PROCESS AND MATERIALS INTERACTION INVESTIGATION: TEST METHODS FOR ELECTROCHEMICAL CONSISTENCY IN PCB ASSEMBLY PROCESSES - REVISITED

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ABSTRACT

There are several industry-accepted methods to determine the electrochemical reliability of electronic assemblies. These methods are typically designed to either simulate humid environments in accelerated lifetime testing, or assess the species of ionic residues present on surfaces. Some can be used to test prototypes or test boards, while some are more applicable for quality and consistency testing in a production environment. The increasing complexity of high-density assemblies, along with low standoff components, imposes greater associated challenges related to assessing electrochemical reliability. This has led to the development and adoption of new methods for testing ionic residues that can lead to electrochemical migration.

This paper will review traditional and emerging methods to characterize flux residues and cleanliness of finished assemblies, including surface insulation resistance, electrochemical migration, ROSE extraction, and other emerging test methods. Data will be shared to reveal how different methods can detect process variations in different ways, and compare the results.

With new revisions to IPC J-standard-001 and proposed changes to Section 8, the philosophy for ensuring assemblies are clean after a cleaning process has evolved. The way we look at the consistency of no-clean process residues for process control may also be evolving.

Key words: Surface insulation resistance, ionic contamination, cleanliness

INTRODUCTION

Many electronics applications have high requirements for the reliability and lifetime of the assemblies. As related to solder materials, this is typically understood to be the mechanical and thermal reliability of solder joints. The other side of this reliability coin is electrochemical reliability on the surface of the board, which is just as critical to product lifetime. This topic has been heating up as miniaturization moves connections closer together and evolution in component design creates new challenges for reliable assembly. The topic takes its form under many names, ionic cleanliness, electrochemical migration resistance, localized extraction, ionic contamination, to name a few.

When we dive into the true needs for surface reliability, it distills into investigation of the chosen process and materials, tested in combination to assess the interaction of these factors. Previous studies[1] have shown the importance for no-clean solder materials to have exposure to reasonable reflow conditions in order to be rendered benign. There may also be interaction between the solder mask and surface finishes chosen. In general, board and component quality can impact the final reliability of an assembly.

Taking all of this into account, Process and Materials Interaction Investigation (PMI[2]) is the essence of what is being pursued. Testing the reliability of new designs can be complicated because, typically, functional designs will not lend themselves to surface insulation resistance (SIR) testing. This is the best method to assess a circuit's resistance to the results of electrochemical migration: dendritic growth and current leakage.

Electrochemical migration is defined by the IPC as "the growth of conductive metal filaments on a printed wiring board under the influence of a DC voltage bias. This may occur at an external surface, an internal interface or through the bulk material of a composite. Growth of the metal filament is by electro-deposition from a solution containing metal ions which are dissolved from the anode, transported by the electric field and redeposited at the cathode." This failure mechanism is one that develops over time as the circuit reacts with materials in the assembly. When filaments grow within the board materials below the surface it is called conductive anodic filaments or CAF, which will not be discussed in this paper, but is also a contemporary hot topic. When electrochemical migration occurs on the surface of the board, it leads to dendritic growth between traces and is best tested using SIR.

The mechanism for electrochemical migration on the surface electronics assemblies relies on four factors to be present: copper, voltage, humidity, and ionic species. When humidity in the environment forms water droplets on a circuit board, the water is able to interact with any ionic species present on the surface to allow ions to move along the surface of the board. The ions interact with copper and are propelled to migrate between copper circuitry due to the voltage. This is typically summarized in a series of steps: water adsorption, anodic metal dissolution or ion generation, ion accumulation, ion migration to cathode, and metal dendritic growth[2].

When we consider the selection of industry standard test methods[3] in the context of the investigated mechanism, SIR testing arises as the most valid because the method mimics all four critical factors. Other methods characterize what is on the surface, but fall short of testing many factors and the resulting reliability.

Recent changes to industry standard requirements[4] have highlighted the importance of SIR to characterize surface reliability and increased the demand on PCBA suppliers to assess all new designs/processes. Objective evidence is necessary to support decisions related to design qualification, material choices, process optimization, and process control. IPC offers a straight-forward approach by testing the materials set and process using the B-52 test coupon, as shown in Figure 1. This coupon design includes many common component designs. One section is used for SIR testing and another section can be broken off to use for IC testing. Furthermore, testing can be carried out with the process control method of choice to allow clear correlation of process control limits directly to the process qualification testing.

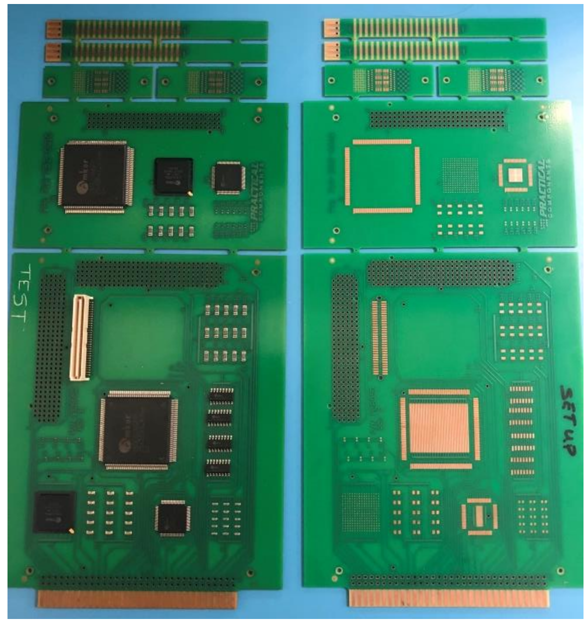


Figure 1: Populated and unpopulated B-52 test coupons

The test coupon preparation and test methods are clearly laid out in IPC-9202 and described in more detail in the IPC-9203 handbook[5]. It is important to realize the differences between this process qualification testing and flux classification. Many of the referenced test methods are the same, but flux classification is a more standardized method, focused on generating results to assure fluxes meet industry performance requirements. Due to this, flux classification is conducted on the B-24 board which has only exposed comb patterns and does not include surface finishes, solder masks, or components in its design.

To assess the reliability of a new assembly design, it is necessary to investigate the chosen process and materials in combination. This paper will discuss an experiment to use IPC-9203 and B-52 coupons to characterize a solder material and process with varied surface finishes.

EXPERIMENTAL DESIGN

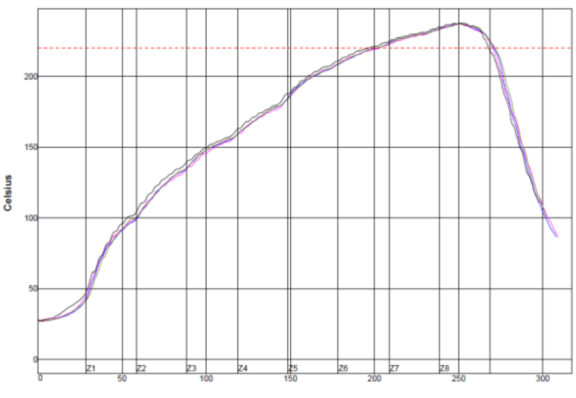
B-52 test boards were assembled using a ROL0, halogen-free, no-clean SAC305 solder paste. To simulate a process qualification, these boards were then subjected to testing as described in J-001 and IPC 9202/9203. One section of the coupon was used for testing in the SIR chamber according to IPC-TM-650 #2.6.3.7 for 1000 hours; another was tested with the resistivity of solvent extract (ROSE) test, the preferred process control method. The last was used for ion chromatography according to IPC-TM-650 #2.3.28.

The reflow profile developed for this study is shown in Figure 2. Boards were processed with copper OSP, immersion tin, and immersion silver finishes. Each set of boards was accompanied by a control coupon for each finish. Four assembled coupons were tested for each surface finish. All coupons were sent out to a third-party lab for testing. Full test results can be referenced in the Appendix.

Setpoints (Celsius)

Zone	1	2	3	4	5	6	7	8
Top	110	140	160	185	215	225	235	245
Bottom	110	140	160	185	215	225	235	245

Conveyor Speed (inch/min): 26.0

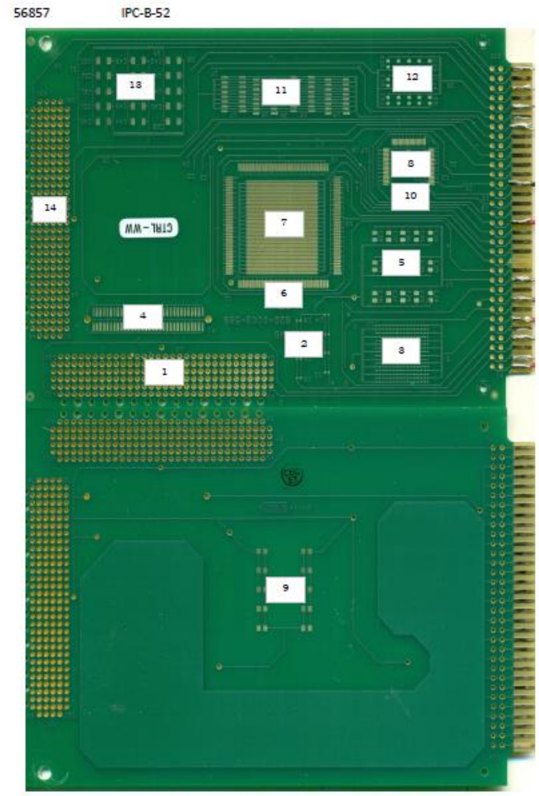


PWI= 62%	Max Rising Slope		Reflow Time /220C		Peak Temp		Ramp- 25C to peak	
<TC2>	1.99	33%	67.74	-45%	237.11	6%	0.85	-52%
<TC3>	2.00	33%	70.00	0%	237.73	36%	0.84	-58%
<TC4>	2.04	36%	72.24	45%	237.73	36%	0.84	-62%
<TC5>	2.00	33%	71.51	30%	237.89	45%	0.85	-53%
Delta	0.05		4.50		0.78		0.01	

Figure 2. Reflow profile for SAC305 solder paste

RESULTS

SIR results were reported with one chart per board. The test was carried out at 40°C and 90%RH for 1000 hours. Resistance measurements were taken every 20 minutes to closely monitor all of the designed channels to ensure all readings were above 10^8 Ohms. Figure 3 shows how the board was separated into different sections to allow non-compliant results to be tracked. After the boards were finished in the chamber, optical inspection was carried out to visually assess discoloration or evidence of dendritic growth.



STOCK IMAGE USED TO SHOW SAMPLING LOCATIONS, NOT OF ACTUAL BOARDS TESTED

Figure 3. Indicates the numbering system for each pattern or component style on each board and correlates to channels in SIR results

Based on previous testing, it was expected that all of the coupons would pass. The profile tested was well within the process window and the solder paste tested is known to be highly reliable. The typical results expected would look similar to Figure 4.

Testing resulted in several coupons with readings below the required 10^8 Ohms, as shown in Figure 5. A failing result needs further investigation to track down the source of the failure. Figure 6 shows that the results of the control were not acceptable.

