NEW TECHNOLOGY, SMALL FOOTPRINT (9' X 4'), VERTICAL CIRCUIT WASHING SYSTEM FOR PCBAS (< 3" X 3")

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ABSTRACT

Data Sciences International's (DSI) customers were experiencing an unacceptably high failure rate on one of our small (1.1 cc) implantable RF transmitters (Figure 1). With the help of Foresite, Inc., circuit contamination was as the primary cause for the poor performance and reliability.

Extensive research was conducted and no viable industry standard circuit washing system existed to meet our specific needs (small circuit size [< 0.2 in^2], lower production volumes [~50,000 circuits per year], thorough circuit drying and continuous flow [non-batch processing]). To fill this need, a new circuit washing technology was developed.

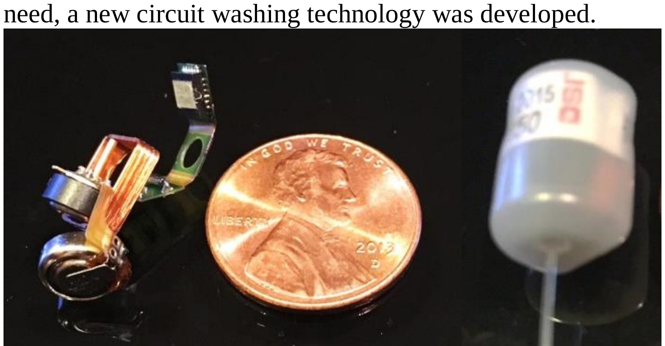

Figure 1. <0.2 in^2, 1.1 cc Non-hermetic housing

Key words: circuit washing system, flexible and configurable design, vertical part orientation, small footprint, low power consumption, automated, heated output conveyor, ionized air knife, superior cleanliness, small critical application (class 3) circuits, saponifier, DI steam, ionized convection oven, Critical Cleanliness Control® (C3), ion chromatography, corrosivity factor

INTRODUCTION

Today's electronic circuits are exposed to severe conditions (from extreme environmental temperature and humidity fluctuations to being implanted in a continuously moist condition) that can cause performance and reliability issues, particularly if component or solder point spacing is tight and circuits have residual contamination. Removal of ionic residue is critical to meeting expected circuit performance and reliability.

CUSTOMER EXPERIENCED CIRCUIT FAILURES

Approach to understanding why

An Eight Discipline (8D) problem-solving approach was used to understand and resolve the poor circuit performance and reliability. By working with a cross-functional team of experts, a Cause Map[1] was created identifying over 100 potential reasons for the premature failures. Evidence was gathered and substantiated.

Visual discoloration as received from vendor

Beginning with visual evidence, samples, as received from the circuit assembly vendor (Figure 2), were sent to Foresite for evaluation.

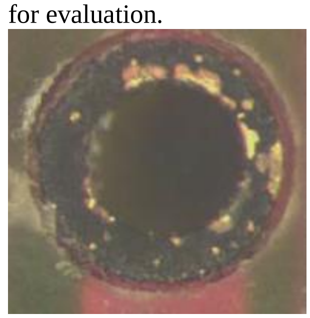

Figure 2. Contamination on gold pads (as received)

Typical ENIG EDS analysis will show gold and nickel. XRF analysis provided a nominal gold and nickel thickness of 5.92µin and 147.6µin respectively. Cross-sectioning and bitmap analysis indicated nickel discontinuities (Figure 3).

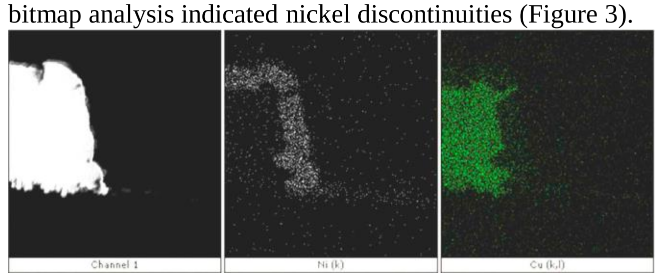

Figure 3. Gold bitmap analysis

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SEM analysis (Chart 1) identified very high levels of copper (Cu) and chloride (Cl^-) on the surface of the gold (Au) and nickel (Ni).

