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RELIABILITY: AS SURE AS THE SUN RISES

Defects cost you resources. They cascade through the product's life cycle and can affect your company's reputation. Businesses lose money when they burn extra resources, like labor, capacity, employee morale, and potential customer liability. This month, we ask the question, "What are the best methodologies for maximizing manufacturing reliability?"

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A Manncorp Success Story: Critter & Guitari

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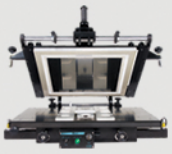

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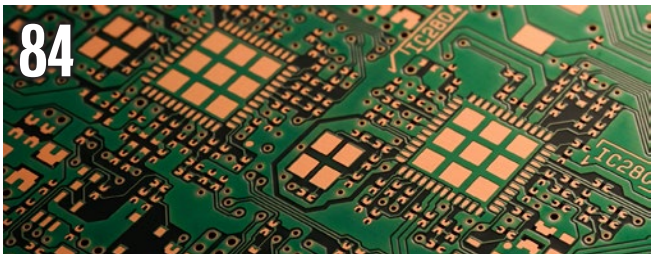

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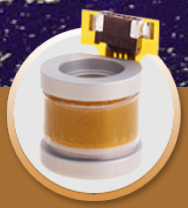

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Racing Toward Reliability

Nolan's Notes

by Nolan Johnson, I-CONNECT007

When I have the opportunity to sit and ponder the pressures on our industry, I continually return to the Executive Forums at IPC APEX EXPO. The drumbeat throughout those sessions was that automotive would require an order of magnitude more manufacturing reliability than we currently enjoy at an order of magnitude more volume. That sort of challenge will require some fundamental changes in how we approach reliability. Iterative improvement will be a requirement, but that certainly won't be enough to deliver orders of magnitude on two different measures, will it?

That set us to thinking about what's happening in reliability, and it reminded me of a bit of aviation history.

Forward fuselage and propeller detail of the prize-winning Supermarine S.6B, S1595 on display at the London Science Museum. (Source: Nimbus227 Wikimedia Commons)

The Schneider Prize competition (officially known as the Coupe d'Aviation Maritime Jacques Schneider) was the trophy awarded to the winner of a seaplane race held between 1913 and 1931 [1]. For aviation history buffs, The Schneider Trophy races are deeply meaningful. The first competition was held in April 1913 in Monaco. From the start, teams for the Schneider Trophy tended to be fielded by aviation clubs or teams. Much like the America's Cup sailboat races, teams represented their country during the competition. In 1913, Frenchman Maurice Prevost was the winning pilot, with an average speed of 45 miles per hour (73.5 kph) [2]—not exactly a screaming speed. The next year, though, the winning plane clocked 86 mph (139.7 kph).

Not unsurprisingly, the contest inspired extreme competition amongst the teams and countries. The Schneider Trophy became a proving ground for the latest aeronautical technology [3]. Throughout, the competition was dogged by equipment failures and failed bids by teams; reliability was a clear issue in those days. In 1923, the first liquid-cooled engine arrived at the race, in an American entry designed by Glenn Curtiss, funded by U.S. government sources and piloted by U.S. Navy aviators, with a winning speed of 177 mph (285 kph). By 1925, the winning speed was just over 232 mph; by 1927, it was 281 mph; and in 1931, the last year of the series,

The trophy-winning pilot (and the first man to just 17 days later break the world airspeed record in the Supermarine S.6B 1596 seaplane), George Stainforth, is shown with his team second from right. (Source: Wikimedia Commons)

a Supermarine S.6B won with a speed of 340 mph (547 kph). It should be noted that even though the S.6B set a series speed record, it was also the only entry that completed the course; it won uncontested.

Still, in the span of 18 years, the speeds of the aircraft in the race had increased more than seven-fold. The engines that emerged out of this competition went on to be the powerplants for some of the highest performance propeller-driven military airplanes of the World War II era.

The Supermarine S.6B 1596 seaplane that broke the world airspeed record of over 400 mph. (Source: Wikimedia Commons)

Using lessons learned in performance and reliability, Curtiss went on to build the USP 38, and Supermarine designed the British Supermarine Spitfire.

These are just two examples of the effect the Schneider Trophy series had on aviation performance and reliability. Besides performance, it was designed for easy and efficient maintenance at the race site that led to increased flight time on the battlefield.

It's easy to imagine that the race participants in 1913 had no concept of what would become of that race in just 18 years. It's that sort of rapid innovation likely to come out of the push for electric and autonomous vehicles, especially when it comes to robustness and reliability. Looking back at the Schneider Trophy, we catch a possible glimpse of our future in automotive electronics technology, even without a competition to spur us on.

Similarly, in this issue we explore reliability from the manufacturing floor. As one expert put it, "Defects cost you resources. They cost you treasure. Defects cascade through the product's life cycle and can affect your company's reputation. Businesses lose money when they burn extra resources, like labor, capacity, employee morale, and potential customer liability."

This month, we ask the question, "What are the best methodologies for eliminating defects?" The racing teams in the Schneider Trophy series were also asking those questions. They took the issue seriously, and over the course of just 18 years, advanced aviation manufacturing's performance and reliability by leaps and bounds. The electronics industry will do the same. **SMT007**

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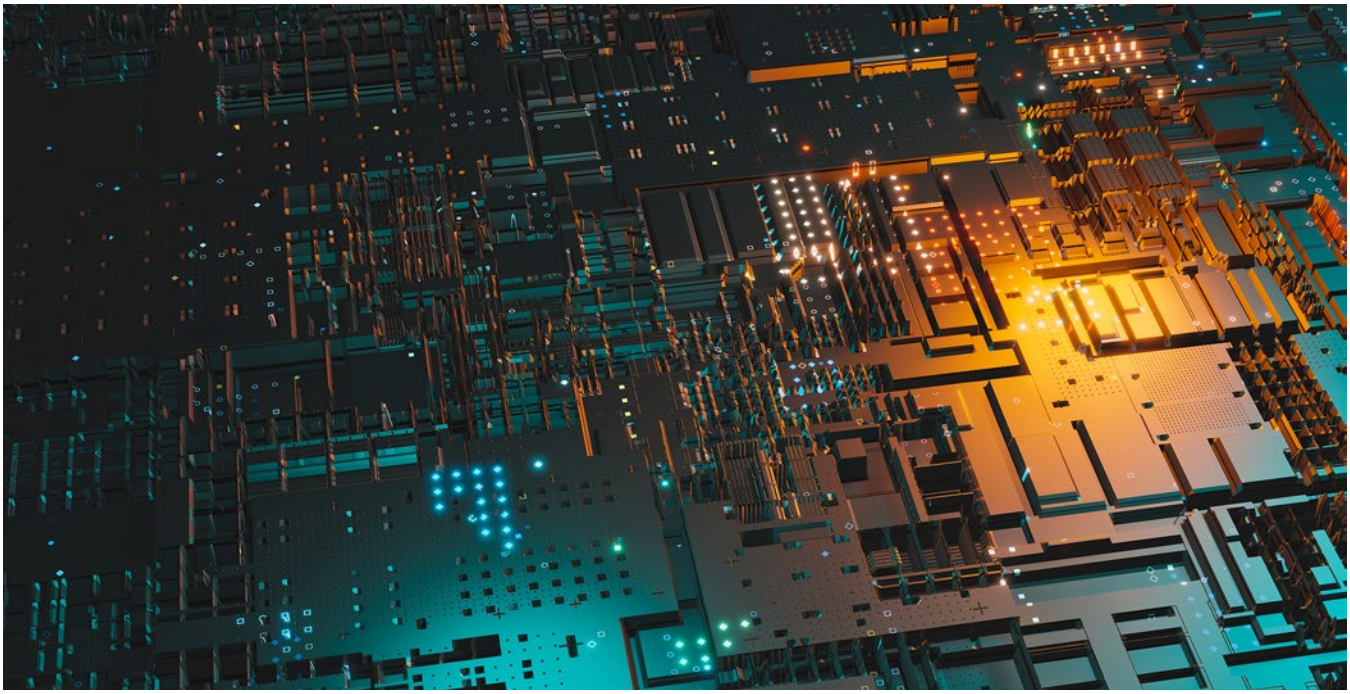
1. HistoryNet, "Aviation History: Schneider Trophy Race."
2. Wikipedia, "Schneider Trophy."
3. "Spitfire: The Plane That Saved The World," David Fairhead and Anthony Palmer, 2018.

Nolan Johnson is managing editor of *SMT007 Magazine*. Nolan brings 30 years of career experience focused almost entirely on electronics design and manufacturing. To contact Johnson, click here.



Robustness Is Not the Same as Reliability

Feature Interview by the I-Connect007 Editorial Team

Bob Neves discusses a disconnect he sees in reliability testing between what's being tested and what happens out in the field, as well as why most reliability tests these days should instead be considered robustness tests.

Nolan Johnson: What are the current dynamics in assembly reliability?

Bob Neves: My history and focus are primarily within the electronics industry surrounding PCBs. My customer base at Microtek, and for testing and evaluation, are the suppliers to the PCB manufacturers, the PCB manufacturers themselves, and the users of PCBs. When we talk about testing, most people who buy PCBs look at the PCB like they would look at a resistor or capacitor—it's just another component on their build list. The truth is that you really can't treat the PCB as a component. You need to look at it as a very complex subsystem like you were buying a power supply or some other multi-component assembly that did something for you rather than just a single attribute component like a capacitor or resistor.

The PCB is relied on for passing signals between components and isolating signals from places they're not supposed to be. When things go bad in an electronics assembly, those are typically the areas where you start looking. Is the signal getting to the correct spot, or are we losing signal some place where we're supposed to have a signal? A lot of problems that I've experienced have to do with the fact that something's gone wrong in the interconnection or isolation process on the PCB. Engineers come to me, saying, "If I press down on this component, it works," or, "If I heat it up with a hot air gun, my system works. But if I take it off, it doesn't work anymore." That's where a lot of failures end up being PCB related.

Reliability starts for a product after the component attachment process. After you've put all the components on, changed anything that was bad, tested it, and it's ready to put it in the field, that's when reliability starts. Any reliability you're testing—whether it's on the bare PCB, a component, or the entire assembly—needs to have some sort of simulation that

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shows that it's gone through this component attachment process, getting you all the way up to the point of where it would be going out the door. That's one feature that not everyone does before testing. A lot of people will take a component and then do testing on that component as it comes in the door, or they'll electrically test a PCB before component attachment and say, "Everything's great." But any type of testing that you do to see how long your product might last needs to have some sort of simulation of the soldering process before testing. That simulation also needs to include the rework and repair part of the component attachment process.

Bob Neves

Reliability is expensive to understand because you first have to understand where your product is being used, how it's being used, and the environment that it's going to be used in. Once you understand these things, you have to find a way to accelerate them in a reasonable amount of time. You don't want to wait 10 years to see if your product has a 10-year life. You have to find some way to accelerate product life, which keeps the connection between what you're doing to it in an accelerated way and what your customer is going to do to it out in the field. That takes a lot of studying and isolating all the individual attributes that go into what your customers will do to your product and how to accelerate that in a controlled manner without adding or removing factors that contribute to failure. Whether it's an environmental acceleration, a mechanical acceleration, or all the other weird things that are going to happen to your product, it's about how to accelerate those in a way that you can use the results from that acceleration to directly understand "in the field" influences on your product's life.

Most people don't do that. Most people are happy to do more of a robustness type of test. They want to do something that's worse than the customer is going to do to it. They don't really understand what's going on in the field, so they'll add more heat, cold, cycles, or vibration to try and be tough on the product. They'll do some sort of acceleration that may or may not correlate to what's going on in the field. I get these all the time. People say, "I want 500–1,000 cycles of that." It reminds me of the American Tourister and Samsonite commercials from the '70s and '80s, where they used to take the suitcase and put it in the cage with the gorilla. The gorilla would beat this around for a while. If it didn't break open, it was reliable—a true robustness test.

Sadly, that gorilla type of robustness approach is a lot of the testing that's done today. They just say, "If it holds up to the gorilla, then it's going to hold up for my customer." That's an attitude, at various stages, that's usually cheap and easy to do. People have some confidence in that. That's what most "reliability testing" has become these days—a robustness test—because there's a disconnect between what's being done in the testing and what's going on in the field. It's easy, cheap, or they're copying what a competitor does or using an industry standard. But they're not going through the process of understanding what the correlation is between the testing that they're doing and what's happening to their product in the field.

Matties: Is part of the issue what they may do the reliability testing on, such as a prototype run, but the mass production run yields different results? How do you overcome that?

Neves: The assumption is that, whatever you're going to run your reliability testing on, the variation in the product that you're manufacturing isn't going to change much from when you run the test. That is rarely the case with PCBs as batch to batch, run to run, and lot to lot, introduce many possibilities for variation in the hundreds of processes that are needed to create a PCB.

Accepting this, reliability testing becomes a capability test. "I am capable of being reliable, but I don't know necessarily if my product, as I build it over time, is going to be reliable for the customer." I do my upfront reliability testing and say, "I'm capable of being reliable. I then have to monitor all the features that could vary, in the process of making my product, and make sure they don't vary in a way that would affect the reliability level I have established." I'm going to understand what variation does to my reliability. I may take lows and highs and run some reliability testing, so I can understand, "If this happens to the board, or that happens to the component, or this happens to the solder joint, this is how it's going to skew my reliability results."

Matties: Often, it may be using different manufacturers for their pre-production run versus where they get their final quantity built.

Neves: In today's environment, it's every component on the board. You have different manufacturers. You have different materials you are sourcing. You have all your trusted source issues associated with that as well and making sure you're getting what you really want—not seconds or copies. You're focusing on getting the product that you expected. Then, you have the normal variation in processing or switching from one component supplier to another component supplier. There's a variety of issues that you have to monitor to ensure your reliability doesn't change from that first big long test you did to make sure your product is reliable enough to be used in the field.

Matties: Are there any repeating defects that you see, time and time again?

Neves: When you start to look at the variables, the more complex the component, the more likely the component is to fail. When you look at a resistor or a capacitor, each of those typically has < 50 processes that it goes through to get to the finished product. Your opportunity for failure drops dramatically when compared to the many processes required to create a PCB because the component itself really doesn't have a lot of variables that can go wrong. It's a lot easier for the manufacturer to control that, and to have a good quality system in place that monitors those fewer processes very well and makes sure that the product continues to be repeatable as they manufacture it.

Moving over to things like transformers, PCBs, or other sub-assemblies that have into the hundreds of processes to create them, now you start getting interactions that become very difficult for the manufacturer to fully account for. Variation inherently creeps into the process via dependencies, and that ultimately affects the reliability of the product in the field.

Johnson: Earlier, you said, "Soldering simulation," in the context of preparing for testing. What is soldering simulation?

Neves: When components were primarily placed in holes, we used to do the solder dip test. We would take a coupon representing the PCB and dip it into a vat of solder to transfer a similar amount of heat to the coupon, as you would see in a wave solder operation. These days, it's mostly convection air reflow assembly and hand soldering for repair or some other sort of feature attachment that you can't do with an air type of reflow. In the field, at least on the PCB side, we have a variety of tests that put the boards through a simulated reflow process. These simulations try to get the surface temperature of the board the same as you would with components in a worst-case scenario of as many times and for the longest exposure that you allow the finished product to endure. However, many times, you would reflow solder the board and then possibly rework or repair the board afterward. The simulation of the component attachment process usually comprises four to six times of a severe reflow exposure. That's pretty typical in the industry. Someone would run a board through a worst-case reflow process four to six times. Understanding the most extreme damage that could happen during the reflow process on production boards, you try to simulate that same kind of damage and stress to

your coupons in the preconditioning simulations before your reliability testing.