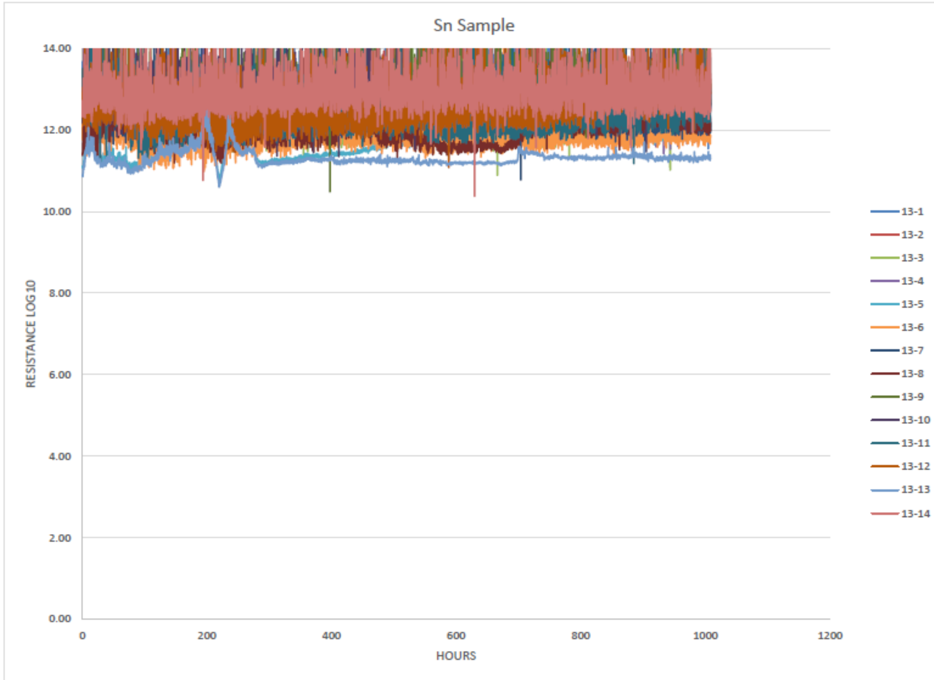


Figure 4. Example of typical SIR results for one test board

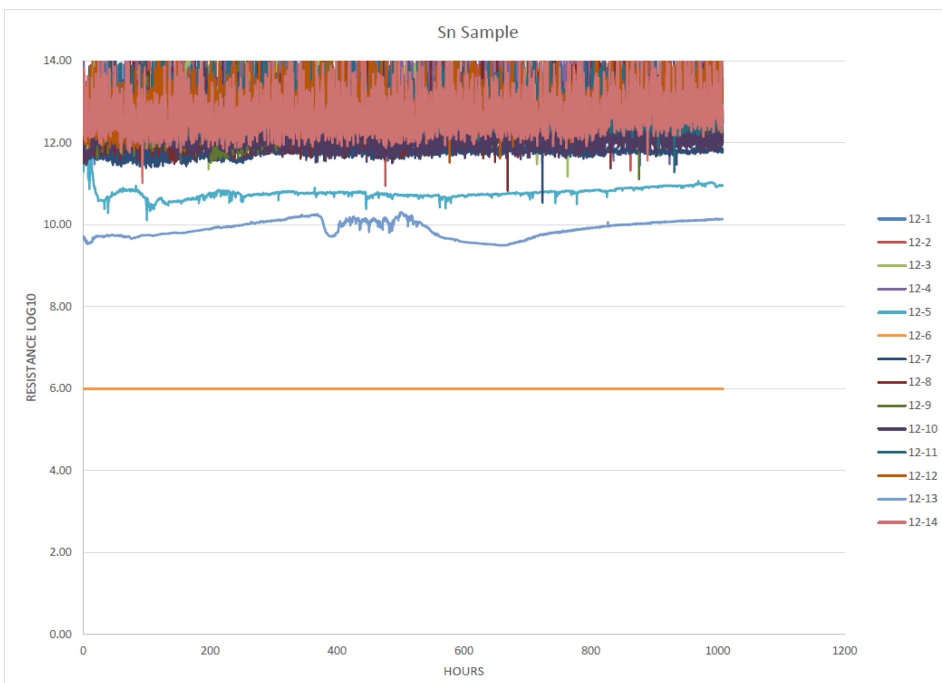


Figure5. Immersion Sn sample 12 SIR with one channel below the resistance limit

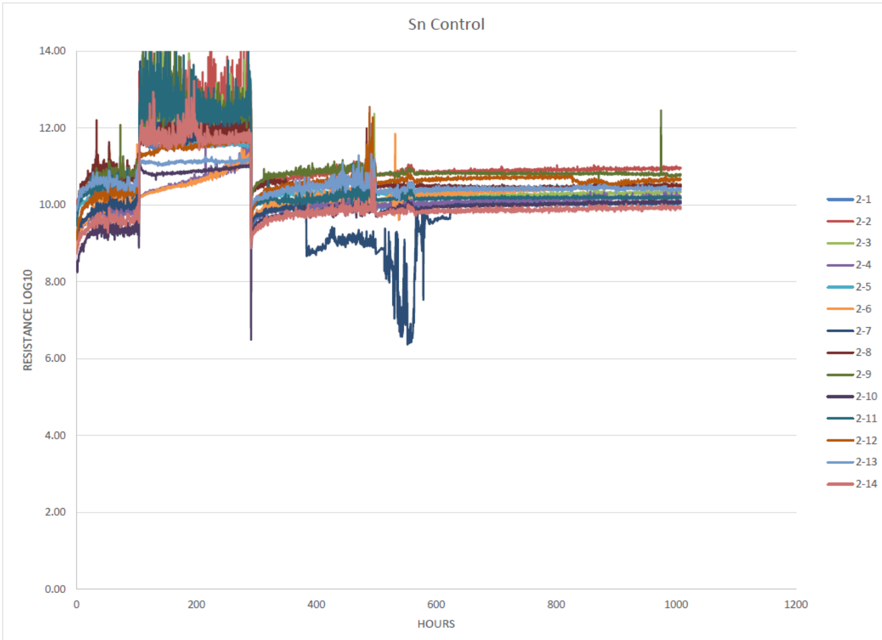


Figure 6. Immersion Sn control SIR results

Further investigation into the appearance of the coupons after testing clearly showed a bridge between IOs on the questionable test area, as shown in Figure 7. While inspecting the control coupon, evidence of some interaction in the same area was found.

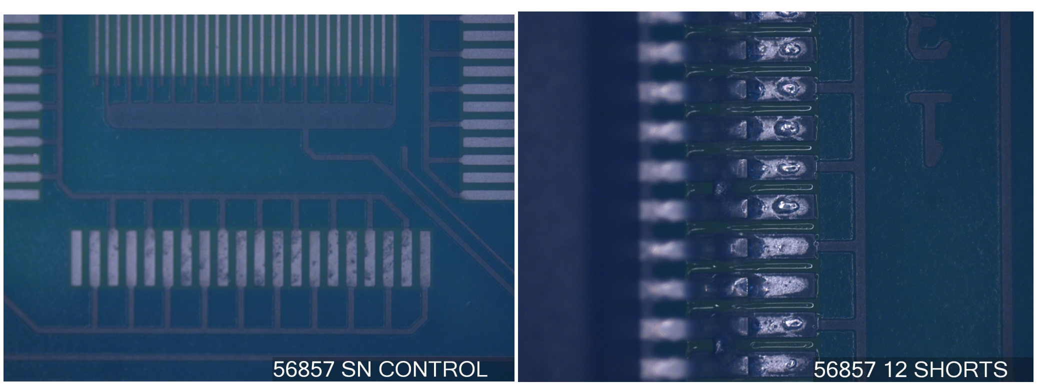


Figure 7. Visual inspection of the area labelled 6 on post-SIR-testing coupons, on the control and on board 12

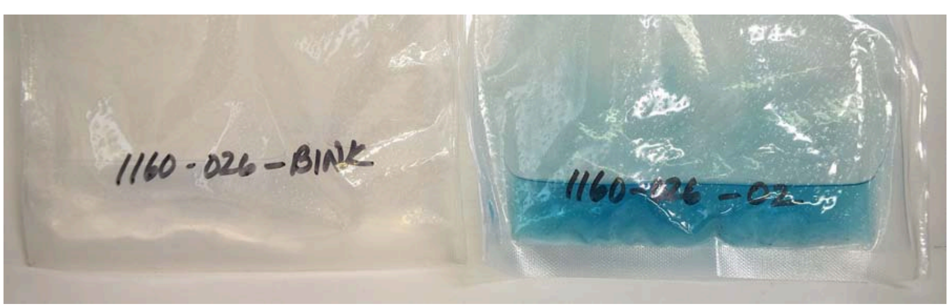


Figure 8. IC extraction bags showing a color change for the extract from the immersion Sn control coupon

ROSE and IC testing were both performed in parallel. Since there are no pass/fail criteria for these tests, it is difficult to say whether the results were within expectations. The IC report showed an interesting finding (Figure 8). The extraction solution had turned blue for the Immersion Sn control. Typically the solution would stay clear. This is hypothesized to be the result of color being extracted from the under-cured solder mask.

Since these results did not achieve results within the SIR requirement, the testing must be repeated. The next iteration will use an alternative board vendor. In addition, preparation will proceed with greater care for coupon cleanliness and incoming materials inspection.

CONCLUSIONS

Process qualification is critical to ensure a reliable end product. Since the testing includes SIR on a test board with components, along with process control methods and IC to characterize any suspicious ionic species, it is an efficient way to tie reliability testing to an everyday process control plan. The inclusion of all material selections including solder mask, surface finish, and solder materials, along with processing aligned with a true production environment yields results that mimic true assemblies as closely as possible.

In order to be successful in characterizing a new process and design, the test method details are critical. Board fabrication, test coupon preparation, solder application, and reflow profiling are all critical to achieving accurate results.

Although the experiment discussed in this paper did not yield passing results, meaningful lessons can be taken away. Ongoing testing will be conducted with a high level of attention to detail to procedures and incoming board inspections. Most importantly, additional work will be done to identify board materials that will standardize the test, enabling use for future solder material performance comparisons and process window characterization.

REFERENCES

[1] Sandy-Smith B., Munson T., Understanding the Effect of Different Heating Cycles on Post-Soldering Flux Residues and the Impact on Electrical Performance, IPC APEX February 2017.

[2] Yang S., Wu J., et al. Initial Stage of Silver Electrochemical Migration Degradation. 2006.

[3] Sandy-Smith B., Investigating Test Methods for Electrochemical Consistency in PCB Assembly Processes, SMTA Pan-Pac 2017.

[4] J-STD-001G, Requirements for Soldered Electrical and Electronic Assemblies, October 2017.

[5] IPC-9203, Users Guide to IPC-9202 and the IPC-B-52 Standard Test Vehicle May 2012.