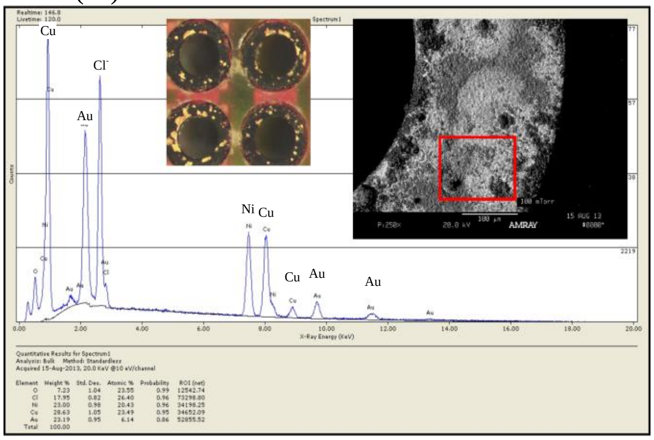

Chart 1. Contaminated gold pads SEM analysis

Ion chromatography from the contaminated gold pads also identified high levels of Cl^- (Table 1).

To identify potential sources of the Cl^-, ion chromatography testing was performed on samples representing all potential contamination sources to which the circuit could be exposed. The city water used to wash and rinse the circuits along with the solder, paste and fluxes used by the vendor were the highest contamination sources (Table 1).

Lastly the gold pads were washed with saponifier (EnviroGold 817 at 10% concentration) and DI steam rinsed. After washing and rinsing, there was no pitting or visual degradation of the gold plating (Figure 4). SEM analysis indicated no unexpected topography (Chart 2) and ion chromatography testing provided excellent values (Table 1).

Figure 4. Gold pad wash & rinse

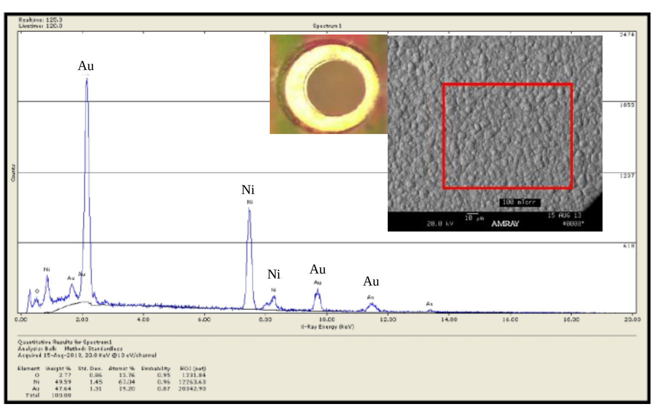

Chart 2. Gold pad SEM analysis after wash & rinse

Sample Description	Cl^-	Na^+	WOA
Foresite recommended (max)	3.0	3.0	150.0
Solder	30.7	22.3	45.4
Flux - 1	306.7	359.4	42778.1
Flux - 2	104.3	377.6	1316.3
Paste	3.2	0	37961.9
City water	15.8	10.1	0
Gold discoloration	40.8	11.7	5.4
Gold after wash	0.7	1.1	0

Table 1. Ion chromatography results

Visual discoloration as received from vendor conclusion

The visual discoloration on the gold pads was corrosion from copper migrating to the surface through small discontinuities in the gold / nickel layers. The chloride rich surface (from remaining water soluble flux and city water used to wash and rinse by the circuit assembly vendor) corroded the copper with no bias at all. After washing with a saponifier and rinsing with DI steam, the gold was intact and excellent ion chromatography values were obtained.