This makes sense for not only interconnection and isolation issues, but it also makes sense if you're doing high-frequency testing because the materials will change their electrical properties after going through the component attachment process. Most of today's materials have a higher glass transition temperature (T_g) to deal with lead-free processing, but these materials are not homogeneous and contain a mix of a variety of different resins and additives. Even if you have a 180°C Tg rated material, that's not made up of a single 180°C Tg resin system. If they were to do that, it would be very brittle. The material would crack. You'd have all sorts of other problems. You have a resin Tg mixture of 130–140s, and maybe 160s, mixed into this magical group of resins to make your resin matrix for your high Tg material. High component attachment temperatures, especially the lead-free temperatures, affect the low Tg resins in that matrix quite significantly and can change the dielectric constant (Dk) and the dissipation factor (Df) of material in the PCB. Exposure to repeated high temperatures can change the resin matrices. When the matrices in the resin system start to break down your Dk and Df, along with it, your impedance will change.

When the matrices in the resin system start to break down your Dk and Df, along with it, your impedance will change.

For high-frequency products, it's important to expose the material to whatever high temperature you're going to do before you do your final high-frequency test because changes to the laminate resin system in the PCB from component attachment processes can affect the result. The solder joints themselves—there's another very complex process of creating an attachment between the surface of the board and the surface of the component, creating intermetallics of dissimilar materials and different surface coatings while preventing oxidation. This whole process has a lot of places where things can fail. Again, going from leaded to lead-free, the actual mechanical properties of the lead-free solder are not as forgiving as they were with the leaded solders. You have quite a variety of different lead-free combinations in the marketplace, and it's a little bit like baking a cake—a little pinch of this and a little dab of that. All these little things go in 1–2% quantities to improve the crystalline structure of the solder so that it doesn't have quite as much stress built into it that can cause failures in the field.

Johnson: For me, with a software background, I was wondering how that was modeled. It's a physical laboratory experiment.

Neves: Correct. In our lab, we have a 13-zone water-cooled reflow oven through which we will run boards and coupons, and other sorts of things. We have a HATS2 tester in the facility that will run reflow simulations on coupons, representing the boards while capturing electrical measurements during the entire process. You can look at the resistance of the vias during exposure to reflow temperatures to see whether they might be separating at the high temperature. Many times, when the materials shrinks back down to normal size again after cooling, you make what appears to be a solid electrical connection again.

If you separate a via or microvia due to the stress of the materials expanding at a high temperature, you can actually see this disconnection electrically at the high temperature. But as the PCB shrinks back down again during cooling, you get a mechanical connection that appears solid electrically, and you may never see that separation again at lower-temperature testing. The only time you're going to see that problem is at the highest reflow temperature when the vias are physically separated due to extreme expansion. You're starting to see that happen more on the PCB side

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where these reflow monitoring tests are starting to make their way into the PCB requirements, where people want to do this type of "electrically monitored" reflow simulation. There's electrical testing during reflow simulation, and then some type of thermal shock regimen afterward to make sure that you get some sort of cycling to show an acceleration of life in the field.

Johnson: Could you also revisit another phrase you used earlier when you said, "Reliability is expensive to understand?"

Neves: Take a vehicle, for instance. We do a lot of automotive testing at the lab. Most automotive customers have five or six different environments that they deal with and that their products need to survive in, such as a single car. You have the interior, on engine, in engine compartment, transmission sensors, brake sensors, etc., and even though they might be in the same car, they're going to be subjected to wildly different environmental and mechanical stresses. What's happening with your transmission sensor versus what's happening in your air conditioning electronics or your stereo system in your car is going to be very different. It would be easier to model life for the worst case and use that model everywhere (e.g., robustness), but that means you will spend a lot of money for parts that don't need that level of reliability to operate for the expected lifetime under less demanding environmental stresses found elsewhere in the vehicle.

If I buy parts that are certified for my braking system at 200°C and use them for my stereo, that stereo is going to be a very expensive stereo. It doesn't make economic sense to do that for every environment that you're in. It makes a lot of cost sense to understand exactly where your reliability level needs to be. That will limit your costs for your product as it goes into the field. Automotive companies have spent a lot of time and money modeling the different environments and understanding what it takes for decades worth of life in a vehicle, which is what they have to guarantee. They've taken that model and pulled it back to squeeze it into 30–45 days' worth of testing to say, "I know that if I use this model, I do a Weibull correlation on the data, and I take it out to a decade or two, my product is going to last for that time in the field. If it can survive this accelerated test, in this modeled environment, I know that product will also do that."

They've done this for each of the different environmental operating zones that they have in a car. When you qualify a product for a zone in your car, there is a set of specific reliability requirements associated with that zone, depending on the end-use environment. There are a certain number of cycles and specific temperatures or type of environment to subject the parts to. With all the different operating environments that you would expect to see throughout a vehicle, they work to understand and model what it means to accelerate that environment. It has taken them many years to come up with those acceleration models. They're very protective of those models because it cost them millions of dollars and years to create. With companies like Tesla that are relatively new to the game, their approach didn't evolve directly from another manufacturer or Tier 1 supplier. They're not using the procurement model that most established car manufacturers are using, where components are purchased from Tier 1 suppliers (HELLA, Continental, Bosch, Aptiv, etc.). These Tier 1 suppliers

have dozens of years' worth of experience in the automotive business, and since they are ultimately financially responsible for the reliability, they have done their homework on modeling.

Newer players in the automotive market decided they were going to start from scratch and build their own supply chain. It has taken them a little bit more time to step into understanding long term reliability because they've had to start from scratch, they're the "new" kids on the block. They're bigger companies, so they're able to spend that kind of money and effort to do that. But if you're a small manufacturer, you may not have the time or money necessary to do an appropriate job of modeling for reliability. In today's changing market, it's difficult going out there to say, "I need to model this," and spend all the money and time to understand it. You end up copying something from somebody else or saying, "This works for my competitor," or, "Let's just do the gorilla test. If it survives, that's good enough." A lot of that goes around, where people have just said, "I'm not going to spend the time. I'm not going to do a reliability test. I'm going to do a robustness test, and I'm going to call it a reliability test."

"If it's robust enough to survive this particular set of tortures, it's surely enough to last in my…" which may be true. That very well could be the case. But people tend to error on the side of conservancy. If you're doing the robustness test, you may end up spending more money than you really need to in your supply chain. Your product may be more expensive because of that because you've had to over-engineer it to be sure, and it may make you a lot less competitive in the marketplace.

Johnson: How does one approach this as a smaller manufacturer? Is one of those ways to use robustness instead of reliability?

Neves: Robustness is what most people end up doing. They call it reliability testing. People mislabel it as an ongoing long-term reliability test. But in reality, they're doing a robustness test. They truly don't understand the correlation between what they're testing and what's going on in their product in the field. They're setting a bar. What's happening right now, at least on the PCB side, is people are saying, "We have to do this reflow preconditioning for soldering. Why don't we just expand on that? Instead of just doing five reflows, let's do 10. If it survives 10 reflows, it's going to be okay in our environment." You start to lose any sort of correlation between what you're doing and what's going on in the field because you have so many additional acceleration factors. It doesn't make a lot of sense anymore. If you fail this robustness test, it doesn't necessarily mean that you're not reliable in a given environment. It could mean that, but it might not mean that.

A lot of products are thrown away today because people aren't passing these robustness tests, where the product may be fully reliable in the intended use environment. We have a long history of correlating ugly attributes as being unreliable. We do a lot of visual inspections, such as evaluating cross-sections or looking at solder joints. If it was ugly, we threw it away. We considered it not reliable if it's ugly, and that's just not necessarily the case. Ugly can be reliable.

Johnson: We have the ugly test, which doesn't necessarily show reliability but is often used. Then, we have robustness, which doesn't show reliability but has also been used. What other tests have masqueraded for reliability?

Neves: Those tests for "ugly" are easy and relatively inexpensive to do. That's why they were used. It's easy to hire an inspector to look for physical defects. It's easy to expose a board to more cycles of soldering. It's hard and expensive to do longer-term tests where you're looking at 30, 40, 60, or 90 days' worth of testing. The hardest thing is to really know where your product's being used and how that correlates to an accelerated test. That's the hardest thing. If people took the time to really know that, and really understand that, working backward toward true reliability would be a lot easier; but few focus on that. Everybody's focusing

on performance out of the box, and making sure that when the customer opens the box, it turns on.

The cellphone companies are great for this. My lab sees nothing from the cellphone companies because they're not concerned with product life five years from now. They don't necessarily want their product to last too long. They want you to buy next year's phone. They really don't need to do reliability testing because their expectation for their product in the field is such that they have a very short life, and they only have to worry about the short warranty period. They don't spend a lot of money or a lot of time doing reliability testing. They're focused solely on cost savings in manufacturing.

Johnson: Any parting thoughts on reliability?

Neves: I spoke in general terms about reliability in my discussion here, but many people talk about reliability and what it takes to be reliable. It's a hot topic. My goal here centers on motivating people to look closely at reliability versus robustness and getting it into people's heads that they're not the same and can't be used interchangeably. Companies need to understand the testing they are using and why they are using it. It's really about understanding what you truly get out of the reliability or robustness testing you are doing. If you're doing a robustness test, understand that you may be paying a little bit less now, but it may be costing you more because you're setting a bar to a higher level than you really need for your product to be reliable in your environment. Shortcuts can cost money, or it may be the other way around. You may set a bar that's too low. If you use someone else's experience and data and set a bar that's too low, all of this money and time you spent on testing doesn't give you what you really want to guarantee the acceptable life of your product to your customer.

Right now, companies seem to be focusing more on legal liability—doing something that looks tough—rather than understanding what it takes to ensure true product reliability. They look at these tests and say that going more cycles in a high-stress environment gives you more reliability. It's just not necessarily so. That confusion has been carried on in specifications, standards, discussions, and papers. People refer to these torture tests as reliability testing, when—in fact—they're robustness tests.

Matties: Bob, thank you so much for all your time.

Neves: Thank you. SMT007

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Reliability Starts at the Bottom

Quest for Reliability

Feature Column by Eric Camden, FORESITE INC.

Well, folks, it's my time to shine—or, at a minimum, be less dull. This is the reliability issue, and that apparently is my quest, according to the title of my column. I'm starting to wish my column were titled "Quest to Eat All the Pizza you Want and Not Gain a Pound," but reliability it is.

For those who might be new to my column, I work for an independent electronics laboratory that deals with root-cause failure analysis and product qualification of electronic assemblies. That includes all the parts and materials that go into that process. It also means that, on a regular basis, we see failed electronics discovered at in-circuit testing all the way to a product that has been in the field for many years.

In a nutshell, I can tell you it is much cheaper to perform product-specific reliability testing before the product goes into the field. If you find out after release that you have to work backward to discover the issue and determine whether everything in the field is at risk of failure and recall, then you still have to go back and do the testing that should have been done in the first place. The monetary cost of a recall can be more than the project was worth in the first place if you look at repairing or replacing products, and that doesn't even consider the other costs associated with a recall like a possible future business with that customer. The most important factor of your product may possibly be related to something that people need to stay alive.

One of the best examples of a recall being detrimental in all aspects is Takata automotive airbags. While it was not directly related to what we do in the world of electronic hardware, it speaks to the need for extensive reliability testing before release. The biggest cost associated with that recall is, of course, the loss of human life, but in the business sense, it cost Takata more than $24 billion and—in the end—the company itself. If the PCBA that controls your pizza oven goes out, the stakes

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are much lower (debatable) but most likely still could have been rooted out with proper upfront reliability testing.

This month, I plan to share some testing recommendations based on failure analysis, as well as lessons learned from a few of our customers over the years using case studies and data on failed units. Make no mistake, I will focus a lot on cleanliness and how it relates to reliability. "Write what you know," they said, so that's my plan.

What does reliability even mean? According to the all-knowing internet, reliability is "the quality of being trustworthy or of performing consistently well." I think that pretty much sums it up from the 50,000-foot view. When we get a little closer to the ground, we need to expand that to refer more specifically to the class of product being manufactured. Reliability and Class 1 don't really overlap in the big Venn diagram of quality; it will most likely work when it goes out the door. That's about it in a lot of cases.

What does reliability even mean? According to the all-knowing internet, reliability is "the quality of being trustworthy or of performing consistently well."

When looking at Class 2 and Class 3 hardware, there is most certainly a need to focus on reliability. According to IPC-A-610, "Class 2 Dedicated Service Electronic Products include products where continued performance and extended life is required and for which uninterrupted service is desired but not critical. Typically, the end-use environment would not cause failures" and "Class 3 High-Performance Electronic Products include products where continued high performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support or other critical systems."

What this tells me is that not all reliability is equal. When it comes down to it, there are minor differences between these two classes of electronics. Outside of some high-end exotic assemblies, most parts and assembly processes are used for both classes. The biggest difference is what happens if it fails. It's literally a matter of life and death in some cases. Sorry, I didn't mean to bring you down there, but it is important to remember that. The good news is that most companies building those types of electronics are on top of it with testing that would not be required for many Class 2 assemblies.

Enough of the pseudo-philosophical electronics talk; let's get down to it. Approving a new supplier for any part of your process is a major key to reliability because you need to know that the bare board and components aren't going to also supply a surprise down the road. Let's start at the bare board level. When it comes to guidance, anything that is agreed to between the user and the supplier will dominate any requirement from any other source.

In lieu of any internal guidance, most companies lean on IPC-6012: Qualification and Performance Specification for Rigid Printed Boards. Looking at the applicable documents specific to PCB manufacturing, there are 23 test methods within the TM-650, 35 related documents, and another 18 joint industry and other association documents. That is a lot of information for those who need it and should cover pretty much every conceivable combination of materials.

In no way am I suggesting you need to review each and every one of these documents, but they are there either way. If you start with IPC-6012, you can go pretty much anywhere in the testing realm, but not all tests are required—or even necessary—for new supplier approval. Some of the parameters to test for include plating thickness on PTH barrels and pads, solder mask cure, conductive anodic filament (CAF) resistance, and cleanliness, among others. Let's look at what some of those tests are looking for and the possible reliability issues tied to those.

I'm going to start at layer one of the PCB fab process. Quality really does start there, and

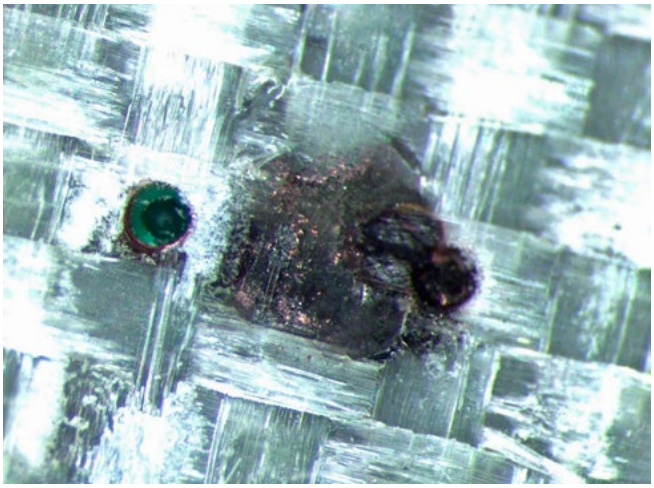

Figure 1: PCB inner layer dry fiberglass weave (All photos taken at Foresite).