APPENDIX: SIR test results

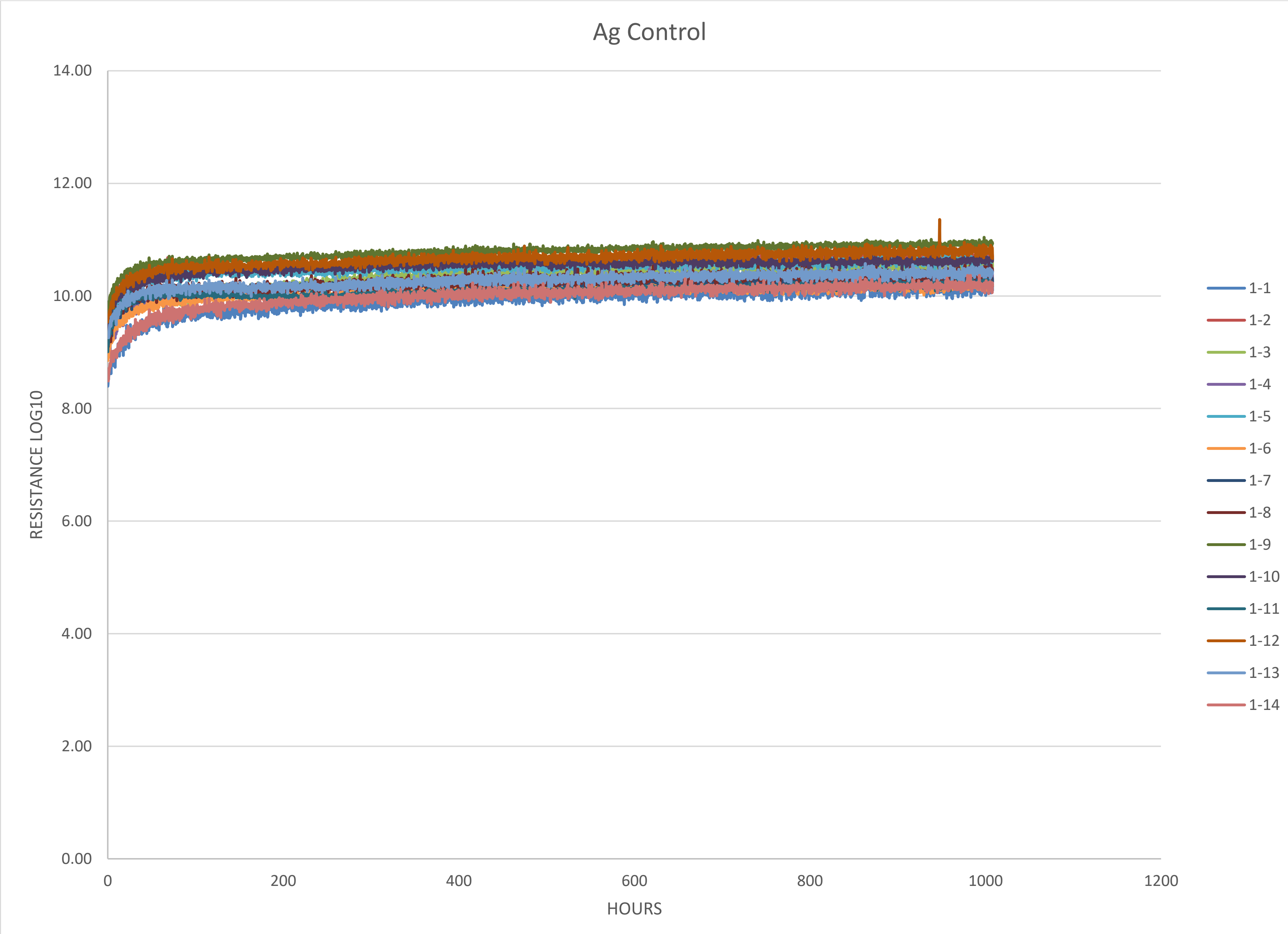
Robisan Laboratory # **56857**

Test Method	Short Description	Performed By	Date	Equipment Used
IPC-TM-650 2.6.3.7	SIR Testing	ms	5/4-6/15/18	27,92
	Wiring of samples for SIR	ms	5/3/2018	11,15

Master equipment listing available upon request.