Additional contamination evidence

A set of samples, representing all circuit configurations, were sent to Foresite for evaluation. A wide dispersion of results was obtained, primarily dependent upon the vendor of the circuit assembly. Based on results, further questions and discussions occurred with each vendor. Those that had saponifier-based wash systems consistently had better C3[2] and ion chromatography results than the suppliers that used only DI water or worse yet, city water in their wash system (Chart 3).

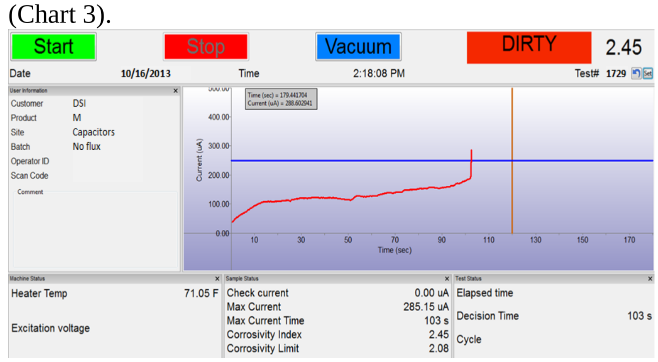

Chart 3. Sample C3 test result as received from vendor

Circuit washing technology in use at DSI at the time was a vapor degreaser using AK225 (transitioned to 3M-72DA end of 2014) followed by an ionograph rinse and oven bake. Sample circuits were sent to Foresite for evaluation and the conclusion was drawn that the existing process was not adequate to wash circuits to an acceptable level.

Criticality of circuit contamination

The importance and negative affect that contamination has on circuit performance and reliability has been well documented.[3-5]

Need identified for a circuit washing system

With the need for a new circuit washing system clearly established, an all-out search was launched.

The core requirements included:

- Continuous flow (non-batch) processing
- Small footprint
- Fixturing to prevent damage to delicate circuits
- Thoroughly dry circuits (not IR flash dry)
- Highest level of cleanliness (consistently pass C3)
- Exceptional circuit performance and reliability
- Low volume (~50,000 circuits / year)
- Highly configurable
- Nominal maintenance

No circuit washing system that met these requirements could be identified[6], so a detailed design concept and specification was developed and reviewed with several local machine automation design companies and TCA was selected as our partner.

New technology becomes reality

A new, easily configurable, automated, continuous flow, small footprint, vertical circuit washing system technology (Figure 5) was created.

Figure 5. Vertical circuit washing system (front)

Some key characteristics of the vertical circuit washing system include:

- Fixturing with supple plastic mesh captures circuits without damaging delicate wires or components (Figures 6 & 7).

