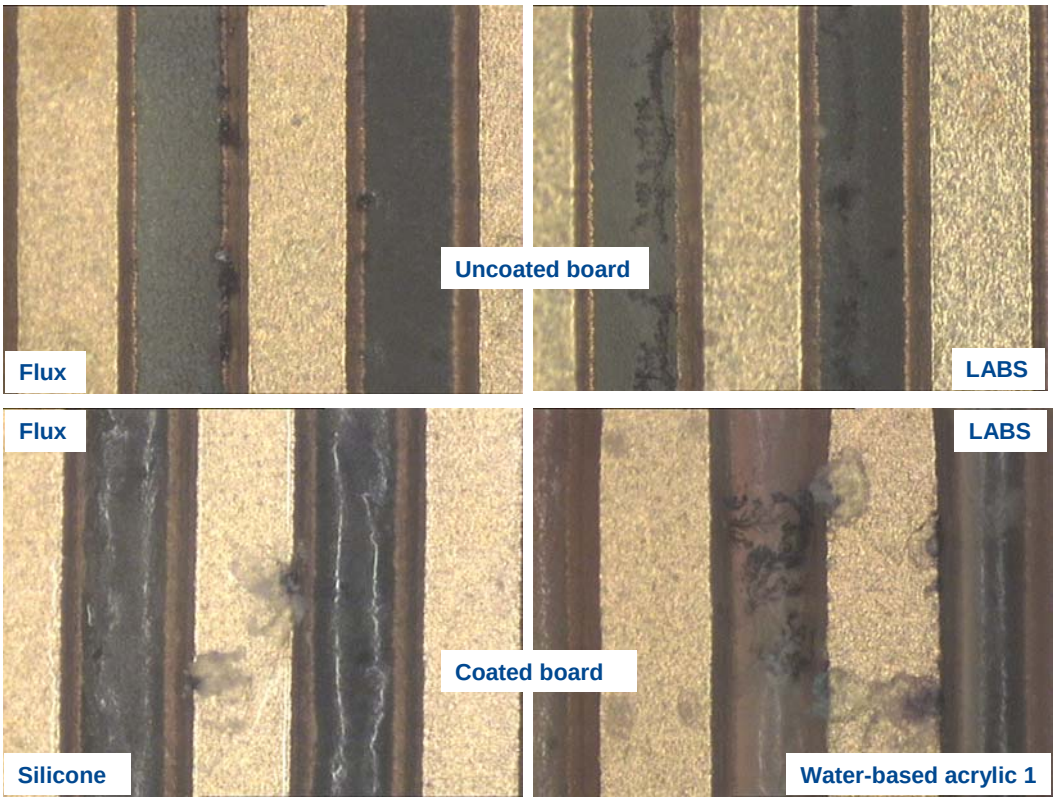



**Figure 43.** Dendrites formed on coated and uncoated TB70 boards

### 3.5.2 Coating Performance with Components on TB70

In Figures 26 and 27 the coating thickness was observed to be relatively thin and only partially covered the SIR patterns A, B and C. However, the SIR results are relatively high for these patterns suggesting good coating protection. These high SIR results may due to a "dam" effect formed by the coating, surrounding the BGA component, and blocking the ingress of the contaminants. This suggests that the SIR patterns under the components are protected by the coatings via two mechanisms. First, the coatings cover the SIR pattern and directly protect it from contaminants, and second, the coating can form a dam around the component preventing contaminants diffusing under the component.

Evidence of the coverage effect can be found by comparing the coverage charts in Figures 25 and 26 with the SIR results in Figure 41. Comparing the A and B patterns for the normal and high stand-off patterns, the epoxy coating only partially covers the high stand-off pattern and the SIR is correspondingly low. For the normal stand-off the coverage is complete and the SIR is correspondingly high. This correlation of complete coverage and higher SIR is similarly apparent with the water-based acrylic (1).