SAMPLE TEST MATRIX

Board	Sample name
1	Ag Control
2	Sn Control
3	Cu Control
4-8	Ag Sample
9-13	Sn Sample
14-18	Cu Sample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10.00
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HOURS
1-1
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Sn Control
RESISTANCE LOG10
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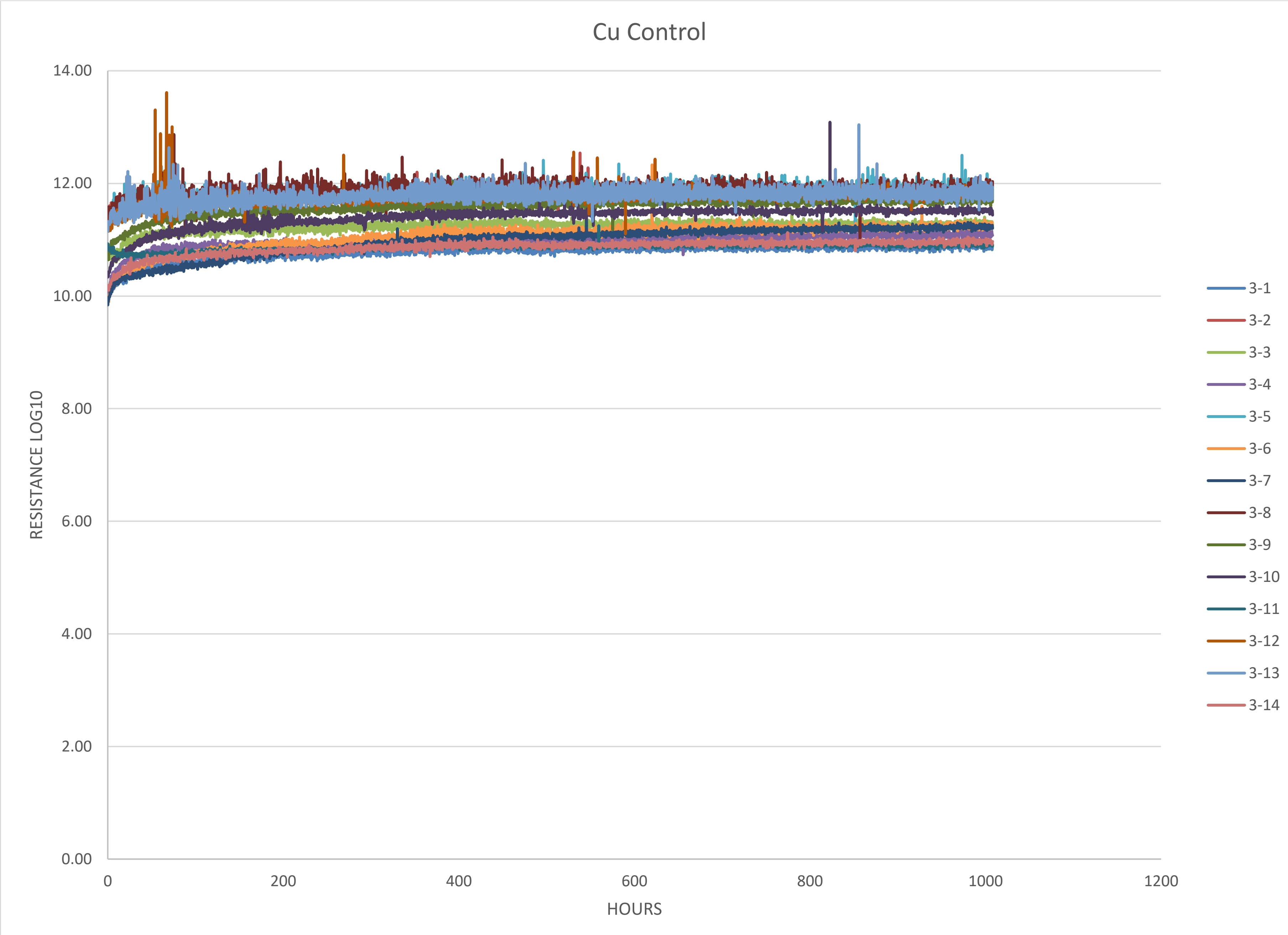
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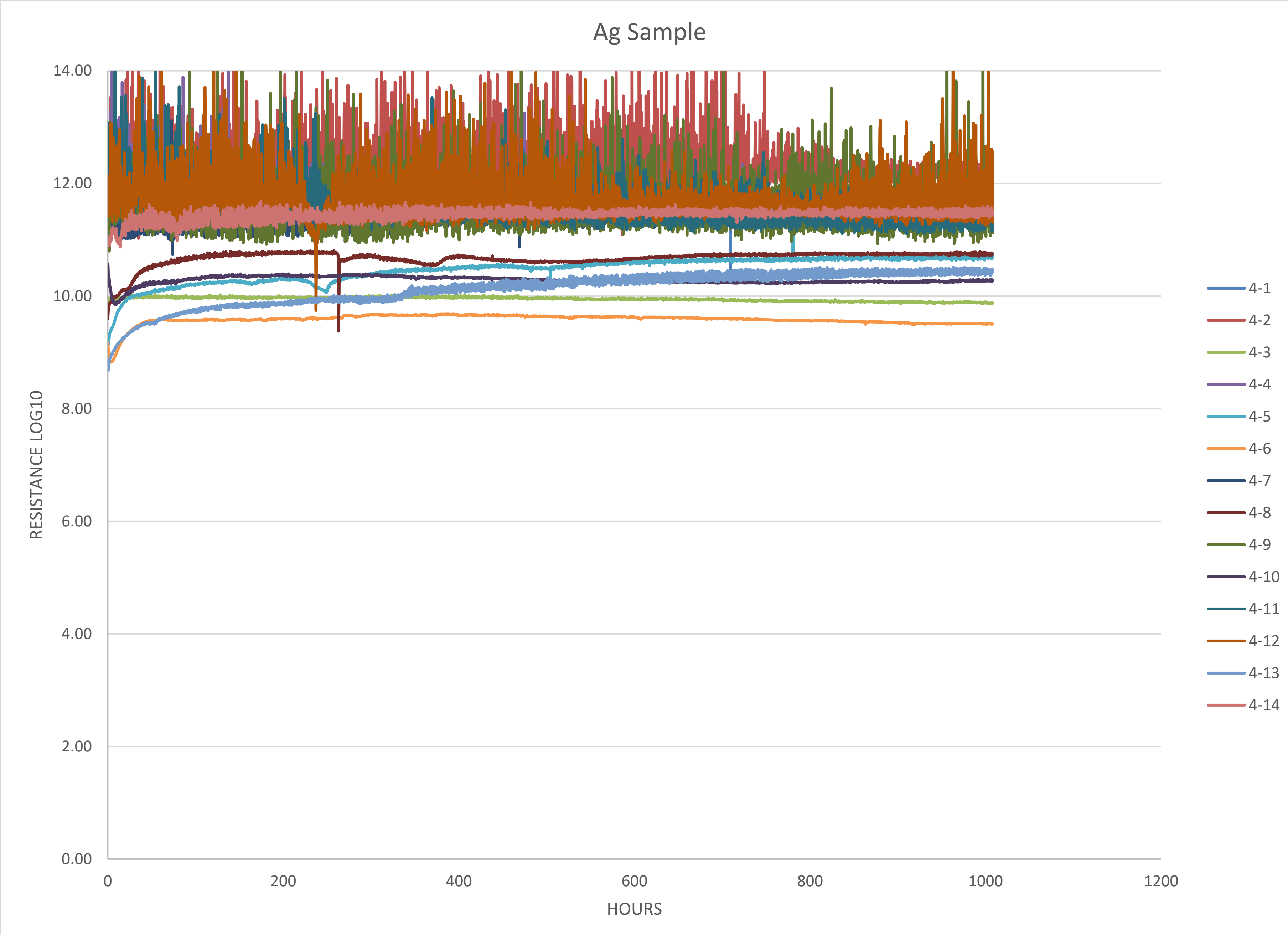
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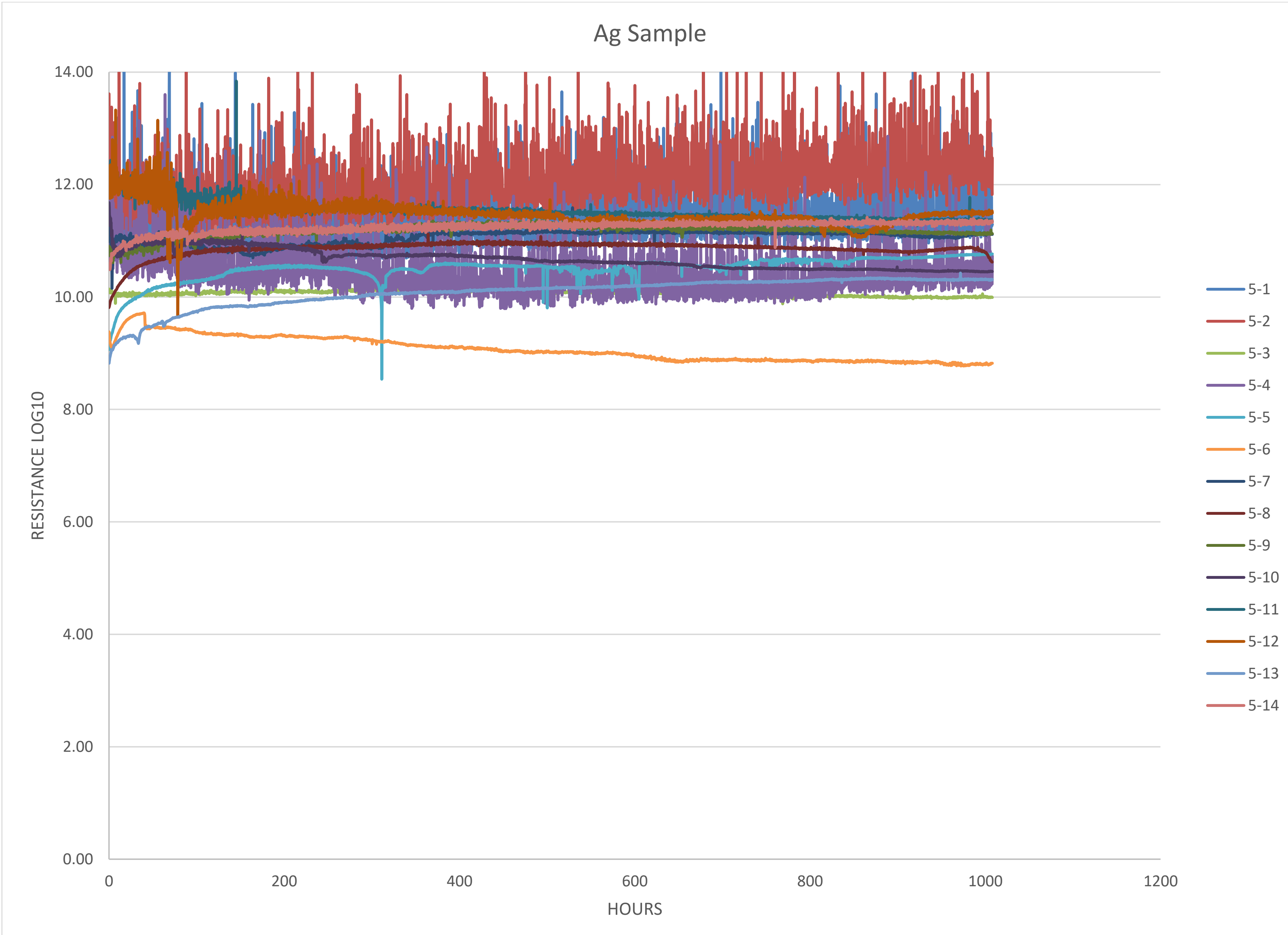
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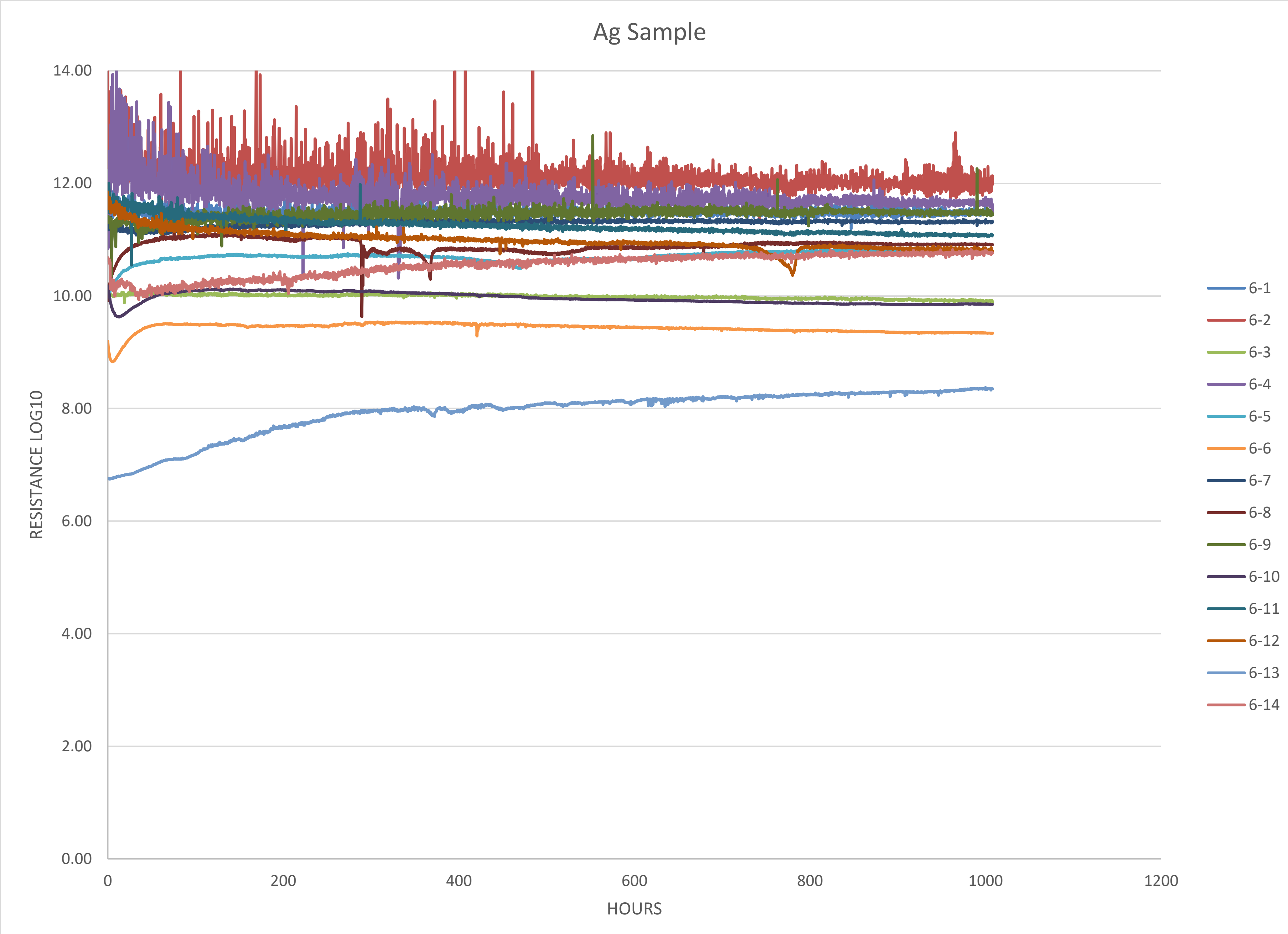
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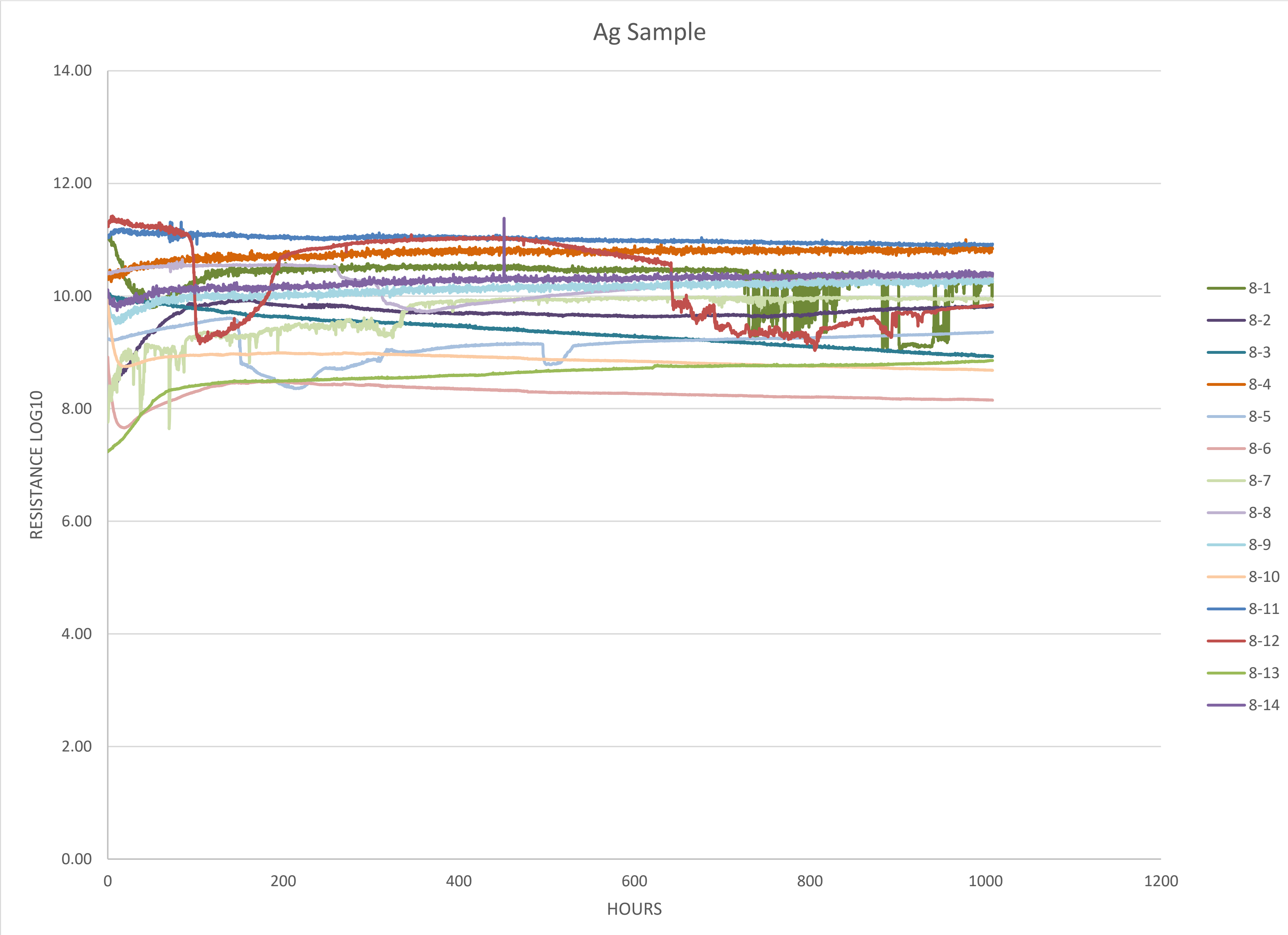
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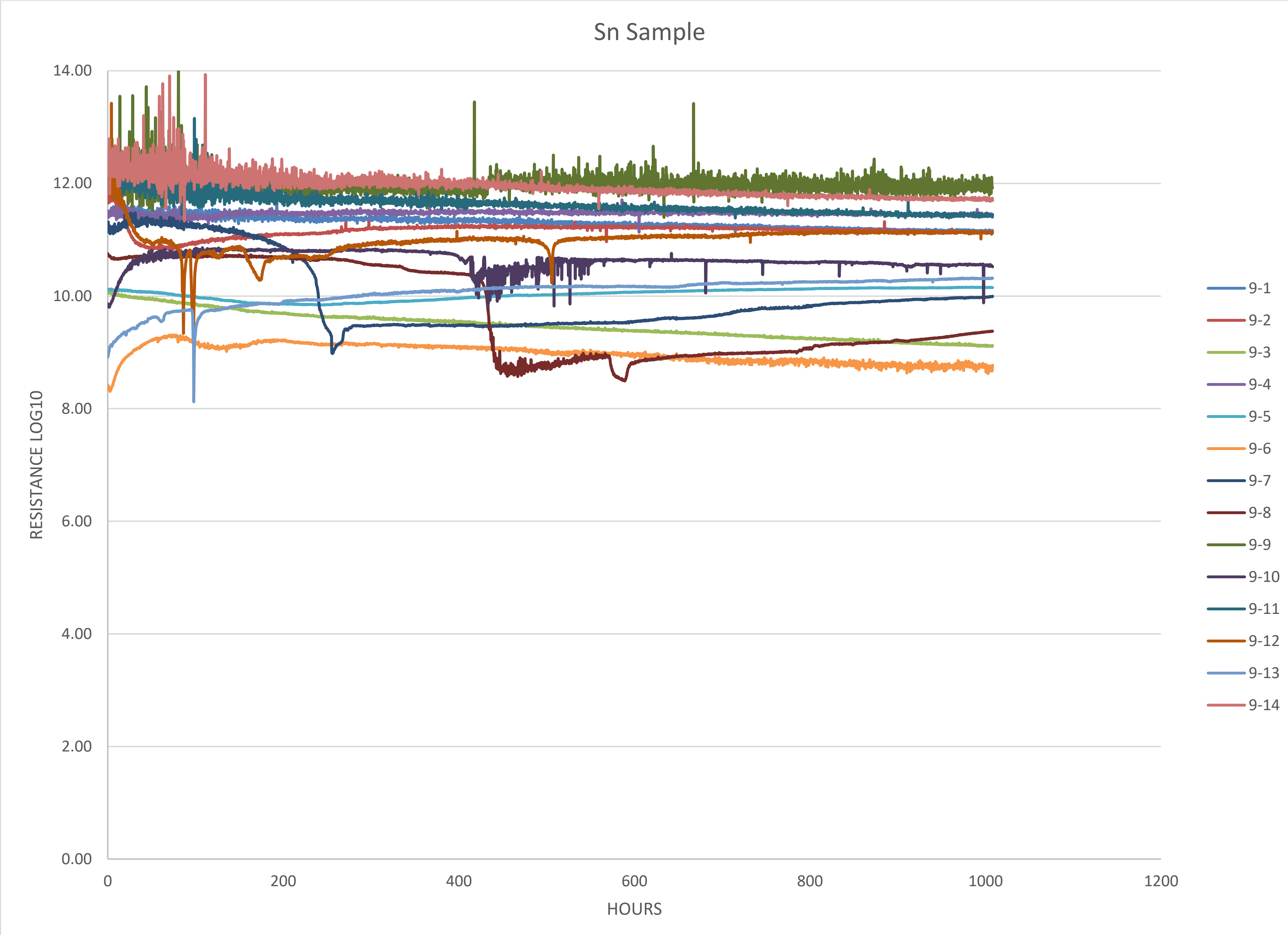