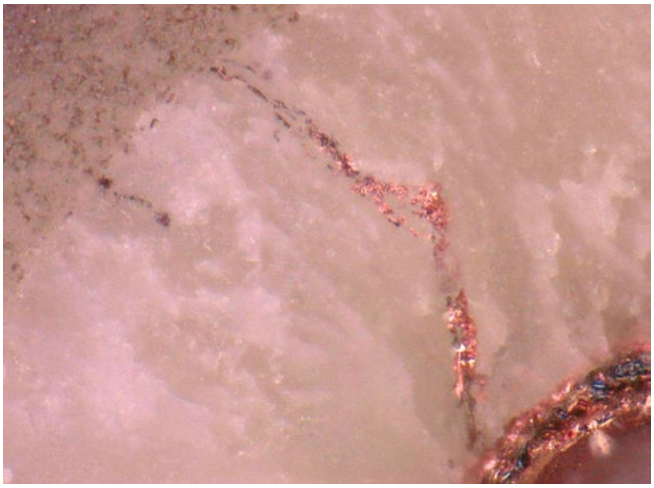

Figure 2: Example of CAF.

each subsequent step adds another opportunity to screw it up. The CAF test is used on bare fabs to determine whether process chemistries are present on the inner layer of the PCB that will produce electrochemical migration. This is the same as dendrite growth found on a fully populated PCBA. No matter where it occurs, if you have conductive residue, moisture, and potential, you run an elevated risk for electrical leakage and dendrite growth.

The CAF condition is greatly aided by poor resin flow, creating dry weave that will absorb plating chemistries and allow them to bridge anode and cathode. The IPC test for CAF is found in TM-650, 2.6.25. This is an environmental test that is normally done on test coupons manufactured by your PCB supplier using the same materials you plan to use for normal production. The test boards are subjected to elevated heat and humidity for at least 596 hours under bias. In Figures 1 and 2, you can see dry weave facilitating CAF that will render any subsequent processing steps meaningless.

Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) are among the best analytical tools for investigating CAF. By using SEM/EDS, you can determine the composition of the material and compare it to the base metals being used for barrel plating. Figures 3 and 4 show SEM and EDS examples. If it matches, you have CAF and need to work with your PCB fabrication supplier to optimize the process.

In your effort to optimize the bare fab process, you need to know what the contamina-

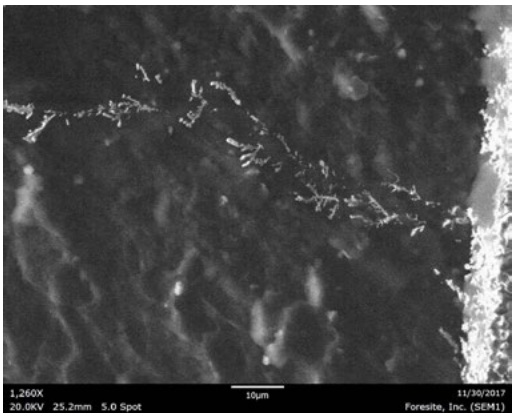

Figure 3: EDS analysis of CAF.

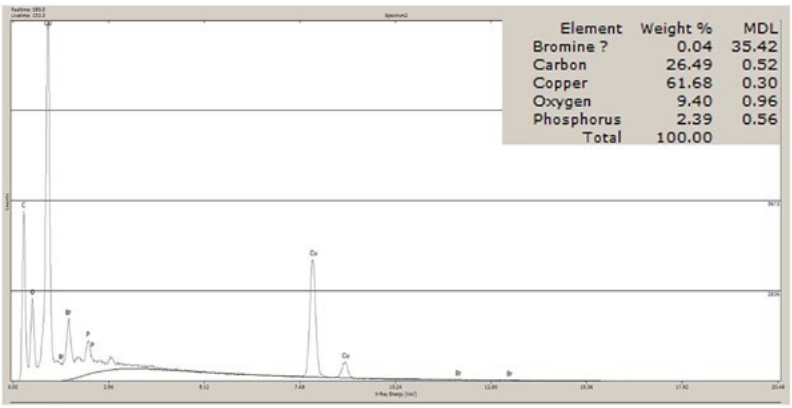

Figure 4: EDS results of CAF.

all values in ug/in^2		Ion Chromatography (Dionex ICS 3000) n/a = not applicable																
	Sample Description	Fluoride	Acetate	Formate	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate	WOA	MSA	Lithium	Sodium	Ammonium	Potassium	Magnesium	Calcium
ID	**Inner Layer Extractions**																	
1	Inner layer sample #1	0	7.96	0	0	0	0.04	0	0	15.34	0	0	0	10.25	0.11	0	0	0
2	Inner layer sample #2	0	7.86	0	0.48	0	0.09	0.05	0	18.46	0	0	0	9.98	0.73	0	0	0
3	Inner layer sample #3	0	8.01	0	0.35	0	0.08	0.04	0	16.39	0	0	0	13.52	0	0	0	0
4	Inner layer sample #4	0	7.82	0	0.39	0	0.09	0.05	0	23.51	0	0	0	10.13	0	0	0	0
5	Inner layer sample #5	0	8.27	0	1.11	0	0.29	0.10	0	24.88	0	0	0	11.91	0.28	0	0	0
6	Inner layer sample #6	0	8.58	0	0	0	0.29	0.11	0	15.71	0	0	0	13.55	0.10	0	0	0
7	Inner layer sample #7	0	9.54	0	0.46	0	0.02	0.06	0	19.32	0	0	0	5.54	0.84	0	0	0
8	Inner layer sample #8	0	8.06	0	0.43	0	0	0	0	18.68	0	0	0	6.95	1.13	0	0	0

Table 1: Ion chromatography results, CAF analysis.

tions are that facilitate the CAF. For that, you want to use ion chromatography. That will tell you exactly what ions are present and at what concentrations. Those results can be matched back to chemistries used in the plating process, and then the optimization is focused and can happen a lot faster in most cases. The IC data in Table 1 shows typical ionic content from an inner layer cleanliness issue, high levels acetate, sulfate, and sodium residues. These ions are normally found in plating chemistries and suggest that the final rinse is insufficient to completely remove all the residues.

Ion chromatography should also be used on normal production PCBs to determine the level of cleanliness on the outside surface. If IC is to be used for process monitoring, you will want to perform global extractions for baseline data. Localized extractions over concentrated distributions of plated through-holes, over-plated pads, and overly-bare solder mask areas should all be considered to get the clearest idea of just how clean each of those parts of the process is.

Solder mask cure is another critical parameter that should be examined. When a mask is properly cured, it will exhibit a continuous smooth texture, like a marble countertop. If the solder mask is under cured, the surface will be rough with nooks and crannies, like an English muffin. The same way that muffin will hold delicious butter and jam, the solder mask will hold flux, wash chemistry, and other processing residues.

The IPC test methods related to solder mask cure are 2.3.23B and 2.3.23.1A. These are chemical tests that use drops of methyl chlorine or methyl chloroform on the solder mask, followed by using a wooden spudger to see if you can scratch the mask. If it easily scratches, give it a "cure bump" with either UV or thermal exposure and then repeat the test. If the mask is then unaffected, you can go back to your supplier and have them adjust their cure profiles. Uneven solder mask coverage can expose the base metals to less than optimal environments, and that alone can be enough to cause issues like corrosion (shown in Figure 5). There are many different tests specific to bare boards, so it's a good idea to consider the end-use environment, warranty period, and any other product-specific details to determine which test is most applicable for your product.

Many of the same processes used for the plating of bare boards are also used for component leads. Both processes use chemistries that can increase the risk of corrosion or issues related to electrochemical migration if not fully removed. This happens with components when those chemistries find a way up into the die area, causing corrosion and dendrite growth. This can easily happen when there is a

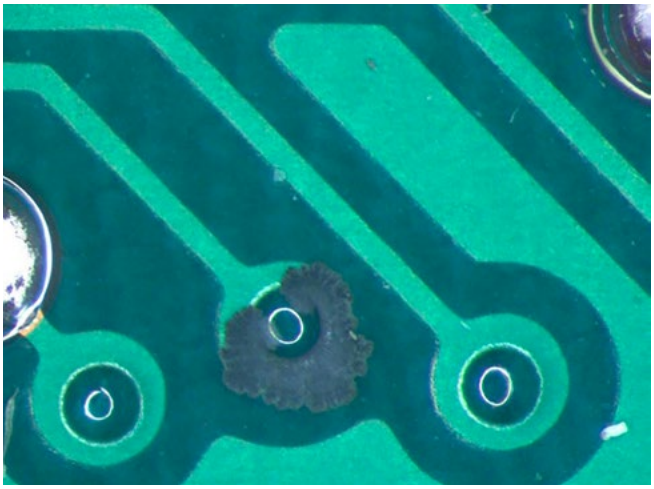

Figure 5: Corrosion in solder mask with pinholes .

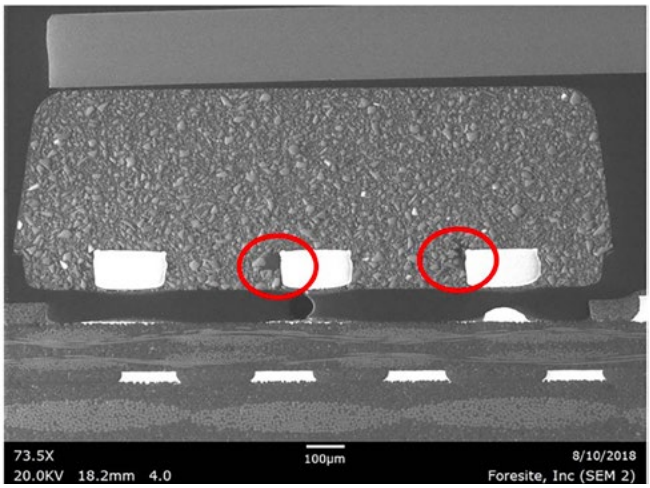

Figure 6: Gap at overmold lead frame interface.

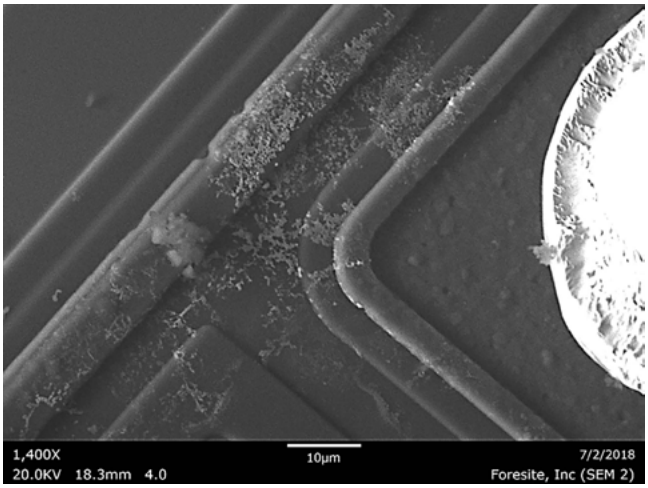

Figure 7: Dendrite on package die.

small gap at the overmold/lead frame interface (Figures 6 and 7). Even if the residues don't make it all the way to the die, they can be present on the edge of the package body between the leads and propagate electrochemical migration (Figure 8).

If you are using a fully no-clean assembly process, you can't rely on an end of the assembly wash process to remove any of those residues. This is when you can use IC analysis to determine the effectiveness of the component wash process. Standard bag extractions will detect any elevated levels of ionics on the outer surfaces. For internal surfaces, Parr Bomb analysis is a pressurized extraction for harvesting possible plating residues that have been absorbed into the component overmold material, down to the lead frame. This can be done without any physical damage to the component. Much like the bare boards, components bring their own inherent reliability risk before the first part is soldered.

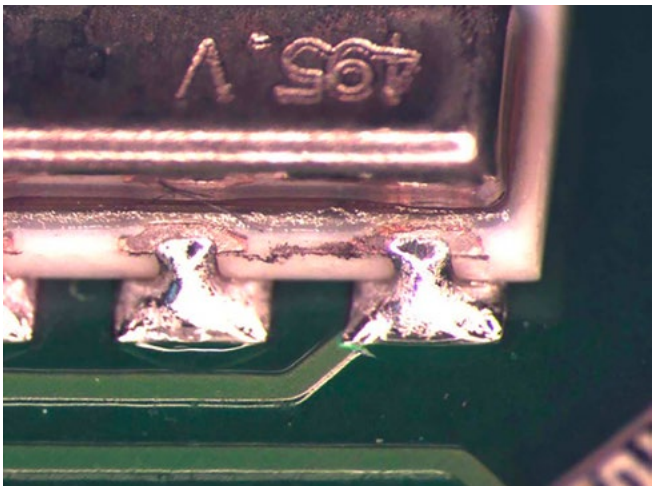

Figure 8: Dendrite growth on package body.

Now that you know how those raw parts can impact your reliability, let's put all those pieces together. Per IPC J-STD-001 Section 8, you need to qualify an assembly process using SIR per TM-650 2.6.3.7 on test boards to show how well the CM is processing the proposed set of materials and what impact elevated heat and humidity have on electrical resistance. This test is the bare minimum that needs to be completed to verify the assembly process. Contract manufacturers need to do this testing to generate objective evidence that can be applied to process monitoring analysis. As most people know by now, the historical acceptance criteria of 1.56 µg NaCl equivalence per square centimeter has been given the old heave-ho, and rightfully so. If you want some details on how and why that criterion was removed, I recommend reading IPC-WP-019: An Overview on Global Change in Ionic Cleanliness Requirement. (Spoiler alert: It should never have been used as it has been.)

Here is an example of how a CM can generate objective evidence and use it for process monitoring. If a company needs to qualify a product with a new customer, and the

plan needs to include monitoring the approved assembly process, they choose test coupons that are most representative of their final product based on the mix of SMT and PTH components. They then assemble boards using the proposed combination of materials and equipment to be used for the final product. Along with two bare reference samples, the assembled test boards are tested per IPC 2.6.3.7. If they pass that test, they are tested with ion chromatography to determine the average levels of specific anions, cations, and WOA to create baseline data.

Next, they build a set of 20 samples of the actual product. A set of 10 boards are tested using ion chromatography with global extraction. The second set of 10 is tested in a ROSE tester. The average of the ROSE test results is the acceptance criteria used on a per shift basis. Remember that the number is being derived from your ROSE tester and can differ from another machine of the same make and model. It doesn't really matter if that number is 1 or 101 µg NaCl equivalence per square centimeter. That number has been verified with other testing. Often, IC testing is done on a quarterly basis for further evidence of process control. The quarterly test results are compared to the baseline.

Some customers will also perform elevated heat and humidity exposure testing with normal operating voltages to further validate the acceptance criteria. This is known as temperature-humidity-bias (THB) testing and is similar to SIR testing. THB testing is done on actual products using normal operating voltages and duty cycles. This is one of the most important tests to consider because while the test coupons are considered predictors of performance, a lot of things change when it's the real deal.

A large percentage of reliability failures we see are tied to cleanliness. In this column, I have addressed bare board, raw component, and test board assembly cleanliness, but those are only three sources for contamination out of a much larger number of options. Anything that can come into contact with the PCBA, either directly or indirectly, is a possible source of contamination. You must consider testing everything around the PCBAs, such as housings, large connector bodies, and any other number of materials.

We see a lot of failures that have good objective evidence of their assembly process, but because they were only testing the PCBAs, they don't see the full picture. Materials like mold release on metal and plastic housings can be very ionic. If enough atmospheric moisture is available, it will collect at a low point and drip down on the board. That moisture can contain high levels of ionic content from the housing interior surface.

We have seen vibration dampening foam be extremely high in ionic content that was pressed directly against the surface of the PCBA without doing any cleanliness testing on the material (Figure 9). This was used in an under-hood application and not hermetically sealed. This was done on purpose by someone getting paid to make those types of decisions. It can happen to the best of us. With any luck, someone reading this right now will start to think about every part of their product outside of just PCBA manufacturing that can impact their product reliability.