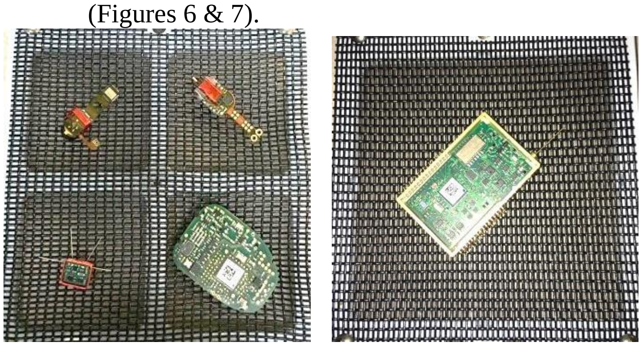

Figure 6. Fixture isolates and protects delicate circuits

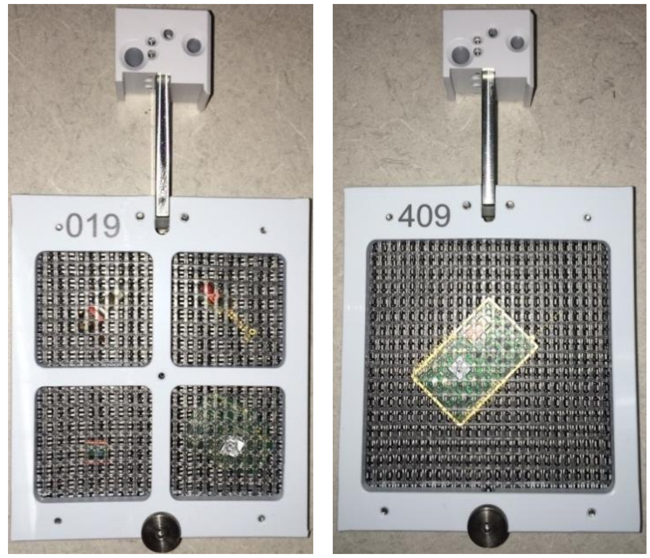

Figure 7. Fixture securely captures circuit

- Input conveyor provides simple poka-yoke operator interface. Operator places fixtures onto input conveyor (Figure 8) and system automatically detects, transports and transfers fixtures to main conveyor.
- Fixtures can be continuously loaded, the system will indicate when the maximum number is reached (approximately 100) and output conveyor must be offloaded or no additional fixtures will be accepted.
- System automatically goes into standby mode after designated period of inactivity to further reduce facility demands.
- Standby mode allows operators to “load-it-up” at the end of the day. The parts are washed and held in a clean, warm and dry environment, for an extended period of time, until needed.
- Vertical fixturing allows for uniform low-pressure, high-volume spray patterns, ensuring both sides of the circuit are consistently and thoroughly washed.

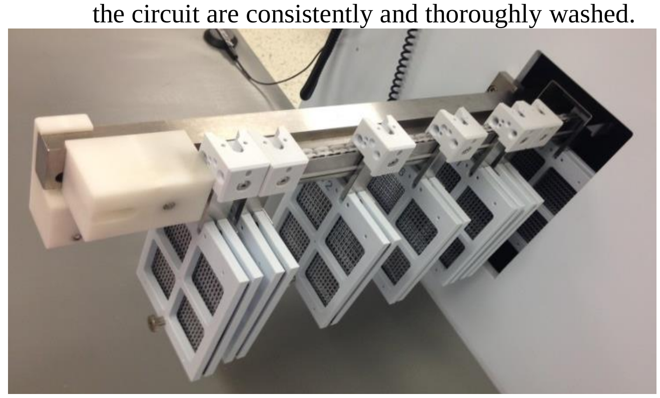

Figure 8. Input conveyor

- Main conveyor has ample speed range to maximize throughput vs circuit wash and dry time (typical overall cycle times range from 40 to 90 minutes).
- Precision metering pump provides accurate, repeatable and adjustable saponifier concentration. Software automatically maintains the desired, tightly controlled saponifier concentration, thus eliminating the need for daily refractometer and PH checks.
- Heated saponifier spray (Figure 9) lowers surface tension and provides thorough PCBA washing, even behind low stand-off components.
- DI steam rinse removes the majority of saponifier, penetrates behind difficult to rinse components and significantly reduces saponifier transfer to initial DI water rinse tank (Figure 10).


Figure 9. Saponifier wash
Figure 10. DI steam rinse

- Heated initial DI water rinse (Figure 11) with controlled purge (water is exchanged every 12 minutes) and auto-replenish keeps water fresh.
- Final DI water rinse (Figure 12) with controlled purge (tank water is exchanged every 3 minutes) and auto-replenish maintains high water resistivity, viewable on meter display.


Figure 11. Heated initial DI water rinse
Figure 12. Final DI water rinse

- Ionized air knife (Figure 13) removes majority of water droplets prior to convection oven.
- Ionized air convection oven (Figure 14) with optional dry times ensures parts come out completely dry and ready for hermetic enclosure or next processing step.


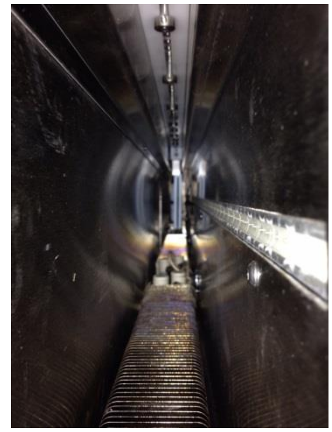

Figure 13. Ionized air knife
Figure 14. Ionized air convection oven

- Isolation between tanks reduces contamination transfer.
- Highly configurable and adjustable nozzle design (Figures 15 & 16) allows extensive flexibility to optimize washing and rinsing.