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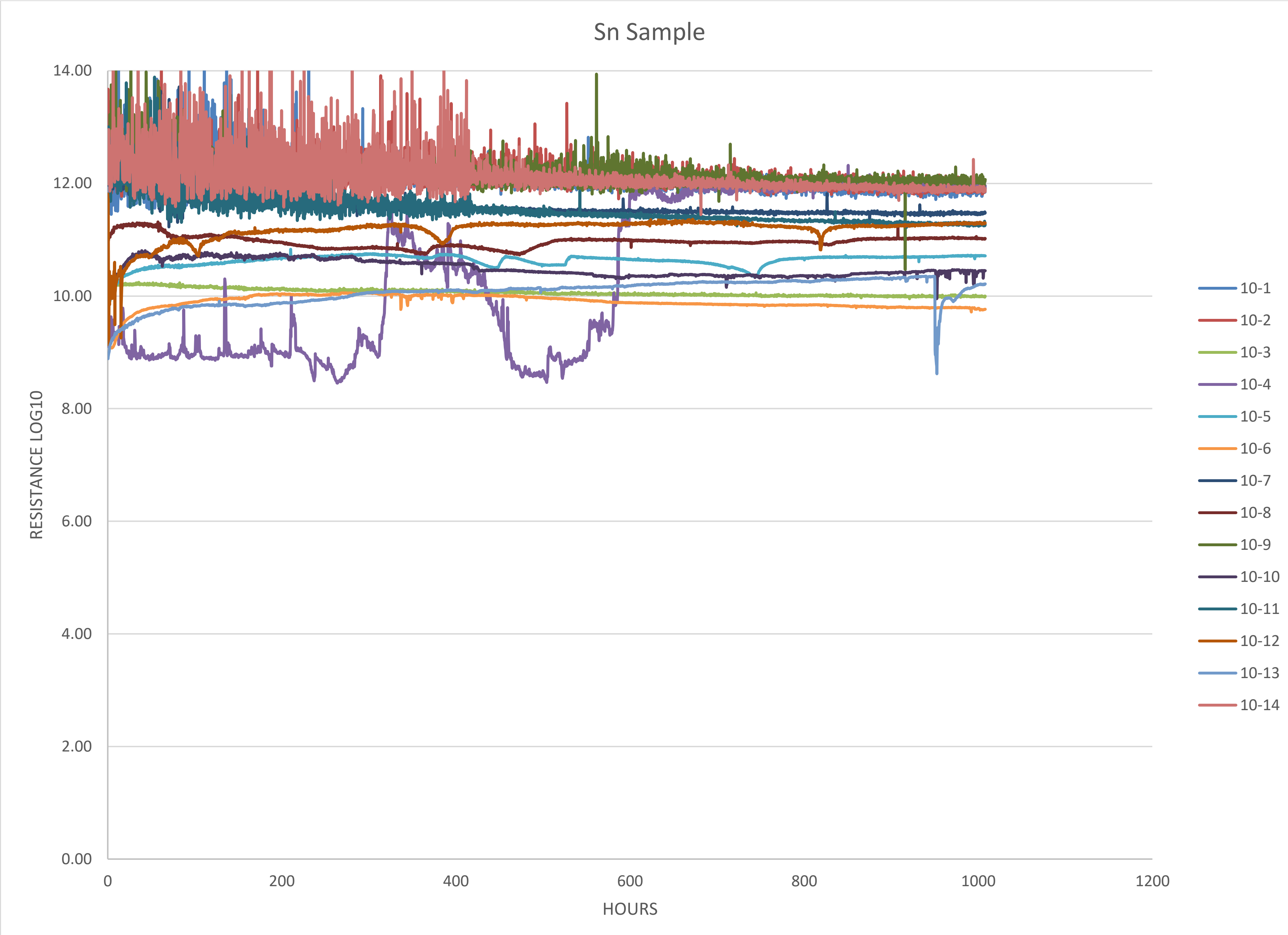
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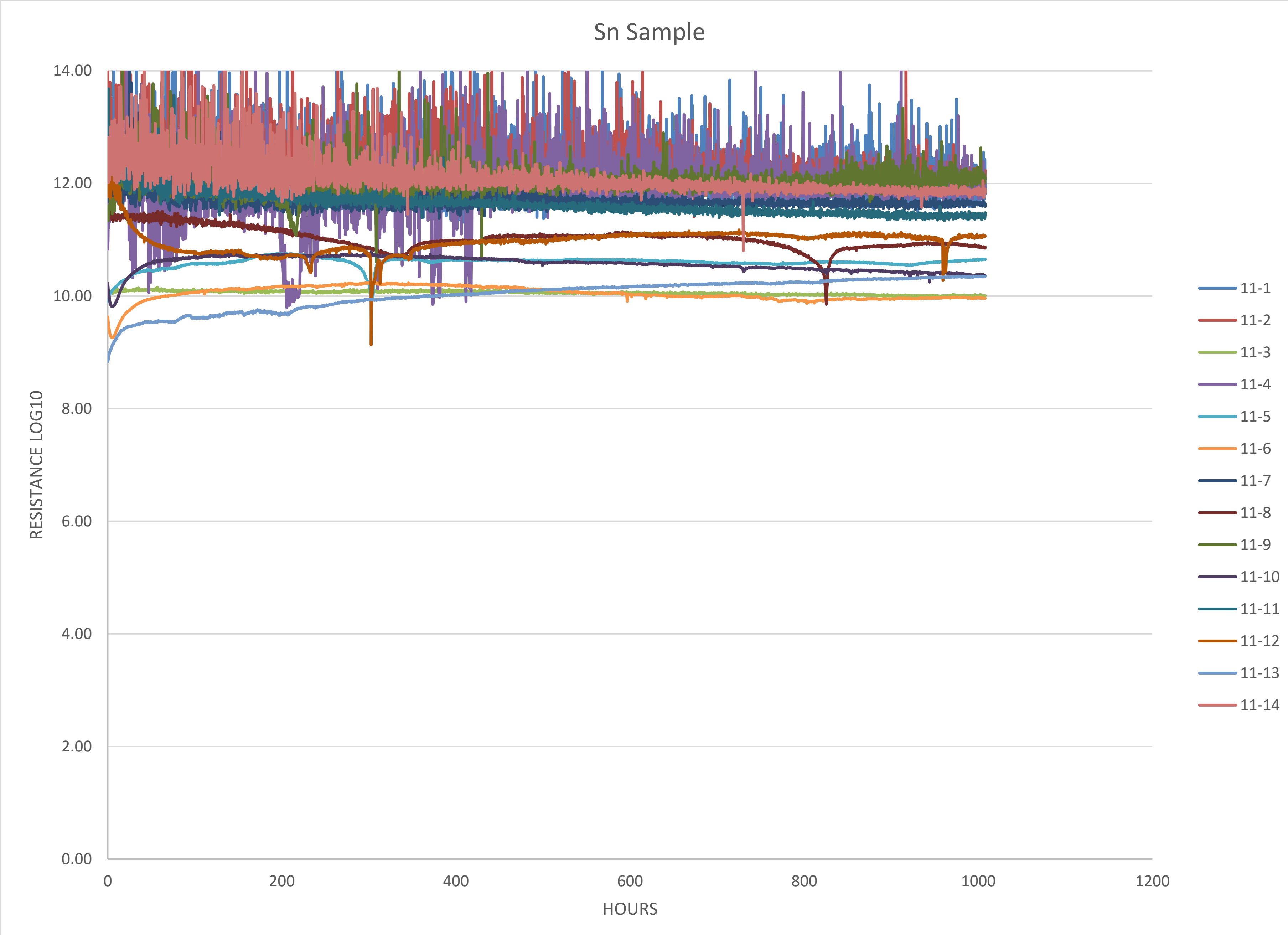
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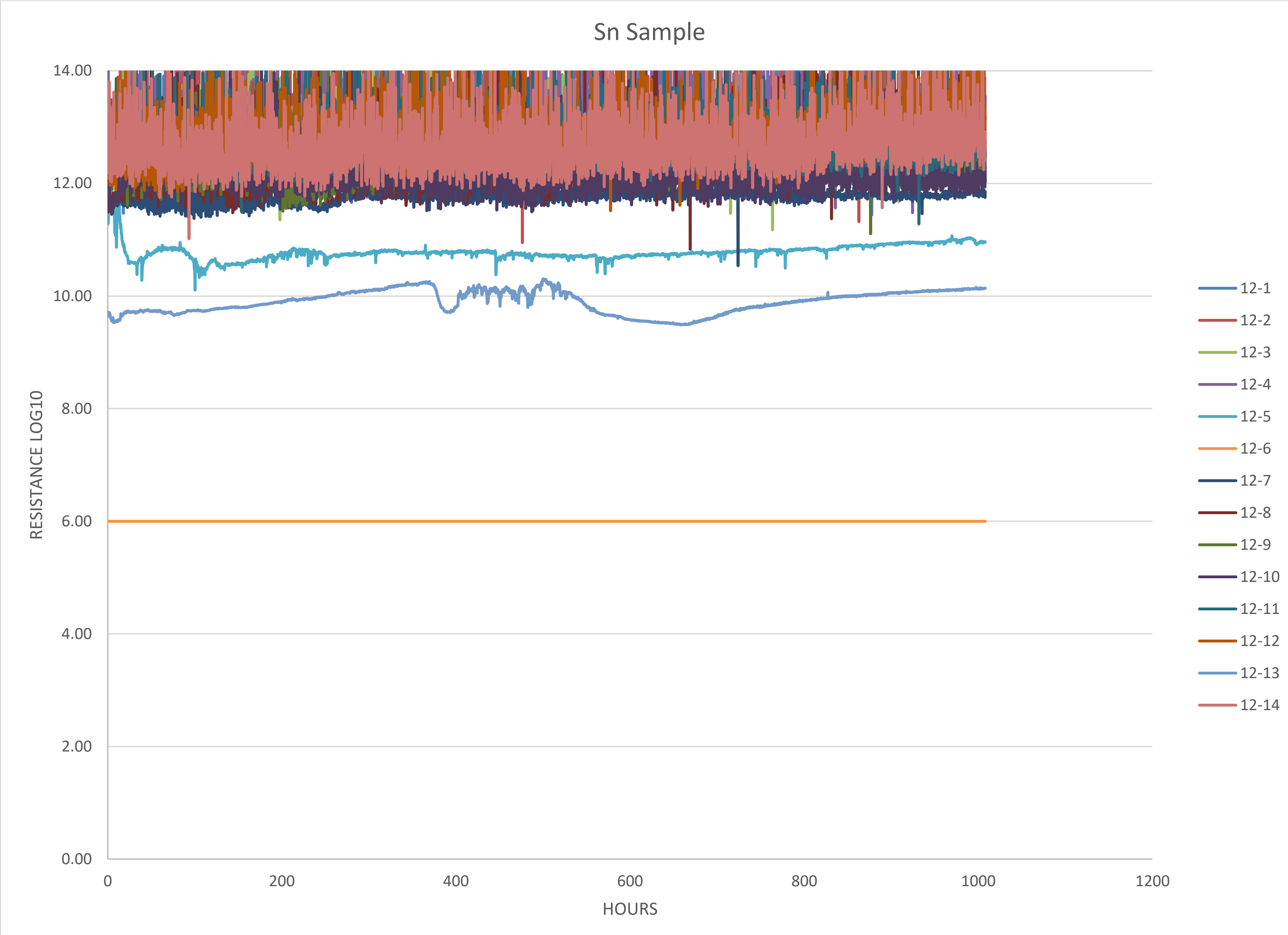