I have barely scratched the surface on reliability testing, as so many are product-specific. Some products require a lot of vibration or extreme temperature exposure testing, but what I have covered applies to every product foundation. The title of my column this month

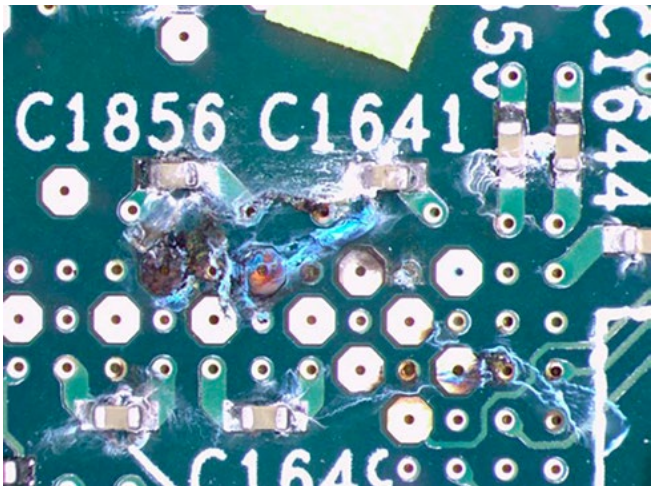

Figure 9: Impact of vibe dampening foam.

is "Reliability Starts at the Bottom," and by that, I mean at the base of every electronic product. At a minimum, you must have components, bare boards, and assembly materials to build an assembly. You must be able to confirm that you are building on a reliable base.

I reference IPC test and guidance documents frequently for a good reason; they are compiled by industry experts and, when followed, will more than likely yield a reliable product. I also frequently say that IPC has no idea what you are building specifically, so it's imperative that you own your product. By that, I mean which tests are required for both initial acceptance and ongoing process monitoring? Being product-specific with your requirements might go above and beyond what IPC—or any other industry association—recommends, but it's the best thing you can do for your product's reliability. And isn't that what it's all about? Well, that, and pizza, of course. SMT007

Eric Camden is a lead investigator at Foresite Inc. To read past columns or contact Camden, click here.

Eight Ways to Create Transformational DNA in Your Organization

Businesses of any kind and any size can infuse transformational DNA into their organizations. Creating a strong foundation is key, but having a culture ready to transform, be adept at adapting, and able to pivot on a dime are necessary to thrive during unexpected times.

To move a large organization in a new, positive direction requires much more than a top-down approach. It's a wavelike motion starting at the top of the organization, but the movement quickly needs reciprocation from the bottom. Here are eight ways to form transformational DNA within your organization:

1. Customer Success Obsessed: We are living in the age of the customer. Embrace it. Analyze how actions benefit the customer and look for ways to improve the process.

2. Define Your North Star: Clear goals, free from interpretation and laid out without contradiction, eliminate distractions for your organization.

3. A (TMO) View of Success: It is not good enough to simply deliver a project management office (PMO). Full value derivation is only truly realized when transforming people, process, technology, and culture, or transformation management office (TMO).

4. Different Problems Require Different Technologies: You have to select the technology very carefully and ensure it is in service of business and not a goal unto itself. Solutions should be solving problems, not looking for them.

5. Commit to a Framework: Any transformation requires interweaving people, process, technology, and culture.

6. The Most Important Element = Culture: Individuals need to be engaged, and teams need to be high performing.

7. OpsDev: Have developers sit directly with operations teams, observing fast-paced flows in real-time, then deploying highly effective enhancements and fixes.

8. Recruit Everyone: Recruit everyone's minds and hearts. A broad and deep collection of transformation-minded individuals can be the difference between collective execution as opposed to endless stakeholdering.

(Source: AT&T Newsroom)

Ensuring Definitive Manufacturing Reliability

Feature Interview by the I-Connect007 Editorial Team

The I-Connect007 editorial team spoke with Russ Steiner, ECAD team leader at CASCO Automotive, about the manufacturability guidelines he has implemented for their products to enable better communication through the supply chain.

Nolan Johnson: Russ, let's start with an introduction to your background, where you work, and what your role is.

Russ Steiner: I am with CASCO Products, an automotive division wholly owned by Amphenol, and we operate worldwide. My role is leading the design team globally using Altium NEXUS and maintaining our ECAD library and working with our sourcing group so that we use our Altium NEXUS system to control all the components that we use in our managed library. Those same library components are shared with our sourcing group so that we can collaborate through our ECAD tool and make sure that as we design things, our sourcing group has visibility into what we're doing. This way, they can start planning manufacturing success early on with our component selections and help us verify the supply chain and get costing. I lead the group and manage the whole NEXUS operating system for our engineering teams around the world.

I have been doing PCB design since 1979, so that's 40+ years of doing the same thing. One would think it would be boring, but it never is. I absolutely love my career choice. Generally, other than the pressures to get it out right and on time, this job has been great to me. I like furthering my knowledge so that as I'm designing, I'm always looking for things that we can bake into our components or design practices so that a lot of the DFM work that we do with our suppliers is captured as lessons learned and embedded into our processes.

Johnson: At the union where CAD tools and manufacturing meet, are we doing a better job with design for manufacturing and anticipating manufacturing in the design process?

Steiner: I believe we are. Companies have the insight and knowhow to set up things like spe-

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cific footprints to take care of specific conditions that you run into in manufacturing. For example, bottom-terminated components were a real challenge to get acceptable solder joints and acceptable flux residues when one does no-clean board assembly. Cleaning is an expensive thing, so we have weighed that at CASCO. For the last 10–12 years, I haven't been doing anything like military or avionics or anything that mandates thorough cleaning. The commercial and automotive stuff that I've been focusing on is all no-clean.

Russ Steiner

In the example of bottom-terminated components akin to QFNs, I include some things in our footprints like weeping wells for the flux so that, as the solder paste is reflowed and the part collapses, solder gases from the flux have a place to go and collect that's anywhere other than under the component. If you have the experience and knowledge and can anticipate things, cooking things like that into the footprints really helps.

Johnson: If you look at the demographics of our industry, we have a lot of engineers, designers, and project managers who have been around for a long time. There's a large age gap. The next wave behind is in their 20s and early 30s. How do we keep that critical information around?

Steiner: That's an interesting question because the entire ECAD/EDA industry has shifted to focus on that up-and-coming group of individuals. Again, last fall, I was at AltiumLive, where they polled everyone to find out how many people were PCB designers using the Altium platform and how many engineers were doing their own circuit layout. It is interesting to see that each year, more and more are coming straight out of school and laying out their schematic and then doing their own PCB design. There is a loss of tribal knowledge from the more experienced people in getting all that information. There are a lot of things that I don't need to think about, as it's just second nature to me. But to someone who does not possess all that experience, there's a lot of things to learn.

Johnson: I'm thinking about the specific example you just used a few minutes ago—the well to allow for gases to escape, etc. With experience, that would become second nature, but that's not the sort of knowledge that's particularly obvious if you strictly design and haven't been exposed to what happens on the manufacturing side.

Steiner: In the '80s, there was a lot of surface-mount development going on in some of the designer groups that I participated in, like SMTA and the IPC Designers Council. In the SMT fledgling period, when parts became widely available, we didn't really know what to expect in design as no one had that experience. And we started putting surface mount parts on everything. A lot of that knowledge had come through trial and error because even in the IPC-type communities, SMT specific standards were being developed along with the industry learning. We started doing a lot of trial and error learning. There really wasn't very good information, so we were all learning together.

Johnson: You have a team of people that are doing design that you watch over. How do you bring them up to speed on what are the appropriate manufacturability guidelines for your products?

Steiner: I asked myself that same question, and I didn't have a good answer. I created a system where I use SharePoint, and I have a desktop shortcut that I created and have pushed out to all of our engineers. Anything an engineer needs regarding a PCB design—from the design queue to the work logs and all the way through what acceptability requirements—will

apply. I have written a number of engineering requirement documents that are all clickable through that SharePoint link. My users will open up that desktop link, and it presents them what looks like a website with clickable links that bring any of the documents to the user's desktop, and the nice thing is these are evergreen; the documents they open are never out of date.

No matter what part of the design they're in, they can just click to open the documents that we've written, collected, and linked that way. I've put it out at their fingertips because there is a ton of information, and that has been working out pretty well.

Johnson: Do you find that you're getting traction?

Steiner: Absolutely. With the number of questions that were coming up—and even worse than that, when the questions didn't get asked, or schematics start coming out looking like they're from a couple of different companies—having a set of easily referenced guidelines keeps us all headed in the same direction. Board layouts are evolving the same way with design consistency. Our schematics look the same, and our board layouts have the same good techniques embedded.

Johnson: To what extent are these guidelines driven by your supply chain or your manufacturing chain? Do you have a captive facility there that you are using?

Steiner: Our captive facilities are at the box build level. All of our electronic manufacturing is outsourced to EMS partners, and we house some of our EMS partners right in our buildings in some locations. It's nice that we can push over the requirements, go over and participate or just be readily available to make sure everything looks good. That's working out great for us.

Johnson: Some of these partners are "captive-like" in that they're as close as if they were just a department for you.

Steiner: That's true because the lines that they run within our facility are only going to be for CASCO or Amphenol products.

Johnson: How close is that collaboration between manufacturing—your EMS partners—and what ends up in your design guidelines.

Steiner: The thing that you would need to know is what capabilities this supplier has, do they have everything that we need and are those operations something that we can go audit and approve? And so that's what we did. I joined Amphenol in 2018 in the spring, and I've already gone to five of our board fabricators in China and three of our EMS operations. By learning what the possibilities are and understanding what the equipment is, we write some of our design guidelines based on what our suppliers could do specifically.

Johnson: It becomes a working relationship to make sure that you have the guidelines set up for what the machinery and the skills and the techniques are with your manufacturing?

Steiner: Right. Our sourcing group does what sourcing groups do, and they're out looking for opportunities all the time. When we find an advantage, such as a lead time or improved PPM, those need to be reined in and contained. Our engineering group must approve any of the fabricators that are used.

Johnson: With this work to put together guidelines, etc., what metrics do you track through the product life cycle? How do you calculate ROI?

Steiner: It's hard to directly measure the return on the efforts of engineering to follow estab-

lished practices like I am promoting. As far as the management of product quality, we have industry standards our customers measure our products by. With good results at the factory, it's difficult to measure the ROI on the enhanced efforts we go through, but it definitely contributes.

Johnson: Do you find that your design requirements drive your EMS providers to change their capabilities?

Steiner: At CASCO Novi, we design power inverters. Power inverters have to handle a lot of power. We design automotive DC-AC power inverters that take 12-, 24-, or 48-volt DC voltage, and from that, produce 110- or 230-volt AC output. Some of the units we have need to go above 2,000 W (two kilowatts). That is a lot of power to process. We have some copper areas onboard that handle in excess of 100 amps. Getting the components to be able to conduct that much power and make them solderable at the same time is a big challenge. A specific example is that for cost reasons, we would normally like to wave solder. For through-hole devices, it's a low-cost option, but we can't always do that. We sometimes need to go to selective soldering instead, where we can put the dwell time and temperature exactly where we need it to get particular joints adequately heated and produce a quality solder joint. There is a lot of learning that goes on in that kind of situation.

Johnson: It sounds like the fact that you have your EMS providers so close to your design team, physically in the same building, is pretty important to the success here. It would seem to me that if you were working with vendors who were more at a distance—an open job shop, if you will—it would not be as open or detailed.

Steiner: Communication is king. The worst case is having something that needs to be asked or mentioned and it isn't happening, or if you're working at long distances, communication is often in a second language and sent through PowerPoints and emails. The ability to stroll over and take a look at what's going on is really nice. We don't just invade their operation, but at any given time, a question may come up, and we can look and participate.

Johnson: Do you have any projects for which you use an open job shop? Or when you scale up into full-scale production quantities, are you moving outside of the EMS providers in-house?

Steiner: No, not currently. We have to evaluate as we go. Markets and geopolitical climates change over time. As we are all aware now, in a global pandemic, we ask whether we are doing the right things. They're set up to go from NPI activity right into production at our EMS partners. Our various products run anywhere from 50,000 units a year up to millions of units a year, so they're not small operations. The only thing that we do on the open market is development and prototype as a quick turn. And as any engineer knows, you'd go anywhere to get that quick turn done and save the day. The development stuff we do early on is usually done in the quickest we can get it. Having quick-turn access to prototype assembly helps keep us nimble and flexible to changing demands. As early as possible, we want to run our development stuff down our intended production line. We'll schedule for that and make sure that before we start going through our release gates, we've already run our product down the line to verify it's going to be successful.

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Happy Holden: When I joined an automotive supplier, I asked their design manager, "What's the operating life for the products?" They said, "15–17 years, which is well beyond the warranty period." I said, "Great. Can I look over the data on your fabricator's components in assembly and materials, indicating that they're capable of that?" They didn't have anything. Indirectly, I brought up, "How do you know you're designing for 15–17 years?" They responded, "We don't see any products coming back." I pointed out, "After the warranty, it is difficult to get products back that may have failed."

I started looking into the basics of having 15-year reliability. For some of their customers, any kind of field failure required them to jump through an infinite number of hoops to find the root cause. I was surprised to find that some of their fabricators and some of their materials were a three- or four-year life. They didn't have a 15-year life, and those were dropped and replaced with the appropriate capability. When you're doing manufacturing reliability, what does that mean from a design manager's point of view?

Steiner: I'm not a design manager myself. I enable the engineers to be successful in working with our engineering management and design managers. It's not exactly a question for me, but you have to get the right tools to the right people with the right requirements. That comment about 15–17 years is strange when you look at the available components. None of the components in any combination would get you close to that kind of a time span. However, using them properly and making sure you're not stressing particular components to their very edge helps to make that longevity possible. As people used to say, you may have flat tires and an engine that is broken, but the radio still works. It's still true. I find the electronics that go into cars are designed so well, in most cases, that you exceed the component's recognized capabilities. It happens all the time.

Holden: The components are well-handled. What's not well-handled is that the individual product is designed by groups like yourself. They select the materials, the fabricator, and the assembler. When you put it all together, is it going to work sitting in the Arizona sun or last through the winter in Alaska or Finland? Automotive stuff can be long-lived, and some of the products that we designed were anti-collision and safety systems, and if they have to be replaced out of warranty, they're a $2,000 replacement. You can imagine how unhappy the customers are when five years after they bought the vehicle they have a $2,000 replacement.

I took it seriously when they said they design a product that's going to last 15 years. And they had the environmental buildings and environmental chambers to take their products and put them through the accelerated testing that would indicate 15 years in terrible conditions., as well as sites in Arizona and other places where they stake things out, power them up, and sit there with 15 years' worth of inventory in day-to-day conditions.

Steiner: Happy mentioned taking products out into Arizona and things to do with the entire automotive environment, it's got to be one of the harshest things because you never know where the vehicle will spend its life. Is this going to Siberia, or is this going to the Sahara? Those are opposite ends of the temperature spectrum, and it affects the PCBs in different ways. But one of the things I learned at my former employer was that cleanliness on a PCB is something that you need to maintain a grip on. Whether it's sulfur gases, salt, temperature extremes, or combinations of those, you either have ways to control the cleanliness and protect the surfaces or, sooner or later, you are going to have early life failure problems in your product. I have focused an enormous amount of energy within the last 10 years, ensuring that we have the ability to test specific areas on our electronic assemblies and understand what the cleanliness level is. Not doing that can quickly lead to recalls.