Figure 15. Nozzle adjustability – location
Figure 16. Nozzle adjustability – rotational angle

- Enclosed and heated output conveyor (Figure 17) keeps parts clean, warm and dry until operator is ready to easily access and remove fixtures.

Figure 17. Enclosed and heated output conveyor

- Intuitive user interface (Figure 18) makes system easy to use and light bar provides visual status.
- Operator interface displays part tracking, time to last part, system status indicators, temperature set-points and status as well as descriptive alarm messages.
- Password protected engineering screen allows customizable configurations.

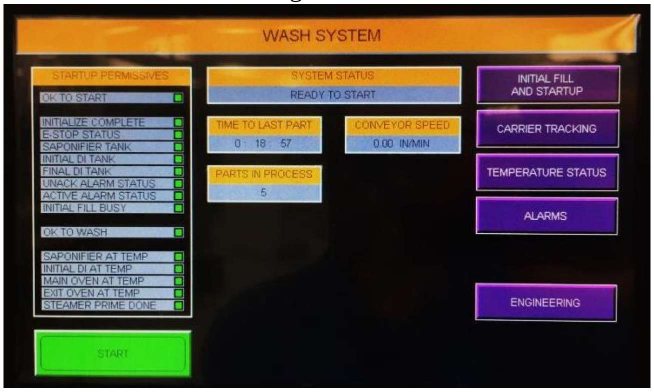

Figure 18. Intuitive user interface

- System's low profile and easy access tank drains (Figure 19) allow all portions of equipment to be easily reached for periodic wash-down.
- Front storage compartment (Figure 20) conveniently houses DI water sprayer for system wash-down and organizes measurement equipment or other supplies.
- Push-of-a-button automatic tank refill and control allows system to be back up and running with minimal down time.

Figure 19. Storage compartment and tank drain access

Figure 20. Storage compartment

- Only highly reliable components, designed to withstand continuous use and corrosiveness of high purity 18MΩ DI water are used in the system for unparalleled performance and uptime.
- Large removable panels around the cabinet perimeter provide ready access to all system components for effortless preventive maintenance (Figure 21).

Figure 21. Back of vertical circuit washing system

VERTICAL CIRCUIT WASHING SYSTEM QUALIFICATION

Summary of performed testing

Attributed to the easily configurable vertical circuit washing system design and by utilizing the Foresite C3 tester, the system parameters (main conveyor speed, saponifier concentration, nozzle configurations, process temperatures and oven dry time) were quickly optimized.

Key parameters:

- Dry circuits – measured by weight
- Clean circuits – measured by C3
- Functionality
  - Performance – accurate and stable signals, current draw
  - Reliability – extended temp and humidity testing

Determining oven cycle time:

1. A large set of representative circuit samples was selected and put into a vacuum oven at 55°C for 48 hours (minimum) to ensure complete dry-out. Parts were weighed three times and average calculated.
2. Circuits were put into fixtures and run through vertical circuit washing system at an initial main conveyor speed. When circuits completed the process, they were weighed three times and average calculated.
3. Pre and post-wash circuit weights were compared.
4. This process was repeated until a minimum cycle time was determined (<0.01% weight difference [considered to be within measurement error]).

Optimizing saponifier concentrations, nozzle configurations and main conveyor speed:

1. Initial settings were determined.
2. The worst case (tight capacitor array) along with representative circuit configurations were identified for testing.
3. A set of samples were processed under "current" operating conditions.
4. A second set of samples were intentionally flooded with no-clean and rosin flux (those used in production) and baked at 65°C for 1-hour minimum (Figures 22 & 23).