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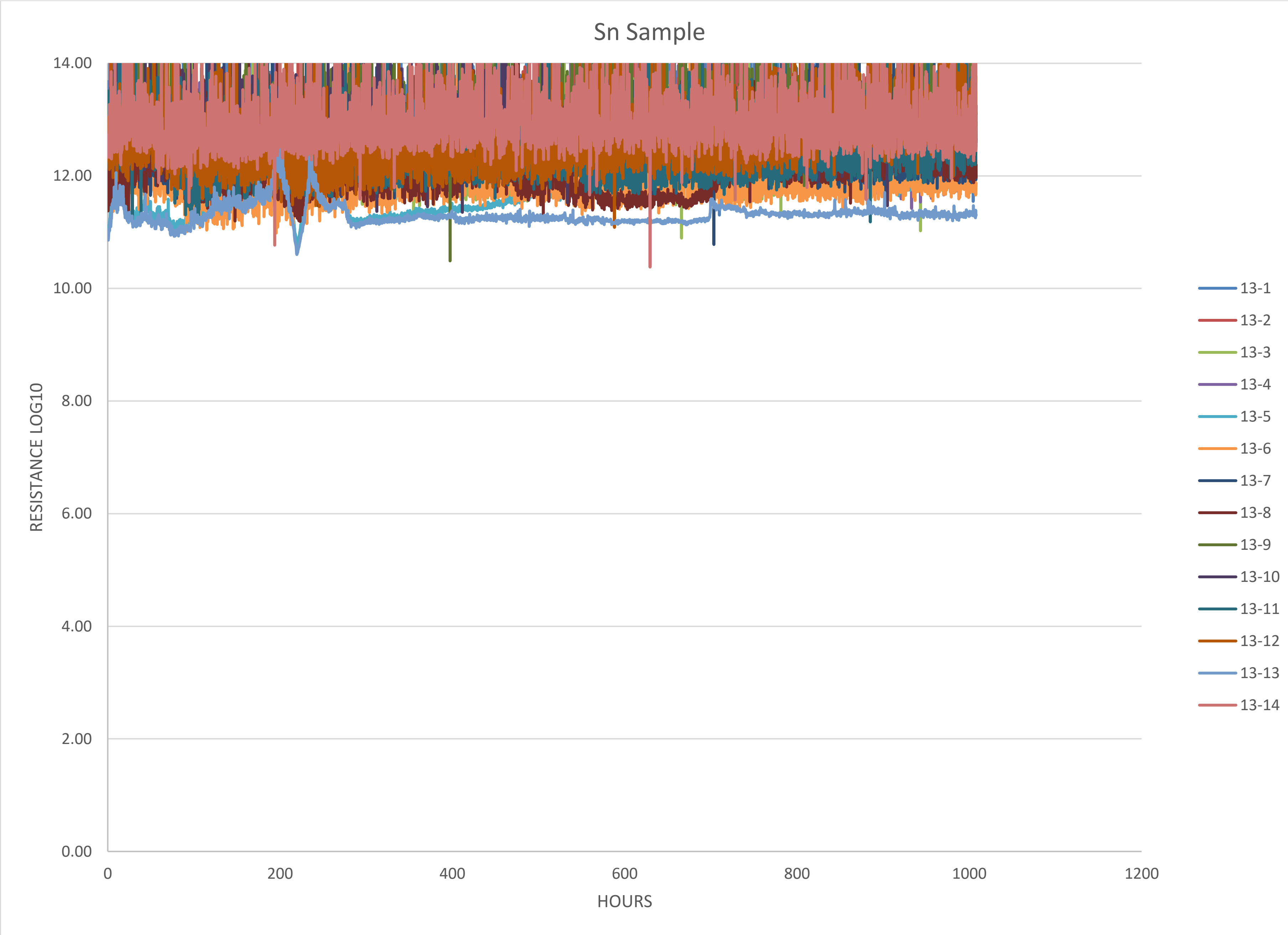
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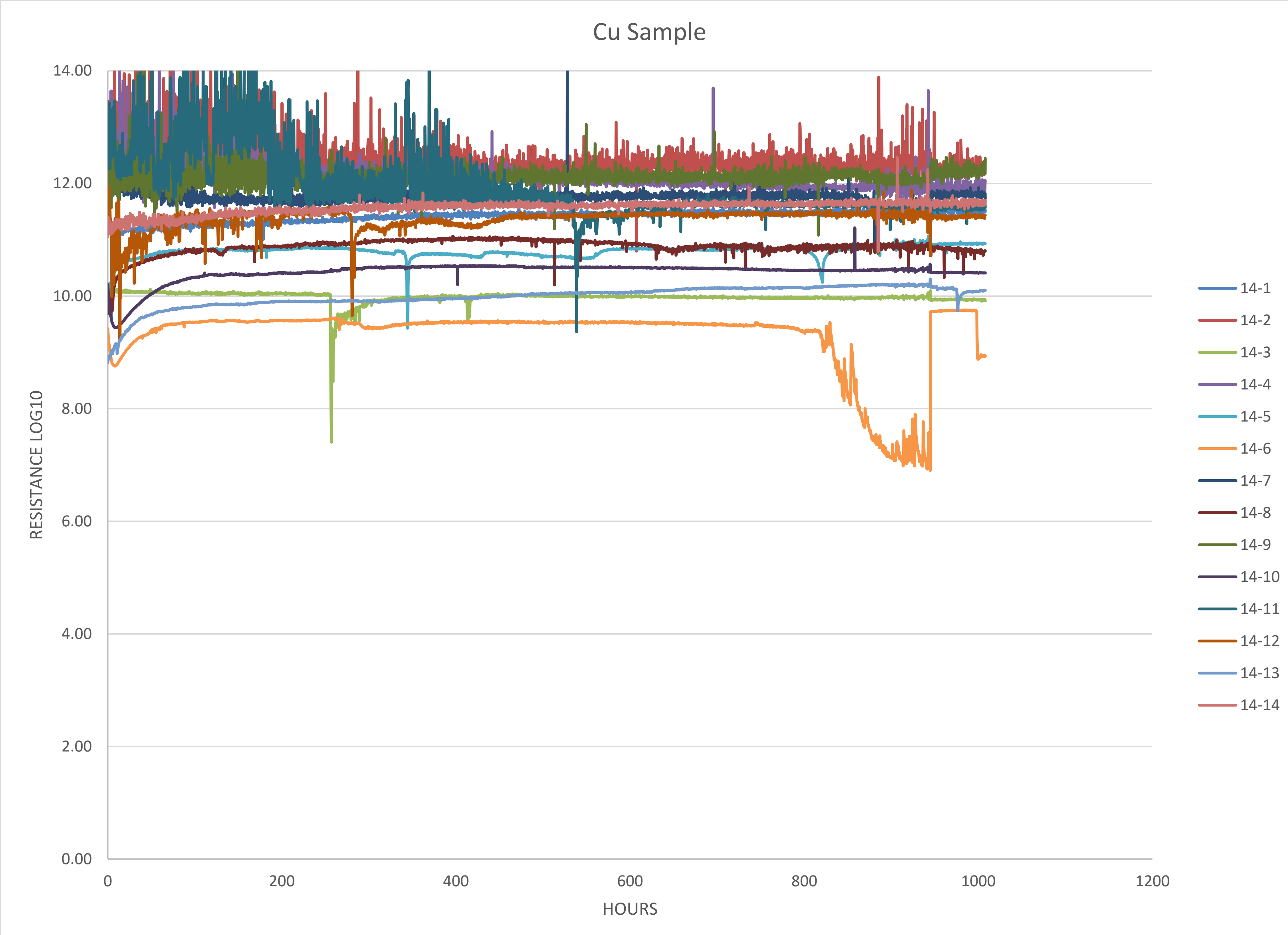
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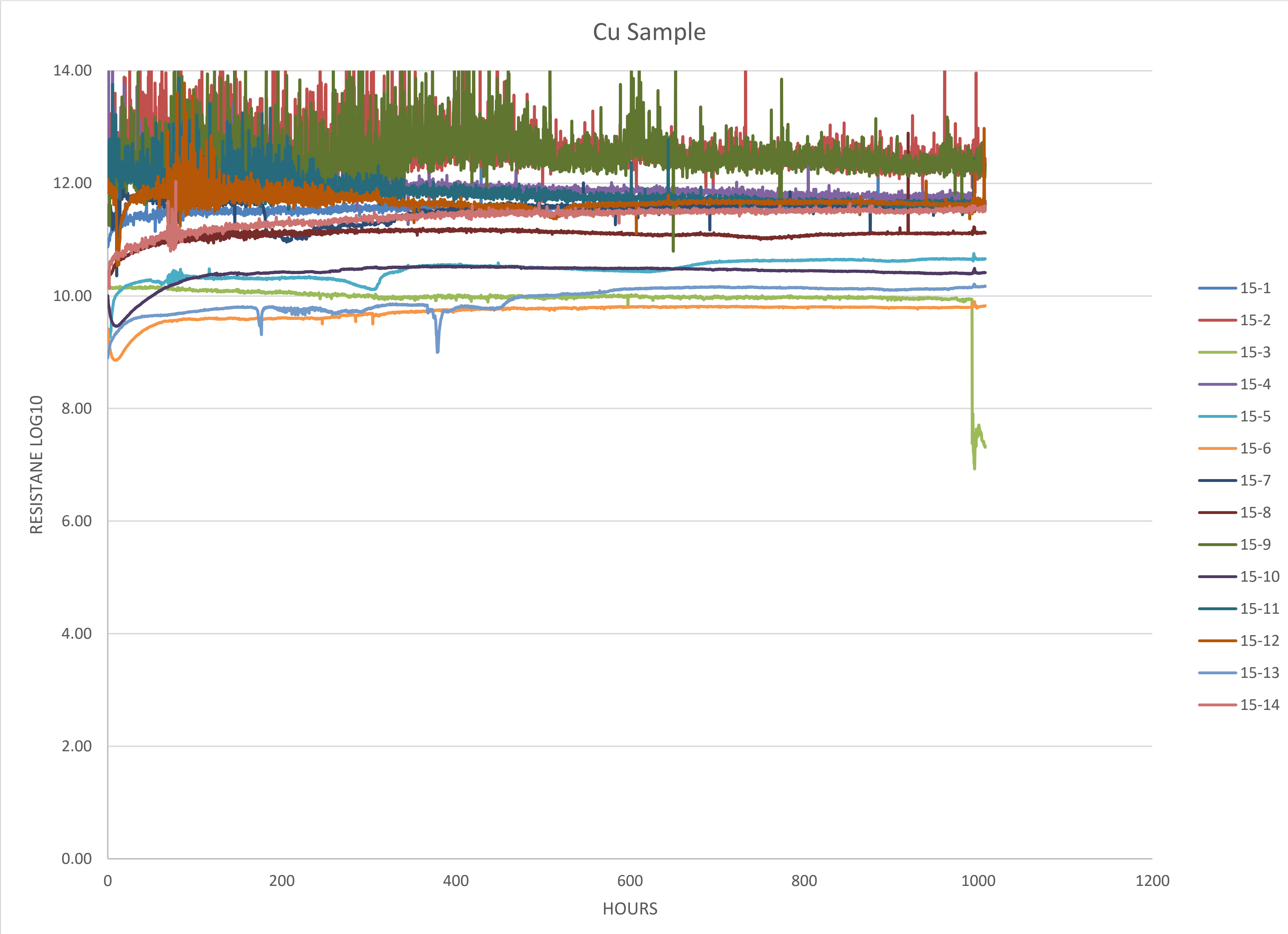
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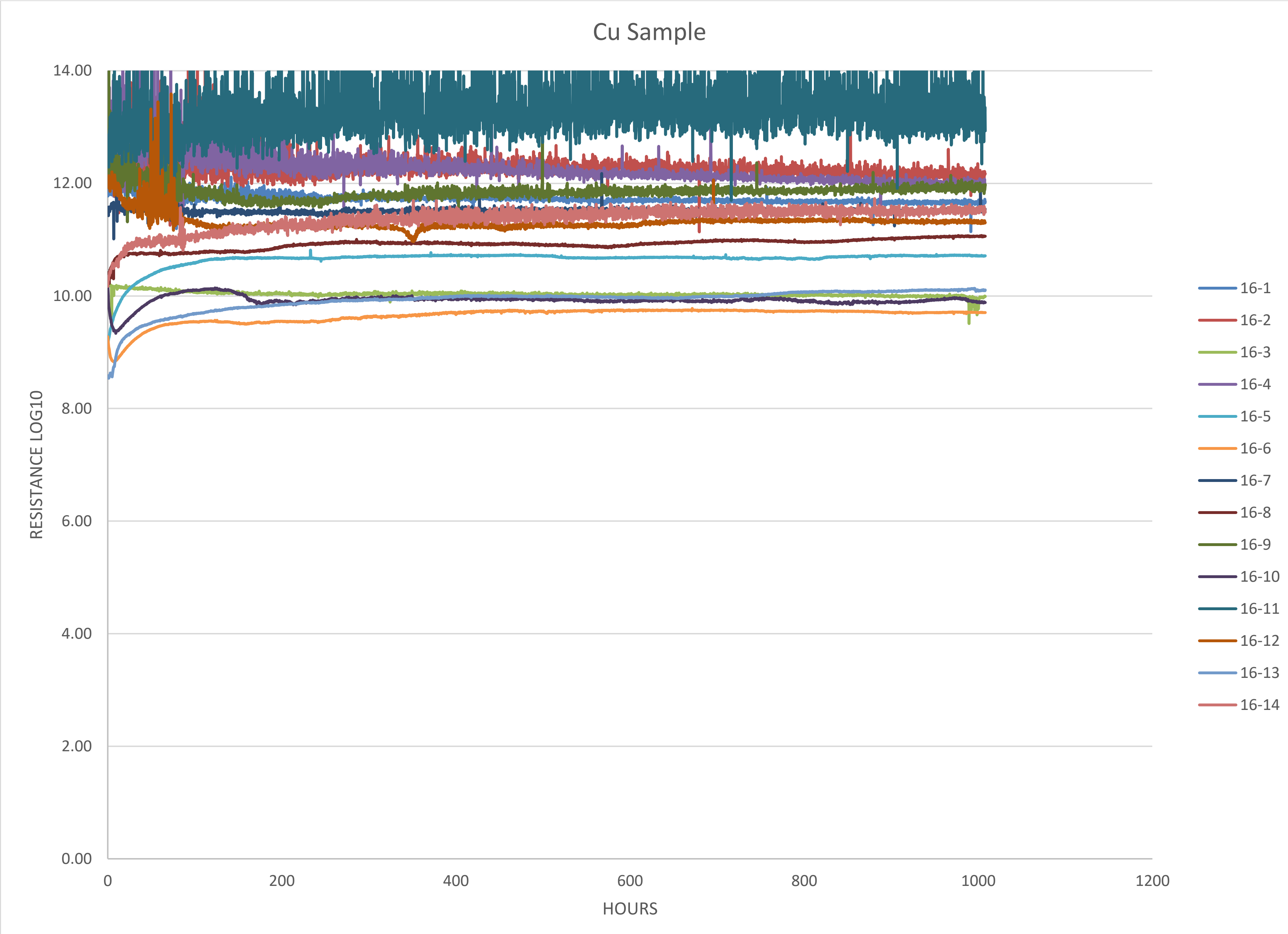