There is a particular event that happened when I was with a door lock company that really opened my eyes to the fact that soldering residues are an outright enemy of good

electronics packaging. I learned all about what excessive heat, humidity, and temperatures can do to an electronic door lock if the PCBAs are not acceptably clean. Through that, I learned a lot about how we can assess the cleanliness at a very detailed level at specific locations on a board assembly and understand what chemical residues are going to be acceptable. That whole area for us is something that our customers don't require. Customers demand and expect that things that affect longevity negatively, like cleanliness, are handled by CASCO, and we deliver. They need our product to go out there and work for a given length of time at a given performance level, but they don't require us to hit specific cleanliness levels. They leave that up to us to maintain or to manage, and they trust that we get that right.

Johnson: Where do you still struggle to get the kind of reliability from manufacturing that you're looking for?

Steiner: Probably that cleanliness area where the industry recognizes that the standard we had used, like the ROSE standard—which measures the bulk electronic assembly gross residues that remain—is almost a useless task to go through. It doesn't give you all the information that you need. That whole area is not well-controlled by any of the standards organizations. I know that ROSE testing as a standard was removed from one of the specs recently, and the intention now is to have a more specific understanding of the residues that are in areas of concern on your board. That probably is the area that we can't just point to a standard and get success. You really have to do your homework and come up with your own standard to follow.

Johnson: What do you see on the horizon as upcoming challenges? Where's the industry going with regard to design for manufacturability?

Steiner: In general, we find that our buyers, as we get to know each other, know what things to look for, such as weaknesses in our design inherently because we have to design a specific way. There are challenges, such as the difficult components to solder. We use heavy copper. Like this 2,000-watt inverter I've mentioned a couple of times has 22 ounces of copper in a six-layer board. That's extremely heavy copper. But if you think about what it would take to conduct, for example, 100 amps of current, that's an enormous amount of copper. Getting that kind of learning on how you can pull this off and then reducing that to an acceptability spec, there's some stuff in there that we pay attention to. But at the end of the day, you have to meet IPC Class 3. That's the goal. Getting there is something that somebody needs to focus on, making sure you're maintaining all those things that go into those good solder joints and reasonable residues and things. But the lack of a single specification or a single direction to follow makes it a little challenging.

Johnson: How does test and inspection equipment fit into this process? Does this work reduce the critical nature of the test and inspection, or are you more readily able to design the defect out so that test and inspection finds fewer issues?

Steiner: We ask for feedback from our suppliers—anything that they can Pareto out and get the heaviest hitters to bubble to the top so we can look for areas we can improve on in the design. We don't get a lot of that feedback, and

that's a good sign because we're doing things right before we get it into manufacturing. But we do go back and Pareto those defects and look for what we can do to get the defect rate even lower.

Johnson: Are they fixing the issues and keeping quiet about it? It's common knowledge that some fabricators and assemblers simply do that.

Steiner: The analogy of "we'll send out Gerber files and ask for a good board" is kind of the same. Unless you document the actual requirements and ask your suppliers to show their work, they're not going to because it all takes time, and there are costs associated. I look at it as an investment rather than a cost, though. When we put something like a C3 tester out on the line, we monitor our production residues, and when some trend starts to head the wrong direction, you can quickly get that process back in line due to the live monitoring of residues. By continuing to do the nondestructive testing like the C3 offers us, we are always aware of residue levels so that they don't get out of hand. We have written our standards so that anytime we may make a request, our EMS providers need to provide us the C3 results. You're only going to get what you ask for. And if you don't ask for it, suppliers are not going to make extra work for themselves.

Johnson: And then you can bring that data back into making decisions around how to design later designs.

Steiner: Yes. When we see something that's causing issues, we seek to avoid that situation the next time wherever we can. Layout affects how difficult it will be to get reasonably clean results. There are things that we have learned and continue to learn. It is reassuring that we can obtain conformance documentation like that when needed. It works out well for everybody.

Johnson: For CASCO and Amphenol, what's the objective with all of this effort in design and manufacturing? What's driving this work, such as aiming for longer product life, better overall reliability, and better manufacturability that allows for better margins?

Steiner: It's the need to avoid controllable defects from escaping a supplier and to maintain low warranty issues. Avoiding manufacturing losses is a goal. Of course, fewer defects are good for maintaining margins. There are always things to be learned when we get feedback from the field or from suppliers. That gets addressed, good or bad, and then, as needed, we update our guidelines. Surprises come less and less frequently these days. Our efforts in this area contribute to operational efficiency.

Johnson: Those certainly are good goals that help cost reduction up and down the product life cycle. And it's clear in the company culture that a well thought out, well-planned design of the product will do exactly that.

Steiner: It does. And we were talking earlier about the younger engineers that are coming on. The better you set those engineers up with the ability to put their fingers on something they need to be answered as they're thinking about it, the better the return. It helps our suppliers, too, because the less variability that we ask for in our designs from the common practices, the more we ask them in effect to do the common processes a consistent way with less variability, which allows our EMS providers to be a better supplier. We don't want them to have to learn something different for any two or three different oper-

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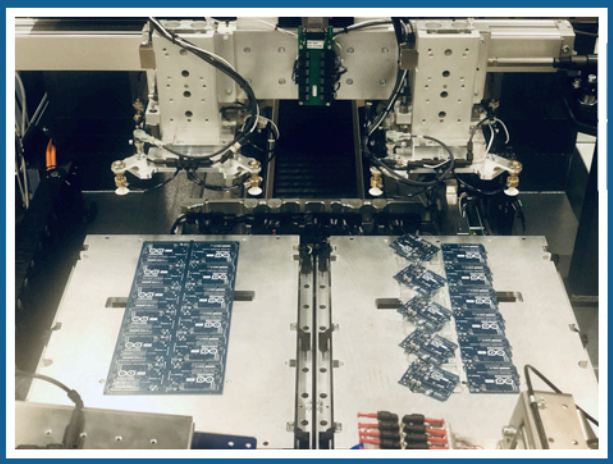

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ations that could be done the same way if there's really no compelling reason to do a given thing differently.

Holden: A couple of times, you mentioned transferring Gerber files and things like that. Gerber is a 60-year-old artifact of our industry that many of us wish would go away, but we can't seem to kill it. What's your opinion about data transfer and Gerber versus ODB++ and IPC-2581?

Steiner: One of the things that we maintain is a separation between our fabrication requirements and our assembly requirements. And when we generate packages for our suppliers, we generate everything to do with fabrication, which goes directly to the fabricator. We don't put the same information mixed in with our assembly stuff, so we maintain some security and privacy around trade secrets and things, such as pushing all of that information in well-documented formats that are easily understood and controlled, like Gerber. G-code is hard to mess up. If I do something more complicated like IPC-2581, I need to separate the fab from assembly. I understand I can do it, but I can separate my assembly portions and push those out to the EMS provider, and then the same is true with the fabricator.

But being that we're automotive, all of our industry suppliers and customers understand Gerber. They don't all understand IPC-2581; even though it's really cool, it's still not widely viewed as mainstream. And for me, I don't get to see IPC-2581 outputs in the same way I can separate that stuff and analyze each output the way we've been doing in some industries, like automotive, to maintain that known good comfort level and standard. And for us, the data exchange is working out fine using the old stuff. You mentioned it is a 60-year-old artifact, but I'm a 62-year-old artifact, and I'm doing fine using that old stuff!

Holden: Does your organization have any roadmaps regarding the smart factory and Industry 4.0 looking at the future?

Steiner: CASCO is not really focused on the leading edge or Industry 4.0. That's sort of thing is left up to our EMS providers to pursue on their own.

Johnson: From your perspective, do you see that situation as enabling better design for manufacturing, or could that potentially get in the way?

Steiner: I don't know because I really don't know how much our suppliers are focused on the new factory automation and controls and communications. I'm more results-oriented at the product level than the business level. I couldn't comment on how it's going or if we're suffering from not having it.

Holden: One interesting thing about power inverters is that temperature and thermal is a big design issue.

Steiner: There's heat everywhere. There are spots on a lot of these products that handle so much current, efficiency losses, and thermal management must be handled well, or you can end up with an area you could cook on. Our engineers work hard to produce designs that can be operated cool enough to extend that lifetime as much as you can. In designing high current power inverters, you're often up against many limitations of components or physics, in general. Locating robust components with adequacy in availability, cost, and junction temperatures can really be a challenge.

Holden: A lot of those new power devices were bottom termination, especially the lead-free, that induced the whole new set of how to clean with lead-free and not have voids. That's why, a lot of times, they use the bottom termination.

Steiner: And it's a challenge sometimes when we use surface mount devices. There are pros and cons. Thermal management is something that we spend a lot of our time on when we're doing a layout. I focus on making sure that we have design rules that are adequate, as well as the production capabilities that our EMS providers are going to be able to produce that

layout. We have thermal challenges in terms of solderability that need to be addressed because, in the end, we need to get that Class 3 solder joint, every time.

Holden: Up to what thickness of copper do you sometimes have to use on your inner layers?

Steiner: Four ounces is a common inner layer for us. But on the external, we start with one-ounce foil, plate that two ounces, and plate heavy vias and heavy barrel plating. I often require double the normal via barrel plating. Instead of one mil, we're sometimes at two mils, and all of those things add up together to get us the thermal conduction performance that we need.

Johnson: Any parting observations?

Steiner: We're having success. The biggest thing that you need to do is write things down so that you can share that knowledge and point to a document that's legible. When the industry standards are lacking for your needs, create your own. I do that as needed, and these become CASCO standards. It's worth the effort. You reap benefits by doing things in manufacturing the same ways, consistently.

Johnson: Any team, any size should be following that practice. Thank you for your time.

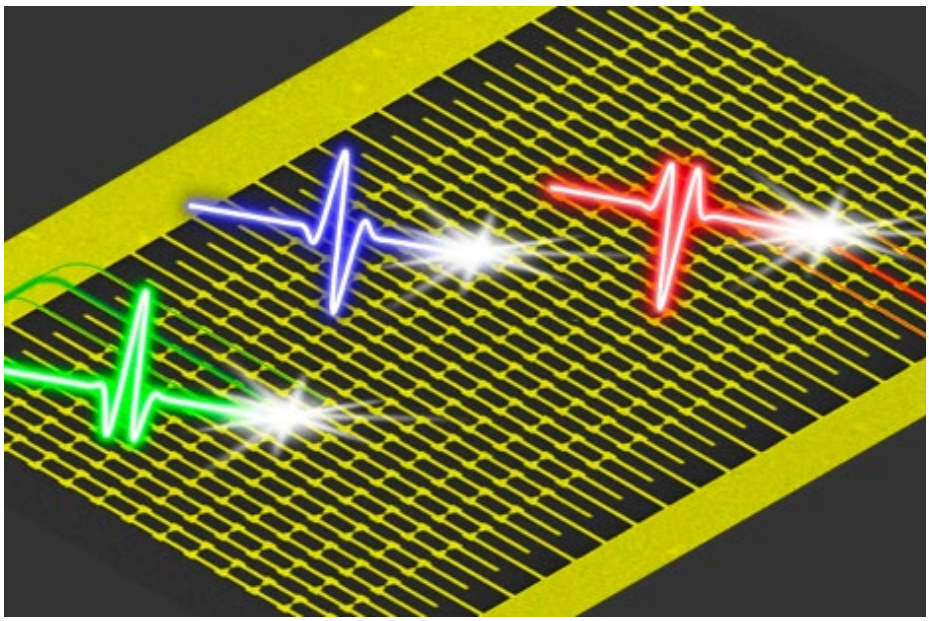
Steiner: Absolutely. SMT007

Integrated Lightwave Electronics

Light waves oscillate far faster than most sensors can respond. Essentially all commercial light sensors act like a microphone that can tell what a crowd of people saying but can't make out any of the individual words.

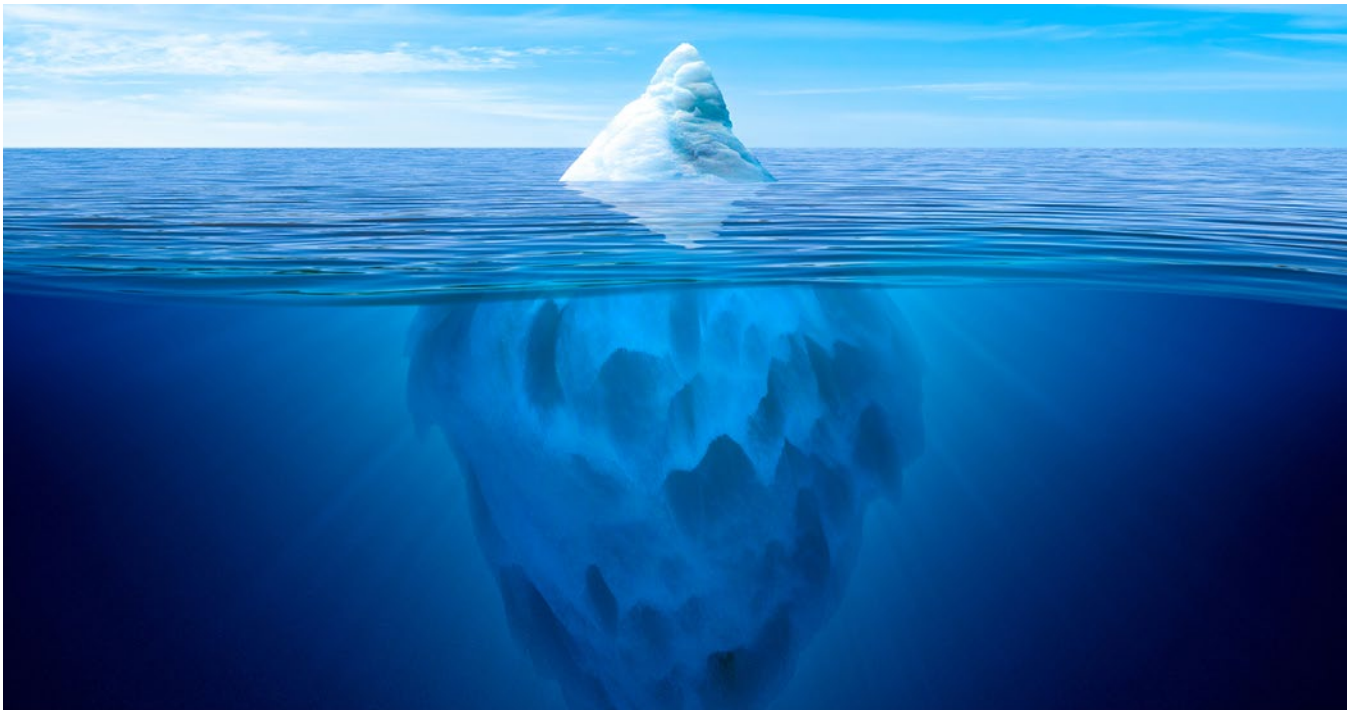
Scientists and engineers have been devising clever techniques to sense the light field itself, not just the total energy it delivers. This is difficult because the required timing precision is so short–just a few femtoseconds. As a result, work has been limited to a few specialized research laboratories. What is needed is an approach that is compact, manufacturable, and easy to use.

MIT postdoc Yujia Yang and collaborators at MIT, the University of California at Davis, the Deutsches Elektronen-Synchrotron, and the University of Hamburg in Germany, demonstrated a microchip with nanometer-length-scale circuit elements that act like antennas to collect the electric field of light oscillating at nearly one quadrillion times per second. The chip is small, self-contained, and requires only inexpensive electronics for readout.



"We see a wide range of new optical and electronic devices that could be based on this technology," says Karl Berggren, MIT professor of electrical engineering and co-author of the work. "For example, this technique could have a future impact on applications, such as determining the distance to remote astronomical objects, optical clocks critical to GPS technology, and chemical analysis of gases."

(Source: MIT News)



The Value of the Last One Percent

Feature by Andrew Scheuermann
ARCH SYSTEMS

One of the best questions we get from a potential customer goes something like this: "If my product quality is already at 99%, what can advanced technology really do with the 1% that's left?" For manufacturers talking about the 1% left behind after they've achieved the coveted 99% product quality, the answer is pretty straightforward.