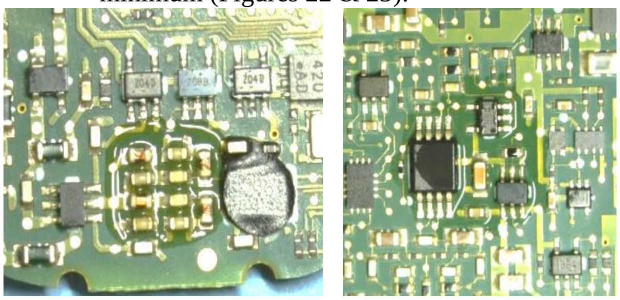

Figure 22. Worst case circuit configuration – Intentionally flooded with flux

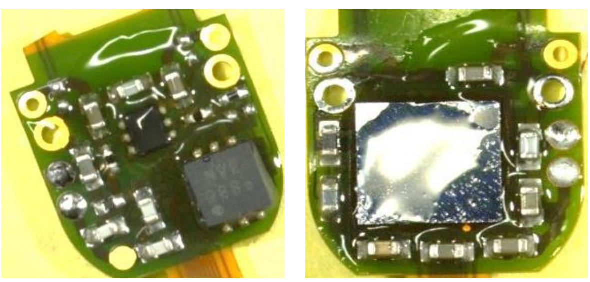

Figure 23. Representative circuit configuration – Intentionally flooded with flux

5. Both sets of samples were processed through the vertical circuit washing system.
6. Circuits were C3 tested.
7. Some C3 results from both the "current" operating conditions and intentionally flooded circuits were "Dirty".
8. Ion chromatography testing indicated residual saponifier was the contaminate that caused the "Dirty" C3 results.
9. Inadequate heat cycle was thought to be the likely cause, so new samples were washed and put into an oven at 55°C overnight, but again C3 results for some samples was "Dirty".
10. Saponifier concentration was reduced and nozzle configurations were modified.
11. Circuits were C3 tested.
12. This process was repeated until the optimal system configuration was identified and consistently "Clean" C3 results were obtained (Chart 4).

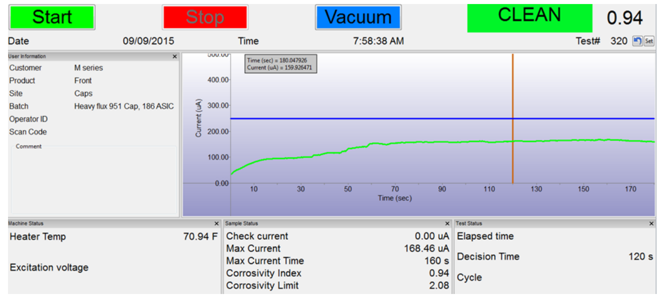

Chart 4. Sample C3 test result

On-going testing:

- Representative products are functionally tested to ensure high reliability performance.
- Samples of worst case and typical circuit configurations, intentionally flooded with flux and baked, are run through the vertical circuit washing system and C3 tested to verify continued "Clean" results.
- Outstanding corrosivity factor[7] results, exceeding standard high-volume, in-line circuit board wash systems utilized by DSI suppliers, continue to be obtained.

Saponifier concentration control:

- Saponifier concentration and condition was initially checked daily using a refractometer and PH meter.
- Based on comprehensive data analysis and trends over time, slight software modifications were implemented that automatically keeps the saponifier concentration within a very tight desired range, thus eliminating the need for daily refractometer and PH checks.
- The required frequency, for how often the tanks need to be drained, rinsed and refilled, was also defined to maintain optimal performance while minimizing downtime and saponifier usage.