The impact of the penetration effect can be seen by comparing the results from the A and B patterns with that of the C patterns, where typically, higher SIR values are achieved with the C pattern due to the increased difficulty of contaminant penetration. The penetration of contaminants is complex, and depends on many factors such as the coating material, the gap under the component, the component size, the contaminant volume and the wetting ability of the contaminant over the coating. The results from the SIR patterns under components, reflect the ability of the contaminant to penetrate under the component, and this dominates over the permeation of the contaminant through the coating.

## 4 CONCLUSIONS

Conformal coatings are often used in electronic assemblies to afford protection to the underlying circuits, especially when the latter are to be used in aggressive environments. However, manufacturers provide relatively little information on how their products perform under various environmental conditions. Hence this NPL-industry collaborative study was aimed at generating some data regarding the protection performance of seven coating materials against contaminations selected as representing harsh environments (i.e. sea water; acid rain; surfactants; de-icing fluids; hydraulic fluids; fluxes).

Specially designed test vehicles were assembled and coated, and then subjected to exposure to the contaminants under high temperature/high humidity conditioning. The levels of protection given by the coatings were assessed using SIR testing, a technique which essentially monitors any leakage currents at the substrate interface associated with, and generated by, the presence of the contaminants and any lack of coating integrity. The salient conclusion from this study are:

- The protection by conformal coatings is dependent on coating chemistry and the ability to form a uniform coverage. Hence the uniformity of the coating is very

important in achieving good circuit protection. If the coating is thinner than a critical thickness (probably less than 5μm) then corrosion can initiate at this site. If corrosion occurs on the top of the metal track then dendritic growth can occur on top of the coating.

- Dip-applied coatings can form a dam around components, which can act as a physical barrier to prevent contaminants migrating under the components.

- A summary ranking was established *for these tests* in terms of the overall protection performance for the tested coatings with all the selected contaminants:

  silicone > polyurethane > solvent-based acrylic > water-based acrylic (1) > water-based acrylic (2) > epoxy.

- The poor performance of the epoxy material in this trial reflected the thinness of the coatings achieved on the test vehicles

- All the coatings failed to protect the electronic boards from hydraulic fluids, giving rise to coating blistering

- Damp heat testing is appropriate for evaluating the protection performance of the coatings. The recommended approach is to use the 85°C/85% RH with 50V bias test. If the effects are dramatic, then the environmental conditions can be relaxed to the 40°C/93% RH with 5V bias test. Using the two test conditions can be advantageous in discriminating coating performances

- The SIR test has proved very sensitive in detecting the breakdown of the coatings and the onset of any corrosion, and hence a good indication of the electrical reliability of the electronic assemblies.

- Visual inspection of coating coverage showed a good degree of correlation with the SIR results. Visual inspection may therefore be used in discriminating between coatings in terms of likely protection performance. But it should be emphasised that only the SIR technique is capable of providing information on the reliability of the underlying circuitry.

## 5 ACKNOWLEDGEMENTS

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# 6 REFERENCES


1 P-E Tegehall (1996) "*Evaluation of the capability of conformal coatings to prevent degradation of printed circuit assemblies in harsh environment, Part 2*" IVF Research publication 96807, The Swedish Institute of Production Engineering Research, IVF.

2 W.J Curren et al. "*Performance of conformal coatings in severe environments*", Paper No. 338 presented at Corrosion 87, NACE, Houston TX

3 "*Simulated acid rain test*" IPC-HDBK-830 October 2002 ISBN #1-580987-05-2 p66

4 S Ishikawa, M Taketomi, R Shinohara, R (1985) "*Determination of trialkyl and triaryl phosphates in environmental samples*" Water Research Vol. 19, No.1, p119-125.

5 A Mensah, C Hunt (2005) "*The role of permeability and ion transport in conformal coating protection*" NPL Report DEPC MPR 032

6 J. J. Licari (2003) "*Coating materials for electronic applications*" Noyes Publications ISBN: 0-8155-14921-1 p21