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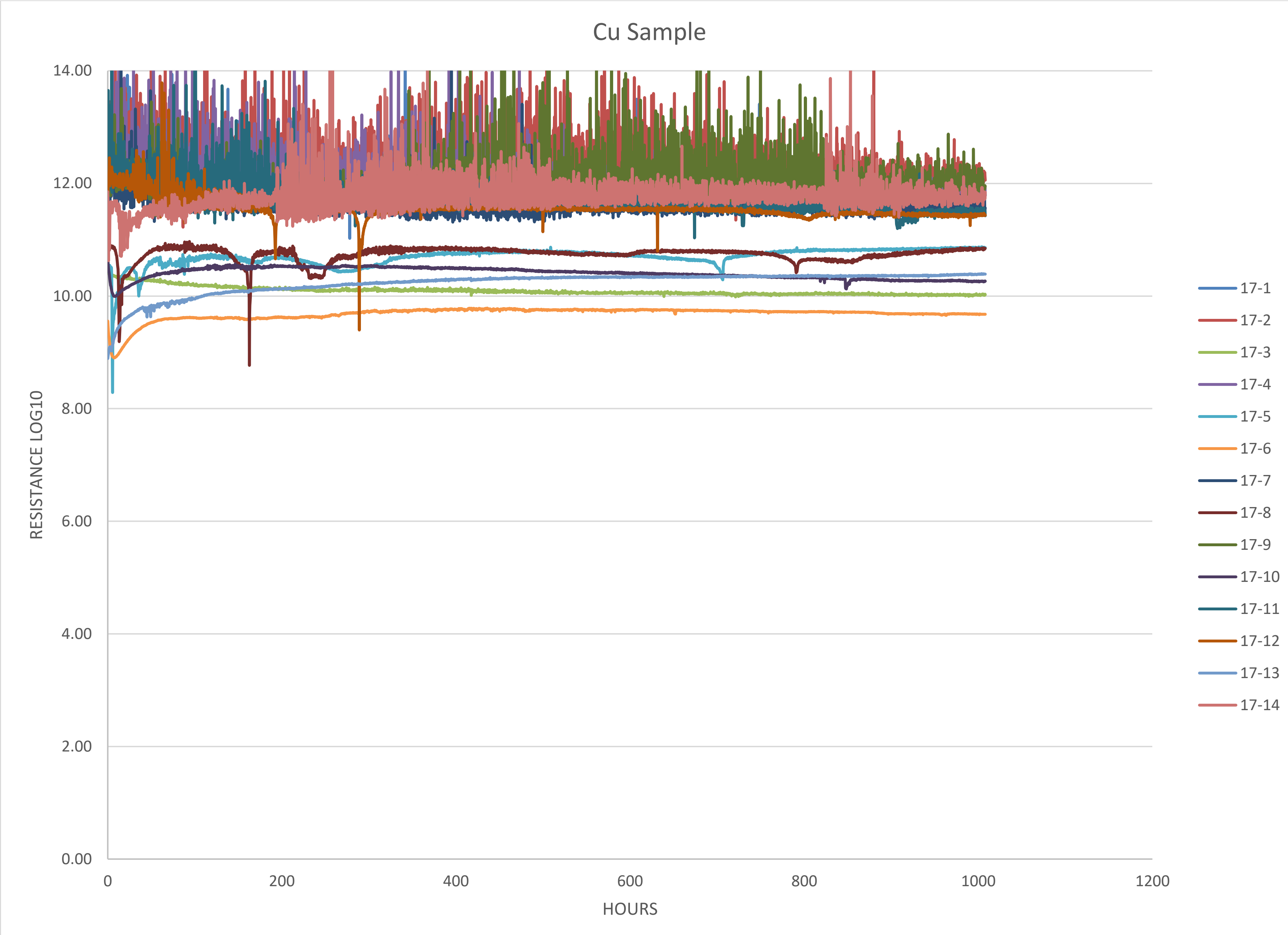
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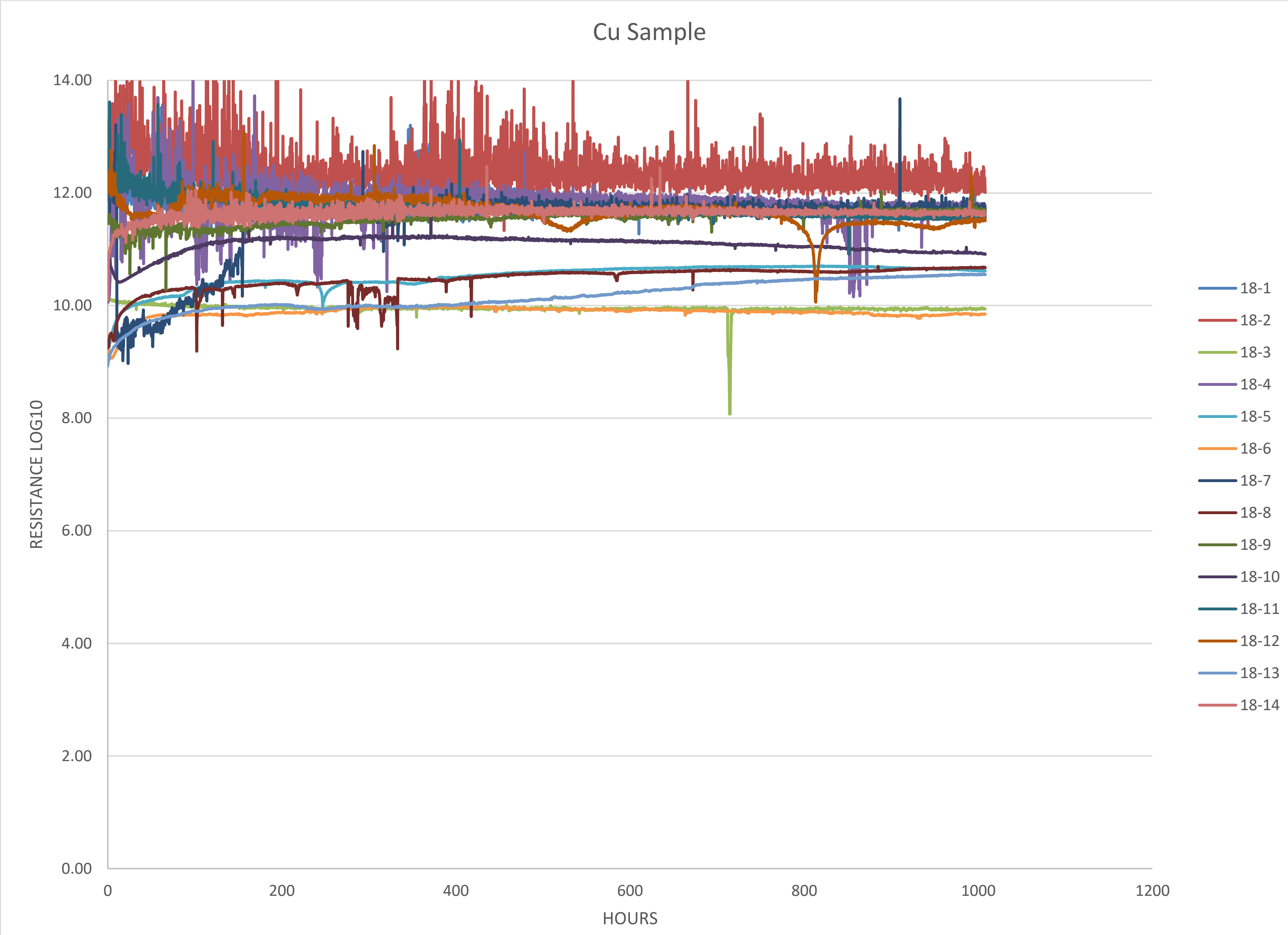
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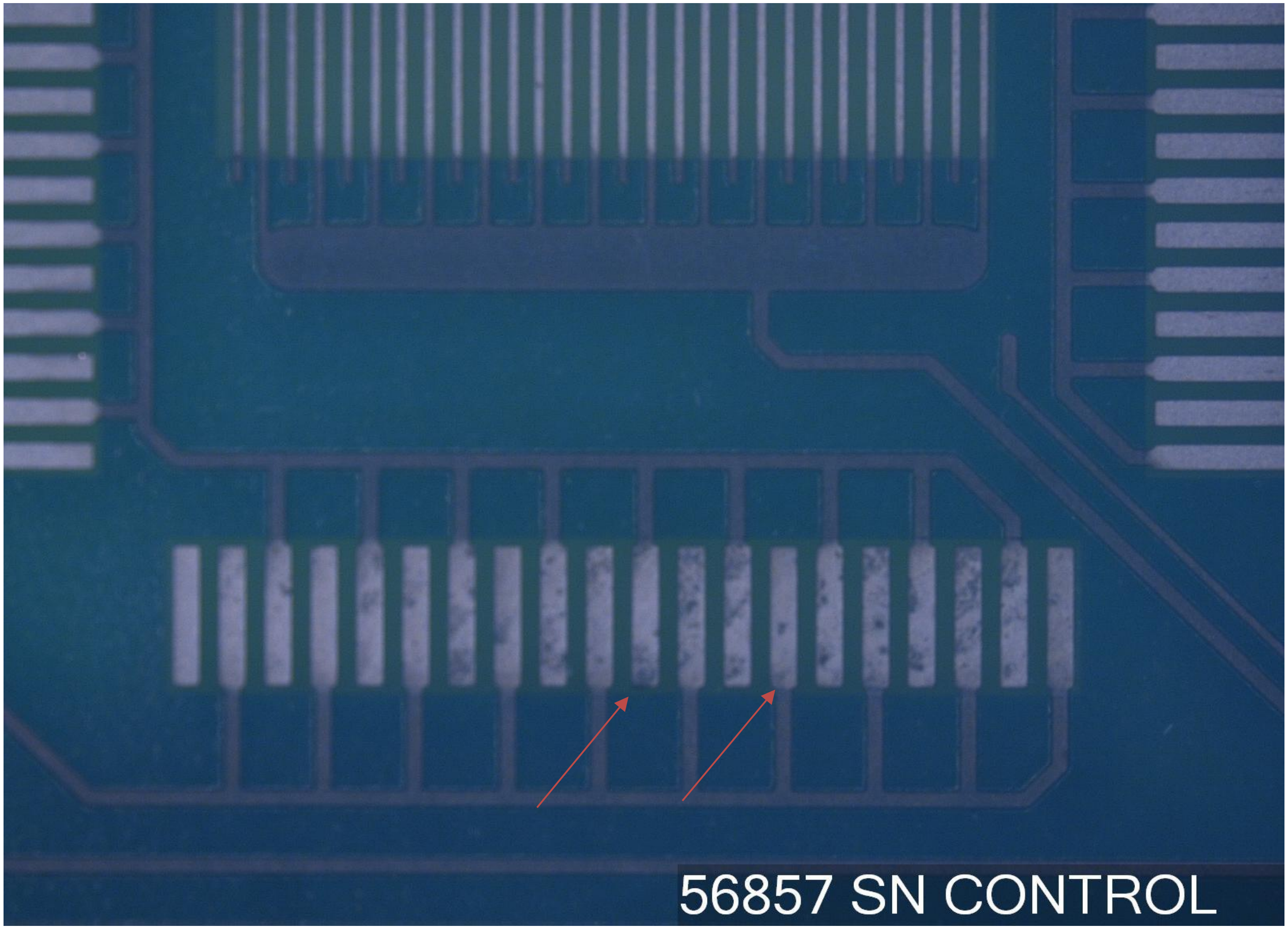
56857 SN CONTROL