Product performance and reliability internal testing:

1. A large set of representative circuit samples, along with intentionally flux flooded circuits baked at 65°C for 1-hour minimum (representing worst case scenario) were produced under "current" operating conditions (representing baseline).
2. An equivalent second set of representative circuit samples, along with intentionally flux flooded circuits baked at 65°C for 1-hour minimum (representing worst case scenario) were produced and processed through the vertical circuit washing system.
3. All circuits were produced at the same time to minimize variability (with the exception of the washing process used for each set of samples).
4. Critical performance parameters (i.e. current draw) were monitored during a defined step-function environmental (increasing temperature and humidity) test sequence. Testing ranged from initial (37°C / 30% RH) to expected end-of-life implant

conditions (37°C / 80% RH) and then continuing to ramp-up with the intent to produce circuit failure (55°C / 95% RH).

5. The performance and reliability of circuits washed in the vertical circuit washing system far exceeded baseline samples and survived the entire test sequence without failure.

Production testing and non-conforming material:

- Internal data is monitored for any impact since the vertical circuit washing system was implemented.
- Scrap and rework have been reduced by >10% and >12% respectively (Chart 5), attributed to the vertical circuit washing system.

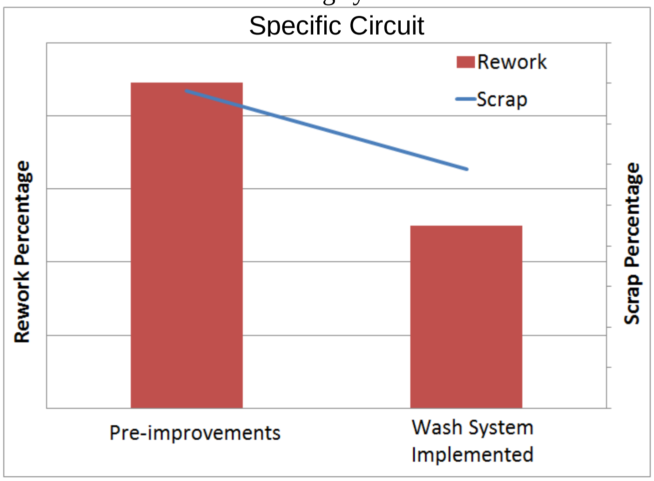

Chart 5. Significant reduction in Scrap and Rework

CONCLUSION

The proof is in the product performance and reliability

Most importantly, since the vertical circuit washing system was implemented into production, more than 7,000 circuits have been washed and delivered to our customers. There has not been any associated product performance or reliability issues encountered. A significant and critically important improvement has been achieved (Chart 6). Customers' confidence is being restored, allowing them to focus on their important research and customer satisfaction is rising once again.

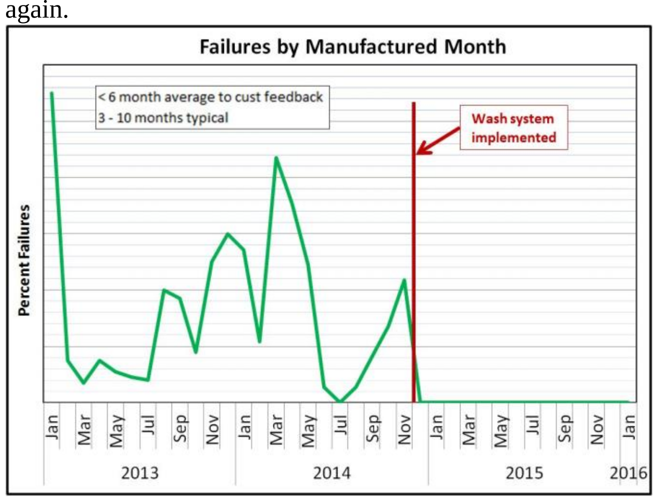

Chart 6. Significant improvement in product performance and reliability

In the process, a new, easily configurable, automated, continuous flow, small footprint, vertical circuit washing system technology was designed, developed, proven and is available.

ACKNOWLEDGEMENTS

1. Terry Munson, President & CEO, Foresite, Inc.,
2. http://foresiteinc.com/.
   http://foresiteinc.com/about-us/terry-munson-foresite-inc-ceo/.
3. Mark Palmer, President, Envirosense,
   http://www.envirosense-inc.com/.
4. Scott Janacek, President, TCA,
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