What can we do with that 1%? Not much. But that 1% is overrated.

For manufacturers who think they have achieved 99% efficiency just because they've achieved 99% quality, they're almost always wrong. That's because no one has ever seen a manufacturer actually running anywhere near 99% efficiency and utilization. For some, that's obvious because state-of-the-art is often closer to 60%. If you are doing more than 60%, you're doing it really well in an Industry 3.0 world. When you actually start looking at the data, many of the top manufacturers in the world have 50, 40, or even 30% efficiency or utilization to get near that 99% product quality. Industry 3.0 baked in the assumption that a trade-off was necessary and that manufacturers had to relinquish massive levels of both human and machine efficiency to achieve acceptable product quality standards. In that pursuit, most competitive manufacturers became hyper-focused on that 99%.

For example, a top electronics manufacturer was operating almost a thousand assembly lines. A high-value section of these lines had impeccable quality targeting the auto industry, doing so at 30 units per hour. Upon deeper analysis, it was clear there was a practical path to 45 units per hour—a 50% increase in throughput with the same people, machines, and products, adding technology for efficiency at an ROI of over 5x. This had nothing to do with the 1% scrap on those lines and everything to do with untapped capacity.

Another top electronics manufacturer with hundreds of pick-and-place machines is operating at a given throughput. Upon deeper analysis, it is clear that the machines—despite

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being simulated for maximum throughput—are operating 10, 20, or even 40% away from a perfect balance. The simulation assumed the outcome would be one way, but their own real data showed it was entirely another—one head dropping more parts than expected, and another far newer or far older than average. The result? Tens of millions of dollars of untapped capacity that had nothing to do with the 1% scrap.

Instead, the first question to ask is, "Are you sure you're looking at the right thing?" What's the real value of that 1%?

The first question to ask is, "Are you sure you're looking at the right thing?" What's the real value of that 1%?

As shown in the previous two examples, the real value of that 1% is the untapped efficiency and utilization that was left behind in the pursuit of it, sometimes for decades. Fortunately, Industry 4.0 brings the tools and processes needed to capture all that value that is now easily within their reach.

Picture an iceberg. There's no way to know the real size of it without measuring under the surface, and there's no way to measure an iceberg without specialized instruments. All modern seacraft utilize these specialized instruments. Without them, seacraft are forced to operate by using outdated methods of navigation. This means they ultimately make their best guess as to where they can't travel and then navigate around it. For those choosing to be extra cautious, they keep even farther away, just to be safe, because they lack the specialized instruments to see all the safe places they could navigate.

Likewise, when manufacturers tightly focus only on the tip, or product quality, they miss the giant mass of inefficiency and utilization that sits just below the surface. This is exactly what Industry 4.0 is all about—using tools now at our disposal to reset assumptions and achieve truly zero-waste, AI-predictive manufacturing.

Before new technology can be adopted, however, every manufacturer looking needs to first ask two questions:

1. What is in my data? Where can I use machines, advanced analytics, or AI for it to do really well?
2. How is my organization willing to adapt? Are we ready for a 50/50 partnership between humans and machines?

A tremendous opportunity lies at this intersection—what the tools are ready to do well and what the humans are ready to step up and do well.

Step back and consider an analogy. Imagine that, instead of running a factory, you run an accounting firm. Your people use calculators to crunch numbers, submit reports to customers, and make a revenue for your firm. Imagine, further, that your accountants use the calculators for addition and subtraction, but not for square root functions. Why? Because your older calculators didn't have the square root function, so your humans are still doing it by hand. Personally, I don't think I've ever done the square root of 2 by hand. If you try to hire me to do it, I think I'd say no. I wouldn't want such a boring job and, if I took it, I would undoubtedly make an unacceptable level of mistakes.

Imagine that an accounting firm is actually operating this way today when it is cheap to buy modern calculators that have a square root function and can immediately calculate it, never making a mistake. They just need to invest in the calculators and teach their people how to operate the square root function.

And yet many factories are operating in a similar way.

Compare two factories to see the difference. In Factory A, a team of seasoned veteran experts is sent through the factory for about 12 months. They pick the right new sensors and hardware to increase visibility. They perform

prescriptive maintenance even earlier than before and achieve 99%—maybe even 99.5% quality—by limiting issues that might arise. They've further defined "red zones" to avoid to achieve that 1% left. After they get to that point, though, there is really nothing more that can be done.

Those at this point need to reexamine and even redefine these zones. The question is not simply whether the green zones are really green. Crucially, regarding all the regimes previously thought inoperable—those red zones—the question is, "Are they really red?"

By comparison, in Factory B, a machine data system is installed to ingest data across all machines. It automatically calculates green and red zones based on the data across the organization, flagging only those specific areas or problems it is not already confident in. Those issues are then served to a Lean team of only two experts. Some of the calculated red and green zones are the same. However, some are very different—identifying areas where life can be extended, capacity freed up, and quality maintained or improved with vast efficiency increases. As the factory continues to run, the new data further paints a canvas of green and red, eventually making it into the perfect picture that defines exactly how to operate.

There is no question which factory fares better, and which is poised to move forward with a modern, adaptive workforce with tools that generate a whole new plane of vision. Embracing that mindset comes with the advantage of workforce recruitment. The majority of incoming workers are interested in jobs and careers that utilize their skills—modern skills that play very well in an Industry 4.0 world. Fewer and fewer workers are looking for jobs without them, and many are coming into the workforce with efficiency and utilization skills already in hand.

But can this alternative approach work for manufacturers with lots of machines and processes all over the world? Make no mistake, while this was a liability in Industry 3.0, it's actually an asset in Industry 4.0 because of the ability to build a larger data set. More machines feeding information equals a faster rate of learning for the algorithms.

Andrew Scheuermann

To really understand what can be done with the remaining 1%, the answer to the question lies in another question: Are you looking at the right thing?

For those still trying to whittle away at the remaining 1%, it requires a process of recognizing, visualizing, and clarifying the giant mass of inefficiency sitting underneath it. Those who continue to squeeze tighter on legacy process controls built up over time just to get another fraction of a percent will find it harder and harder to remain competitive going forward.

Manufacturers who adopt new tools and capabilities, then go back and reevaluate the path they've traveled, are the companies that emerge stronger, smarter, and quicker in an Industry 4.0 world.

Those who have moved forward with the latter have already found that the question was less about what could be done with that last 1% all along and more about what was hiding behind it. **SMT007**

Andrew Scheuermann is CEO and co-founder of Arch Systems.

MilAero007 Highlights

Goodwinds Composites: Putting a Helicopter on Mars ▶

On July 30, 2020, Nolan Johnson spoke with Leland Holeman and Amelia Cook, the owners of Goodwinds Composites. While Goodwinds may be a small business, they still pack a heavy punch in the carbon fiber fabricating business. Case in point, the NASA Perseverance Mars rover mission, which had just launched as we captured this interview, carries a helicopter (named Ingenuity) in its payload and contains custom parts fabricated by Goodwinds.

From the Hill: 7 Steps for MIL-PRF-31032 Certification ▶

Mike Hill's past columns have detailed how military electronics are being used in an ever-increasing application rate. In this column, he shares seven certification steps, resources, and timetables for consideration when certifying to MIL-PRF-31032.

Summit Interconnect Adds John Vaughan to Lead Strategic Market Initiatives ▶

Summit Interconnect Inc. is pleased to announce the addition of PCB and EMS industry veteran John Vaughan as vice president of strategic markets.

U.S. Air Force Awards Virtual Reality Training Contract to Street Smarts VR ▶

Street Smarts VR, whose virtual reality training platform is used across U.S. military and law enforcement organizations, announced a contract with U.S. Air Force Global Strike Command Security Forces that deepens their commitment to maximizing readiness for Airmen through more realistic training.

STI Electronics to Attend 2020 Space & Missile Defense Symposium ▶

STI Electronics Inc., a full-service organization established in 1982, announced that it is a sponsor and an attendee of the Space & Missile Defense Symposium. The SMD Symposium is the leading educational, professional development, and networking event for the space and missile defense community.

Understanding MIL-PRF-31032, Part 2 ▶

In Part 2 of this series on understanding the military PCB performance standard MIL-PRF-31032, Anaya Vardya explains how the first step in the process is to develop a quality management plan (QMP).

Benchmark Delivering on $51M Order for Advanced Surveillance Technology to U.S. Border Patrol ▶

Benchmark Electronics Inc.—a global provider of engineering, design, and manufacturing services—announced the completion of phase two of five phases toward the delivery of mobile video surveillance systems (MVSS) to the Department of Homeland Security for use along the U.S. southern border.

Comtech Telecommunications Corp. Receives $1.5 Million Order From International Space and Communications Customer ▶

Comtech Telecommunications Corp. announced that during its fourth quarter of fiscal 2020, Comtech's Government Solutions Segment was awarded in excess of $1.5 million in new orders by an international space and communications customer.

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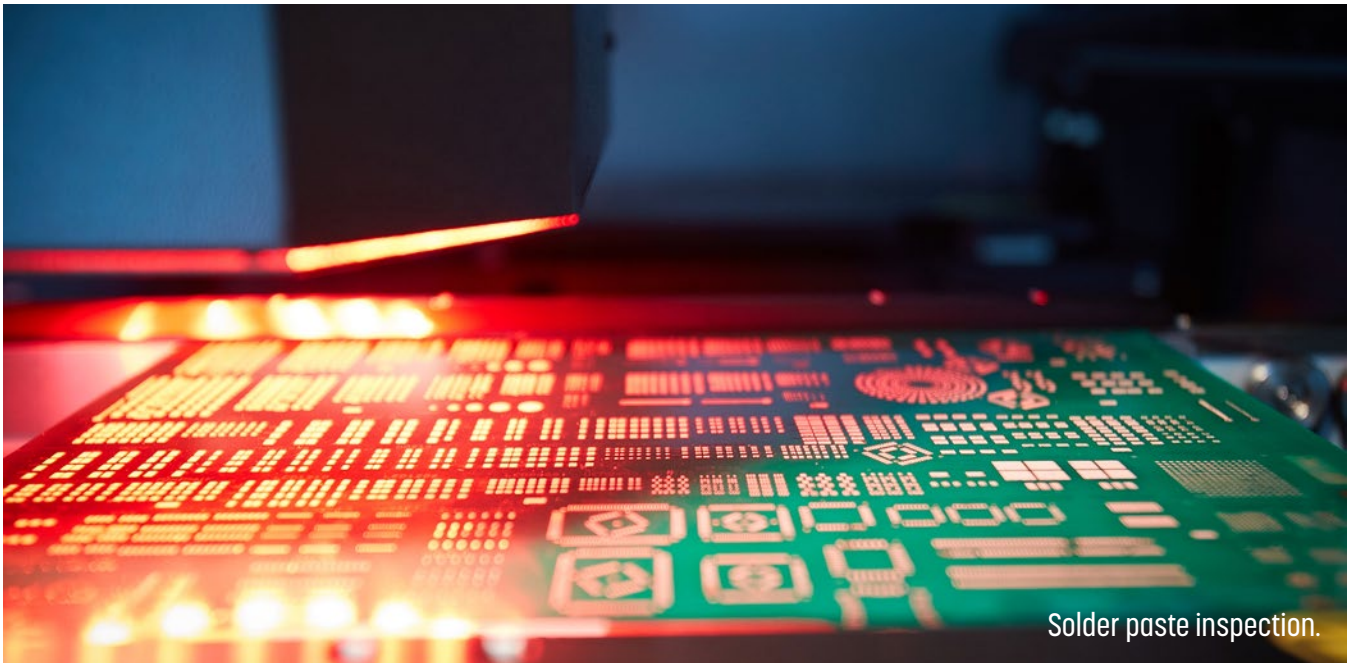
Solder paste inspection.

Improving Tech Support During a Pandemic

Interview by Nolan Johnson
I-CONNECT007

Koh Young's Quintin Armstrong, senior manager of technical services and applications for the Americas, discusses the work that has been going on at the company around field support, including pre- and post-sales support training, and how those areas have been affected by COVID-19.

Nolan Johnson: Quintin, for those who don't know you, what's your role?

Quintin Armstrong: I joined Koh Young in August of 2019. My role is to enhance our organizational procedures and methods in our approach to customer support, as well as to better harmonize our modus operandi throughout our Americas operations. It's always a continuous improvement type of objective between the various different pieces of the operation, technical services in the field, general support, applications type of activities—both pre- and post-sale—and the demo room type of activities. Some of that would include things like evaluation activities at customer sites, as well as training activities—both in our KYA offices, and at customer sites, or even at representatives' office sites.

I focus on each of these different areas, tie them all in together, try to unify our support approach, and look at improvement opportunities within the organization. We have offices throughout the Americas, including in the U.S., Mexico, and down through Central America and South America, with the main markets there being Brazil and Argentina. We have a series of reps, and we have a lot of these subsite facilities set up there for the same purposes. It's about bringing all that together and meeting the overall objective to best serve our customers in every aspect.

Johnson: Given the current situation and the restrictions that accompany it, how do you service the customer differently?

Armstrong: To be honest, it's not a huge difference in the way that we always have done things. As technology evolves, some of these tools make it easier to do some things more remotely. Those are utilized, and they have been even before the onset of the situation that

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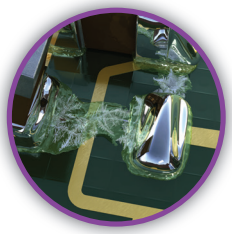

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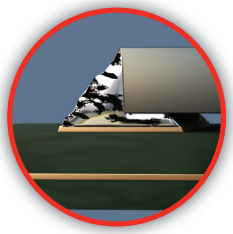

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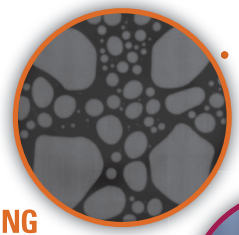

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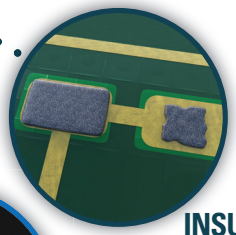
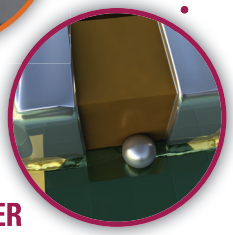


INSUFFICIENT SOLDER DEPOSITS



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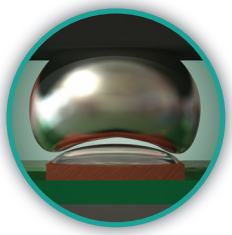

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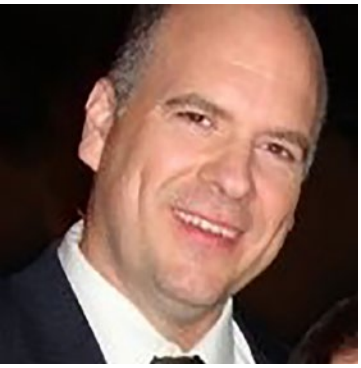


Quintin Armstrong

we have with COVID-19, but we already had a lot of those things in place. And this happened very suddenly. In my case, I went from working in the office on a Friday afternoon to not going into the office the following Monday in March. All of this meant making sudden adjustments. Fortunately, it wasn't a big change in the way that we had to approach things; we just had to focus solely on the remote support aspect of it.