56857 12 SHORTS

IC Results and Discussion:

Table #1: PAL Recommended Guidelines and Results for Samples 1 - 3

Ion Name / Chemical ID	PAL Recommended Guidelines - Bare Boards		PAL Recommended Guidelines - Assemblies		Sample ID and Results		
	HASL	Non-HASL	No Clean	Clean	1160-026-01	1160-026-02	1160-026-03
Anions							
Fluoride (F^-)	PI	PI	< 1.0	< 1.0	0.00	0.00	0.00
Chloride (Cl^-)	< 2.0	< 1.0	< 2.5	< 4 - 5.0	0.63	1.01	0.79
Nitrite (NO_2^-)	PI	PI	PI	PI	0.00	0.00	0.00
Bromide (Br^-)	< 12.0	< 12.0	<12.0	< 12.0	0.61	0.00	0.00
Nitrate (NO_3^-)	< 3.0	< 3.0	< 3 - 5.0	< 3 - 5.0	0.66	0.66	3.67
Phosphate (PO_4^{3-})	PI	PI	< 1.0	< 1.0	0.00	0.00	0.00
Sulfate (SO_4^{2-})	< 3.0	< 3.0	< 3 - 5.0	< 3 - 5.0	0.10	0.11	0.15
Cations							
Lithium (Li^+)	< 1.0	< 1.0	< 1.0	< 1.0	0.00	0.13	0.00
Sodium (Na^+)	< 1.0	< 1.0	< 2.0	< 2.0	0.78	0.88	0.71
Ammonium (NH_4^+)	< 1.0	< 1.0	< 2.0	< 2.0	1.53	2.16	1.43
Potassium (K^+)	< 1.0	< 1.0	< 1.0	< 1.0	0.67	1.12	0.61
Magnesium (Mg^{2+})	< 1.0	< 1.0	< 1.0	< 1.0	1.24	0.74	1.05
Calcium (Ca^{2+})	< 1.0	< 1.0	< 1.0	< 1.0	3.83	0.96	3.40
Weak Organic Acid (WOA)							
SMT Only	PI	PI	< 5 - 20.0	< 5 - 20.0	5.07	0.75	2.33
SMT + Wave	PI	PI	< 20 - 50.0	< 20 - 50.0	N/A	N/A	N/A
Wave Only	PI	PI	< 50 - 100.0	< 50 - 100.0	N/A	N/A	N/A

Table #1: All values in the table are in micrograms per square inch ($\mu g/in^2$). Non-HASL refers to ENIG, immersion Ag, immersion Sn and OSP board finishes. PI means the component is treated as a process indicator, as no industry guidelines currently exist. ***Please note that the various residue levels shown in the table are only recommended starting points, they should not be construed as industry limits.***

IC Results and Discussion: Continued

Table #2: PAL Recommended Guidelines and Results for Samples 4 - 6

Ion Name / Chemical ID	PAL Recommended Guidelines - Bare Boards		PAL Recommended Guidelines - Assemblies		Sample ID and Results		
	HASL	Non-HASL	No Clean	Clean	1160-026-04	1160-026-05	1160-026-06
Anions							
Fluoride (F^-)	PI	PI	< 1.0	< 1.0	0.00	0.00	0.00
Chloride (Cl^-)	< 2.0	< 1.0	< 2.5	< 4 - 5.0	0.47	0.32	0.38
Nitrite (NO_2^-)	PI	PI	PI	PI	0.00	0.00	0.00
Bromide (Br^-)	< 12.0	< 12.0	<12.0	< 12.0	0.00	0.00	0.35
Nitrate (NO_3^-)	< 3.0	< 3.0	< 3 - 5.0	< 3 - 5.0	0.14	0.55	0.13
Phosphate (PO_4^{3-})	PI	PI	< 1.0	< 1.0	0.00	0.00	0.00
Sulfate (SO_4^{2-})	< 3.0	< 3.0	< 3 - 5.0	< 3 - 5.0	1.89	0.89	0.77
Cations							
Lithium (Li^+)	< 1.0	< 1.0	< 1.0	< 1.0	0.07	0.00	0.00
Sodium (Na^+)	< 1.0	< 1.0	< 2.0	< 2.0	0.08	0.76	0.55
Ammonium (NH_4^+)	< 1.0	< 1.0	< 2.0	< 2.0	0.18	0.68	0.55
Potassium (K^+)	< 1.0	< 1.0	< 1.0	< 1.0	0.09	0.38	0.24
Magnesium (Mg^{2+})	< 1.0	< 1.0	< 1.0	< 1.0	0.04	0.35	0.29
Calcium (Ca^{2+})	< 1.0	< 1.0	< 1.0	< 1.0	0.06	0.57	0.55
Weak Organic Acid (WOA)							
SMT Only	PI	PI	< 5 - 20.0	< 5 - 20.0	0.81	1.52	1.57
SMT + Wave	PI	PI	< 20 - 50.0	< 20 - 50.0	N/A	N/A	N/A
Wave Only	PI	PI	< 50 - 100.0	< 50 - 100.0	N/A	N/A	N/A

Table #2: All values in the table are in micrograms per square inch (µg/in^2). Non-HASL refers to ENIG, immersion Ag, immersion Sn and OSP board finishes. PI means the component is treated as a process indicator, as no industry guidelines currently exist. ***Please note that the various residue levels shown in the table are only recommended starting points, they should not be construed as industry limits.***

Appendix

Note:

The photograph shows the extract solutions from PAL's control blank and the Tin control board. The blank represents what the solution should look like after an extraction has completed. The blue coloration of the Tin control suggests that the solder mask was not fully cured and some the solder mask pigment leached out during the extraction process. This was the only unprocessed board sample to show this change in the extract solution. None of the assembled boards showed any color change in their extract solutions.

APPENDIX: ROSE test results

Cleanliness Assessment

Robisan Laboratory #: 56855

SAMPLE ID	Board Surface Area [in^2]	Volume of Solution (ml)	Contamination/in^2 (µg NaCl equivalence)
Ag Control	12	2000	3.836
Sn Control	12	2000	11.430
Cu Control	12	2000	7.533
1	12	2000	2.232
6	12	2000	2.715
12	12	2000	2.439

Test Method	IPC-TM-650 method 2.3.25D
Performed by	ms
Date/Time	6/4/2018
Equipment used	73

Master equipment list available upon request