It's about utilizing the tools that we've had for some time. We have a very good setup with our help-desk arrangement and the incoming tickets. A lot of that support happened via that method. Many people prefer to avoid phone calls and go to a messaging type of system instead. That has always worked very effectively for those needs. Then, there are things like installations, where we basically were doing dedicated support. We'd have a field service engineer assigned to a customer. We use digital aids, and the methods that we have to connect with them, and various documentation sources, supplemental videos, etc. to accomplish those objectives. And tying all those pieces together has helped us meet the various emergency support needs. But we also had some people traveling when it was an absolute necessity for those instances that could only be handled with the on-site support, as may have been appropriate, given the travel challenges and restrictions, and policies adopted by our customers as we all have adjusted to the situation.

The beauty of it is we didn't have to reinvent everything. We just had to take slightly modified or enhanced approaches to how we use the tools we already had, and better focus them on meeting the various extraordinary needs of the sudden situation that we came upon.

Johnson: Have you completely eliminated the need to see a customer on-site?

Armstrong: We haven't completely eliminated that, but I don't think that should be the overall objective. Given the circumstances we have amidst the COVID-19 challenges, there have been a few cases where on-site customer visits were necessary. Some things were put off because our customers themselves were trying to adjust and figure out what they were going to do. Many of our customers were getting involved in this sudden demand for production for PPE and ventilator devices, which suddenly became so important and weren't in a sufficient supply when this situation started. They had needs beyond what would typically happen with the restrictions that were put in place. And we had to help them meet those needs as an essential business.

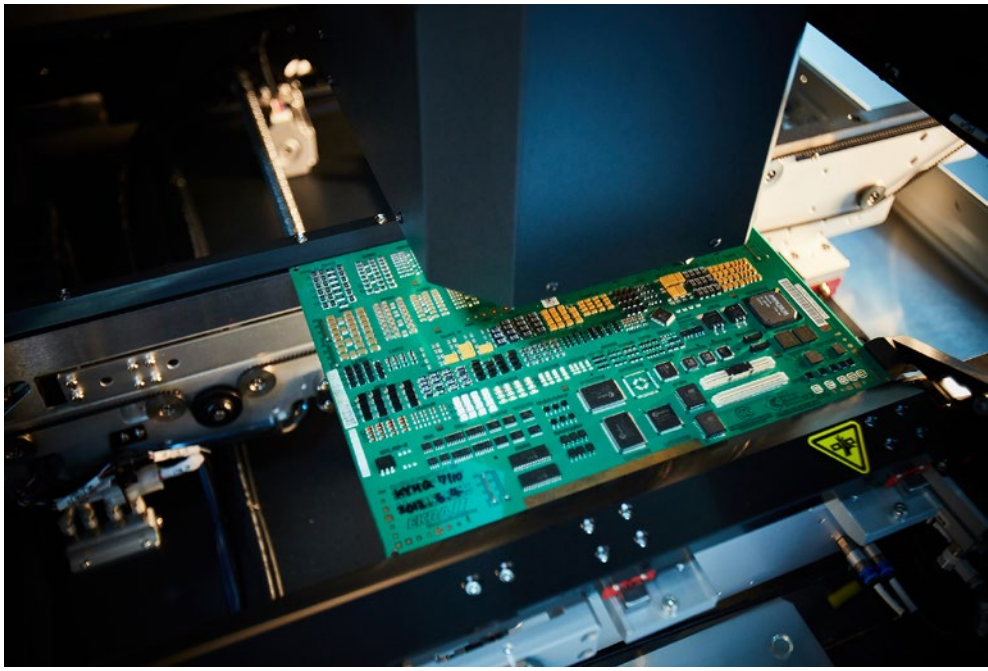
It was a matter of just utilizing various pieces we had and making a few adjustments to fit the customer situation. We found a way. Through a combination of the various tools and methods that we already had in place, as well as better focusing them on that type of arrangement, we met those needs. It's not something I would see ever going away; rather, it has been a little preview into what we can do in the future to enhance support in general, or if we're faced with other such circumstances again.

Johnson: Do you see an increase in face-to-face support as things eventually return to normal?

Armstrong: Certainly. We are already resuming some face-to-face support on a more normal basis, and there is a lot of value in that. No situation is ever 100% perfect from every aspect, but there's a great need for the on-site activities. With training, there's a lot you can do remotely, but there's also a lot more that comes from hands-on experience. And you could compare the situations and options even before COVID-19 challenges, like somebody coming to one of our KYA training centers—outside of the production environment and without those interruptions—versus trying to do that type of training on the factory floor. There, you normally use the production machines and have a lot of interruptions just from the environment, with people being pulled away, and, hence,

you don't have the same type of training environment that's conducive to the best learning process.

We've always had those comparisons in the past, and that applies to the various aspects that we're talking about with installations, service, and training demos. We had to find a way to keep things going without being able to provide the normal type of demos that we would have. That also became a much more remote process.



Automated optical inspection.

Johnson: How does that demo experience work now?

Armstrong: Normally, customers want to see that firsthand at some point in the evaluation or demo process. We always had the materials in the past, with their sample boards, or used some standard boards that fit the type of application. We would have gone through a pre-analysis, determined what they're looking for, what they need, and how we can fit our solutions to those needs. But there comes a time where they want to see it in action—in person—so that they can get the feel and insight themselves. In many cases, that involved doing some of the team-viewer type sessions and other methods that we have, to give them the insight on what's going on in a machine that's in our demo room. The applications engineer may have been remote, but the machine was set up so that we could do that remotely and minimize people in the office, but still be able to provide the needs for evaluating the machines, our solutions, and the fit for their needs. It has worked out well on both ends.

Johnson: What's a day-in-the-life of a customer demo like now?

Armstrong: Typically, it's going to be an exchange of the initial information. What are their products, applications, and needs? What do they expect from the potential solutions? Then, what can we provide to them? From that point, it gets down into the specifics of their product. We ask for samples to be sent to the office, and our applications engineer get that set-up and go through the initial evaluation and set up to provide a meaningful remote demonstration. From there, you can have the customer remote-in and see what's going on virtually. It's not the same as being there, but it's almost as good to work through the questions and doubts, make sure that the solution is a fit, and discuss the adjustments that are needed to make it the best fit.

That's not terribly different than what we've done in some other cases, but in the ideal circumstances, customers have the choice of virtual versus in-person demos. Do they want to come on-site? Do they want us to do this in their factory? But with the situation that we've been facing, we haven't had that freedom, and we've had to opt for these other, virtual methods and make them just as effective as if we were able to have them physically come into our demo room, or give this demo at their site.

Johnson: Are customers running their own samples? Is there a point in the process where they're running their own work?

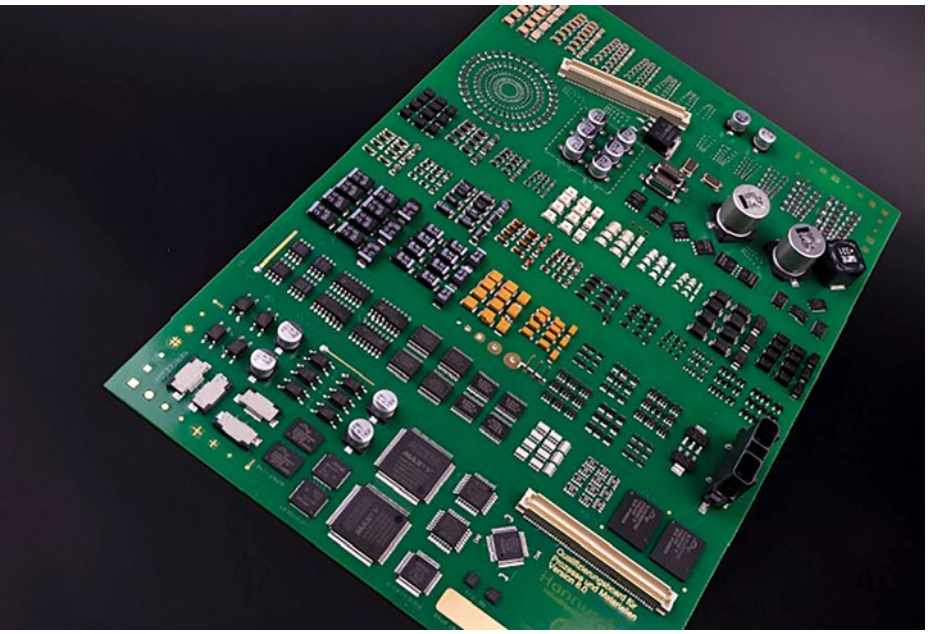
Armstrong: Yes, in most applications. There are some situations where, if it's a military application or something of that nature, we may not be allowed to see the actual product, and perhaps only the people with a certain clearance and qualifications can do that at the customer site. But when it gets right down to it, they want to see the direct application and performance on the particular product for which they are looking to find a solution. Normally, one way or another, we get some sort of sample to be able to do a truly direct analysis of the product that they're looking to run in the equipment.

Johnson: Koh Young is doing a lot of work on user experience. Tell us about that.

Armstrong: Being a Korean company, we've got a large research and development group at HQ in Korea, but we have a very significant R&D group in the U.S., as well. And if we look at it from the overall organization of Koh Young globally, about 60% of the resources are in the R&D, support, and engineering areas. And in our U.S. and Americas situation, combining this research group that is also based here, it's 70% of our entire group that constitutes Koh Young America. There's a lot of focus on that. And if you compare that to other players in this niche of the market, it is something that makes Koh Young stand out. That's one of the keys to being able to provide the solutions that we do provide to best support our customers. It's not only about the equipment, but also the accompanying software solutions, and the support that puts it all together. It sets us apart when we combine what we have at HQ with this research group in the U.S., and the entire support infrastructure.

Johnson: Has the software and development side of the business changed its perspective? What is it endeavoring to deliver based on what we learned through COVID-19?

Armstrong: It has put some more emphasis on certain aspects of it. The whole software solutions subject is something that's constantly evolving, and we've all seen the various things over the years. And now, we're talking about Industry 4.0 and how these software solutions play into that, being able to gather and utilize all of this data. That has been a focus—is currently a focus—and will continue to be a focus. But with what we've faced in 2020 with COVID-19, it has also put the focus on something else that it wasn't the necessity of the moment. It has become more of a necessity as we worked through this. That is affecting some of the other development objectives so that we can even better handle these types of things going forward.



Demo board.

Johnson: One other area that pops up a lot with respect to equipment on the manufacturing floor is service issues, service calls, service requests, and so forth. How has that changed?

Armstrong: There were a lot of restrictions, and I don't know if you've been to an airport in recent months, but I never imagined that we would see airports so empty. They're ghost towns. It's quite shocking to see how all of that

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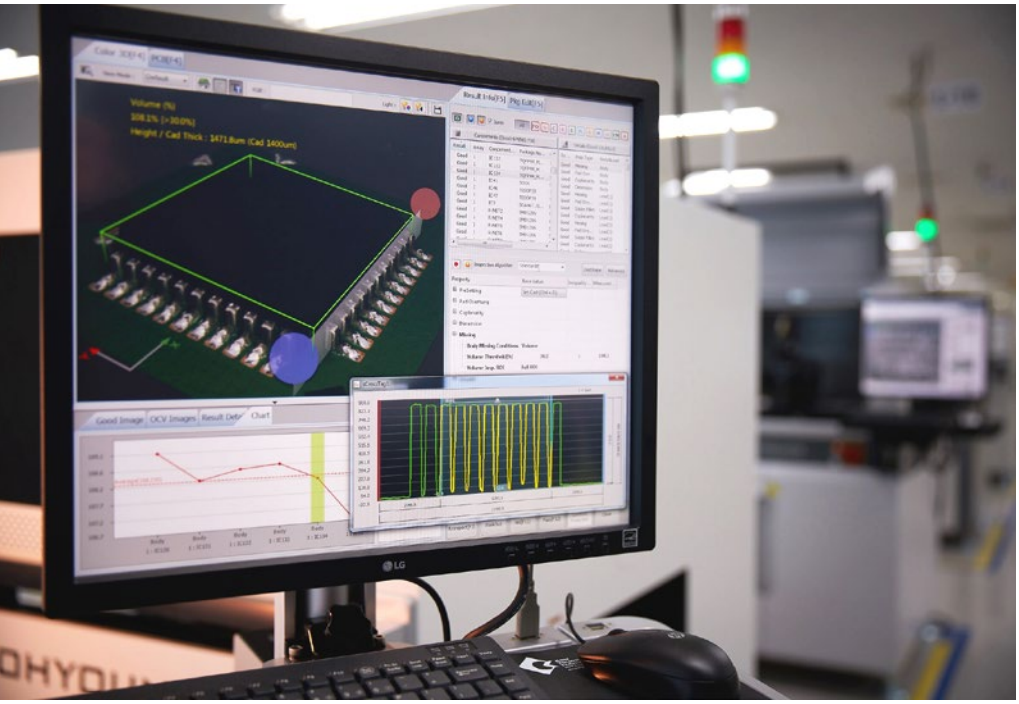

Zenith 3D AOI machine.

can come to such a screeching stop. And that meant that our people, and everybody else involved in all of this, were not traveling as they had been before. Suddenly, we're trying to handle all these from a remote situation. And we noticed the challenges that maybe we didn't notice before because we weren't forced to work through so many limitations in being able to provide the support that we needed to provide. We typically have our help desk, and people work on a dedicated basis to handle all of those tickets and the support that's needed.

But as a matter of handling a lot of these needs through this situation, we've had a lot of our field service engineers that typically would have been at customer sites, working as dedicated remote support for the various needs of our customers. Of course, there are some situations where we evaluated the circumstances and determined that the only, adequately timely, and the best solution was going to be to have somebody go on-site. We made sure that everybody on our side of the issue was good with that, and that the customer was good with it, and addressed the particular concerns that needed to be addressed in each situation. And those people went on-site and took care of those situations. But it's amazing how, when you need to, you can find ways to work around those things that you took for granted before and find other solutions to accomplish the same thing. Fortunately, we had a lot of the tools in place to help us do that rather painlessly, considering the circumstances.

Johnson: When I worked in manufacturing equipment service, there were things that you could rely on the customer-located technical support people to perform on a machine. There were things that required a field support technician from the factory out to resolve. Are you finding that you're still able to deliver on both types of required service?

Armstrong: Yes, to a very large degree. It's quite encouraging to see how much of what needed to be done could be accomplished through these alternative means that we have been utilizing in this situation. Earlier, I mentioned that it also depended on the customer situation. Did they already have Koh Young equipment? Did they already have certain familiarity and expertise with the equipment, or were they totally new? In the cases where it was possibly a totally new customer getting their first machines, even the customer decided they would just like to wait and see how the situation unfolded, to determine the appropriate time to go and do what was needed, on-site. And the way things unfolded, except for a couple of situations, it was possible to postpone some things until the situation was alleviated a bit so that it was more feasible to get somebody on-site without going through so many hoops. It all depended a little bit on both the experience of the customer with SPI or AOI in general, as well as with their experience with Koh Young equipment. All of that came into play as well.

Johnson: You must have some additional resources, not just the FSEs or technical support, who can get on the phone or do a video chat?

Armstrong: In some of the support needs, it may have ranged from an equipment installation, to a repair type of situation, or it may have been more of a programming application type of focus, where they needed some assistance to possibly adjust to a new product or version they were trying to run. Otherwise, they may be working through all the data collection issues and those types of things that would come up. It depends on the situation, but it may have required application support or more field service engineer applications. Through the infrastructure that we have with personnel, their backgrounds, and the technical tools that we have to allow them to help customers, it has been quite effective.

Johnson: Koh Young has been involved with inter-machine communication development, such as CFX. Does that capability change serviceability for the machines on the floor? What does Koh Young see in the field?

Armstrong: Some of those protocols are becoming hot topics because of Industry 4.0 endeavors, and there has been a lot of activity regarding those things on the MES applications. And those things are being addressed. They're typically easier to address from a remote scenario, but they didn't necessarily affect our ability to provide all the other services that might come into play. That's not what they're designed for, but in using a lot of the same tools that we use in implementing MES applications, it helped us to provide those other services that were needed. They're different animals but come into play in providing the support that's needed from all aspects.

Johnson: Any final thoughts to wrap up?

Armstrong: We've covered a lot of the areas of support that come into play, as well as the global infrastructure that sets Koh Young apart, and provides a great benefit in being able to best support our customers. I've been fortunate to have had several years living abroad in South America and handling the market there, so this has helped us focus our endeavors to best support our customers in this large, complex Americas market. We cover the entire Americas market, from Canada all the way down to Ushuaia, Argentina. Being able to enhance all of these capabilities, and enhance them in all these different areas of the Americas to make the overall operation stronger, is a key focus of the Koh Young America operation. Everything is a continuous improvement project, but it is one of the things that sets our solution apart in what is a very competitive market.

Johnson: Quintin, thank you for your time. This has been quite informative.

Armstrong: Thank you, Nolan. I appreciate your time. It's good speaking with you. SMT007

How to Find Reliability in Box Build Assembly

Feature Interview by the I-Connect007 Editorial Team

The I-Connect007 Editorial Team spoke to Roger Malmrose and Lilia Castro of Green Circuits about reliability in box build and how changing customer requirements affects the process qualification to ensure reliable build quality.

Nolan Johnson: We're looking for your perspective on reliability in manufacturing. One of the things that Green Circuits seems to do very well is reliability in box build. We'd love to talk about the current developments, challenges, and trends in box build reliability from your perspective. Let's start with your background and an introduction to the company, and then we can talk more about box build.

Roger Malmrose: My first introduction to the industry was at Avex Electronics, where I ran the advanced technology group and Brazil group. Then, I went to Flextronics and was there for four years, followed by running the Pemstars site in San Jose. That shut down when they sold to Benchmark. Next, I started Piranha EMS, which was also in San Jose, and I worked in mechanicals for a bunch of years.

I met Joe O'Neil, CEO of Green Circuits, a number of years ago, but we connected last year and talked about what we were both doing. He said, "We need someone to run the operations at Green Circuits. Would you be interested?" I was commuting at the time and said, "Let's talk." I came on board as the COO last November, and I'm currently the president-COO of the company.

Lilia Castro: And I'm a quality manager. I'm also quite new to Green Circuits. My expertise is on the SMT side, in addition to QMS, so I can speak to management systems for quality control.

Malmrose: As far as Green Circuits goes, historically, it has been a full-service EMS. At one point last year, we built 3,000 fully assembled, direct fulfillment chassis per week for a Tier 1 network equipment manufacturer. It involved doing the PCBA, board-level test, system build, system-level test, box build, direct fulfillment

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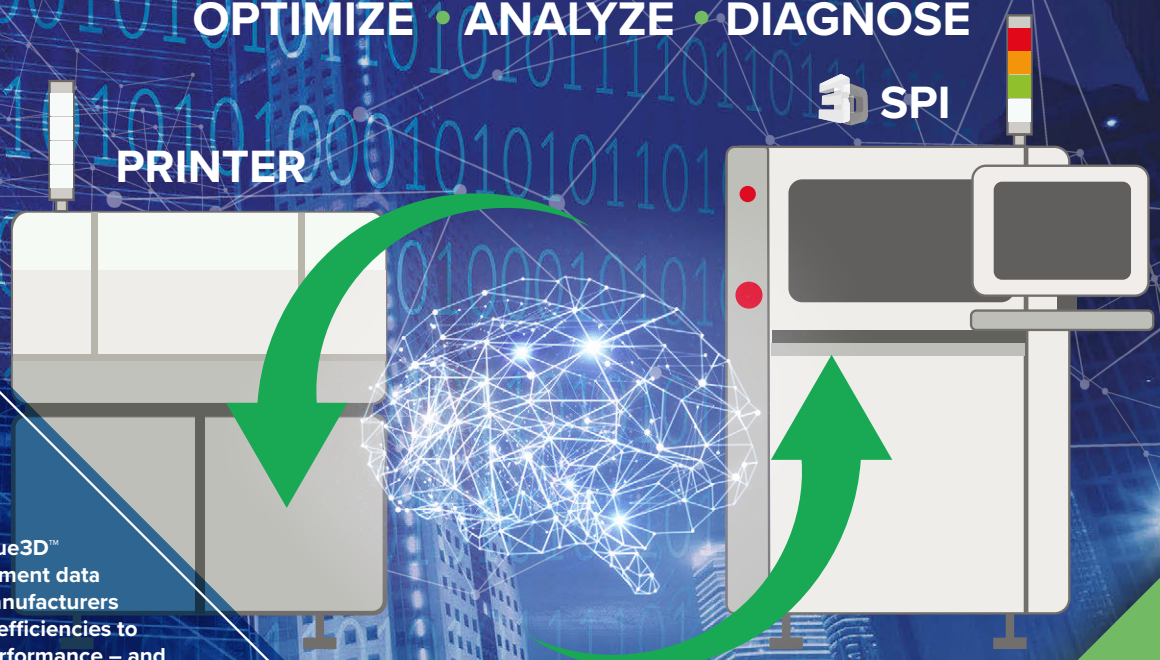

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Touch up and second OPs.

with customer box, customer packing tape, and customer packing slips so that nobody would know that the product came from our company.

We currently do that. Although, for most of the customers, we don't necessarily do the box build. In terms of the box build side of the business, we are quite active in doing complete system build and system-level test.

Johnson: Are there reliability challenges with box build that are more than simply workmanship?

Castro: A very simple thing that is a challenge for us is the mechanical assembly or hardware installations. Sometimes, we have an issue where the front panels don't match with the assembly. That's the main concern with box build.

The customer provides us the design and drawing, which we follow. We order the material that we request for a customer, and we install this during the box build. Sometimes, it doesn't match. We have that issue all the time. The BOM from the customer may tell us we have 10 screws, for example, but they provided us only a few. That's a hardware issue, which is the main thing for the reliability. We need to install it correctly in all these directions to make sure that the design is being followed.

Johnson: The biggest challenge is that you sort out a new job and have to ensure that the parts and BOM are correct.

Castro: That's the main thing. Another problem is if the documentation or BOM provided to us have discrepancies. Sometimes, when materials come, it's a cosmetics issue on box building assemblies.

Johnson: Once you get over the hurdles of setting up the BOM, coordinating incoming inspection for pieces of the sub-assembly, does the process become more straightforward?

Castro: Yes, and that is in the receiving instruction process. When we receive these mechanical parts, it depends. If it is consigned, it is just provided by the customer. If it's turnkey, then we have to inspect all the material that we receive in receiving inspection. If it's provided by the customer, we're going to inspect that during the build. The problem is going to cost a lot if there's an issue with their material when they put it on the floor and start the building.

Dan Feinberg: That brings up a good topic. Nobody has 100% reliability, but we all want to get there. That's the goal. We have discussions at various IPC events stating that reliability has become a major issue over the last few years—much more so than it used to be. It started with the switch away from leaded solder. As we get into more things like autonomous transportation and 5G, those are moving more slowly than was predicted 3–4 years ago. There will also be the ability to do long-distance robotic surgery, not someone running the robot from the next room. Robotic surgery is going to become much more common, but the reliability is super critical. Can you imagine someone doing open-heart surgery from 1,000 miles away, and the interface device fails?

When talking about box build and reliability issues, what areas are of the most concern

when you're trying to build a very highly reliable product? Where do the failures mostly happen? I'm not saying there are a lot of failures; it might be 1%.

Malmrose: One thing that has been an issue, as well as the other places where I have worked, is the calibration of the torque wrenches. When you're putting bolts on, or putting in screws, if the drivers or torque wrenches are not in calibration, the biggest concern is overdriving or underdriving. It must meet the specification of the build on the mechanical. If you look at reliability, something's going to have vibrations, and that's going to be an issue.

Another one I saw at a different company was a latent reliability issue from hydrogen embrittlement of bolts. We found that the bolts in the actual final industrial product were being subjected and exposed to water, and we had bolts breaking in the field. When the bolts were being manufactured by the manufacturer, they were not being processed correctly, so we were having field failures of the mechanicals there.

The quality and calibration of the equipment are also concerns, particularly if you're a small company. If you're doing riveting, it's important to make sure you're not overdriving or underdriving what's going on. We run into this all the time, where a company says, "Here's my drawing. I'm going to launch it over to you so that you can build me a hundred boxes," and they were supposed to be prototypes, but they end up not being prototypes. Many small companies may end up selling them for production. But it's very common to not have assembly instructions with requirements for how tight the bolt should be or how hard something should be driven. If you're driving a screw into a piece of plastic, you overdrive it, and it's going to fall out. It's a lot of looking at the product usage and making sure that the specifications are being followed.

It's not right for any customer just to launch something, throw it over, and say, "We just expect you to figure out what the specification should be for driving this screw into a piece of plastic." There is mechanical engineering needed to create the specifications from the customer. We can always do it, but it takes money. And that's typical with small companies. If they're worried about product reliability on a build on the mechanical side, make sure that it's properly specified in terms of what the manufacturing specs and performance need to be.

Roger Malmrose

Johnson: As we move toward harsher environments and more mobile, automotive, medical, and life-critical applications, the reliability of the enclosures becomes just as important as electronics in many cases.

Malmrose: Absolutely. If it's going into a harsh environment, you have temperature and humidity. Recently, in one of our box build situations, we did different kinds of coating, and one of our coating processes was cracking. If that got out to the field, you could have a latent humidity problem and corrosion in the cabling if cracking occurred.

Johnson: With that in mind, what do the testing qualification procedures for box build look like in your factory, and are those changing?

Malmrose: For some, they'll do drop test. It's like when we used to drop things from three meters and ask, "Does it still work?" But we'll do that, and then we do full burn-in, so we'll do accelerated life testing. We can do humidity testing as well as burn-in on the mechanical side. We have one very large burn-in chamber. If you don't have sufficient thermal conductivity, then you're going to have a board-level failure. Also, if you have adhesive that's part of the box build and is not rated for a certain temperature, the adhesive could fail. Some boxes or enclosures are adhesively attached, not mechanically attached. But we can accelerate life failures for those, both hot and cold, as well as doing basic drop testing and shaking.

Johnson: Are the requirements you receive from OEMs, or the ones who are specifying

these products, changing? Are they putting more or different demands upon box build qualification than in the past?

Malmrose: In the olden days, a lot of products had to be NEBS compliant. There are also UL standards. We had a stretch where we had to be more competitive with China, so we said, "Let's not use the NEBS-compliant box. Let's do something else." Cheapening it or dumbing down the performance of the enclosure is mostly cost-driven. I haven't heard, "I want a NEBS-compliant box," from a customer for a long time.

Feinberg: You mentioned testing reliability by dropping something three meters. Having to do a drop shock is one of the things that I hear a lot about. A lot of that has come with lead-free solder being more brittle.

Malmrose: Yes, we still do a lot of leaded solder. We do more lead-free solder, and we do a ton of it. Not only do you have the shock aspect, but the CTE difference is markedly different between lead-free and leaded. If you're trying to pass REACH and RoHS, it becomes more important if you're looking for higher reliability for your product.

Johnson: Especially if you're concentrating on mobile, in-the-field, portable-type of functionality, the enclosure is there to protect the electronics inside from drop shock. That must change some of the design concerns going forward because mobile and in-the-pocket type usage is becoming the standard for most of our consumer electronics.

Malmrose: And in the enclosure space, for example, you have compression set issues. If you're a mechanical guy and you're going cheap, you may grab some kind of foam product that's going to be your gasketing. You'll say, "I'm going to do my drop test today." If it passes, you still may have a compression set problem in the future with certain types of polyurethane or other materials used on gasketing. You may find that what was good in your product today, two years from today, your plastic or your rubber gaskets are more brittle, you have compression set issues, or you have adhesive fatigue issues. Suddenly, you're going to have field failures.

Johnson: Lilia, are there some common issues that you could point to for the interface to the board itself?

Castro: We always use the IPC standard for solderability and the J-standard all the time. Based on that, what is the reliability of the board? If this is medical, we're using Class 3 for the standard build and the cable. We always use Class 3 for medical devices and aerospace. It depends on the customers' requirements.

Johnson: As long as they're adhering to the appropriate IPC standards, they're going to be in good shape.

Castro: Those are standards for our contract manufacturing; we always use the IPC standard. Sometimes, a customer says, "I don't want to use IPC. I want you to do this perfectly." It also depends on the requirements of our customers. As a contract manufacturer, we need to follow what the customer requires. The book is always in front of people. We give it to them to show we're following that kind of stuff. If you don't follow it, all your components end in failures.

Johnson: Let's pivot and talk about reliability during the assembly process and for manufacturing when assembling the PCBA. What are some of the current trends or issues that you face in the designs you get from customers, especially about when you have to work with them to make fixes before you can be really reliable?

Castro: One issue is when we build assemblies. We run the first article and find out there is a design issue on the boards. For example, when a location designator is indicated on the drawing and the BOM, but the actual design of the board does not include that location, there may be a design problem on a different drawing where there's an issue with the

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pad. If BOM says 0201, for instance, but they have 0402, that's a design issue. Our engineers could provide a DFM report to the customer to correct that design; most of the time, it's a design issue that causes a problem with the manufacturing process.

Johnson: Once those are worked out, the processes are clear, and you're manufacturing it correctly. After you've shaken out all the BOM and component issues and it's running through manufacturing, most of those configuration issues for reliability are now removed. At that point, what starts to pop up on the list of failures? Are we talking primarily about soldering issues and failure?

Castro: Soldering is the most common issue. Sometimes, we have a problem with profiling. The solder has an issue for melting because the profile temperature is not correct. Most defects are soldering issues.

Johnson: Do you find that your customers are starting to specify different kinds of solder for different sorts of functions?

Castro: We have different kinds of solder that customers request for RoHS lead-free, tin-lead, no-clean, or RoHS wash. We have many different kinds of solder that customers request.

Johnson: Does that put a challenge on you to reconfigure the floor or in any sort of method like that? Is that something that takes extra consideration on the floor for you, or does it just flow through?

Castro: We have two general kinds of lead-free and leaded solder. The lines have specific equipment capabilities to run if it's RoHS lead-free or leaded. When the customer requests it, we have to understand which products are RoHS and which ones are leaded. It's been set up already that way with all the tooling because we have to set those aside, like the squeegees in the stencil process. We have to separate it on the manufacturing floor already for us to do it right away, so we don't have any hassle or any issues when you run the product.

Johnson: When a customer comes to you, looking for a solder that is new to you, do you go through a qualification process with that new solder?

Castro: Everything is new, even the products. If they ask us to build a new product, we have to have a qualification process to verify all the materials, the process, the components, etc. We have to make sure that's then indicated on the qualification build, and then we're going to send this qualification build report to the customer to approve. If they say the design is not good, then we'll change it. The customer will provide us a new design or a new drawing or a new solder paste if there's some issue on the qualification build. It should be approved by the customer before we continue running.

Johnson: If they're specifying a new solder paste or a solder mask that's new to you, how much qualification does Green Circuits put onto that component as a part of the process?

Castro: We ask the supplier to provide us all documentation I'm doing the supplier qualification, so I have to check the documentation. For example, for a solder I don't know at all, I request the supplier to provide information for me to accept it and buy this product. I need to require an FAI for this new solder paste, what kind of solder paste, and what kind of chemical they have on this because I need to put this on MSDS if this is a chemical.

Johnson: There's much more to it than just making sure that it works just okay to hold the component on the board. You have a whole lot of administrative work to do for safety.

Castro: We have to ask them for a sample so we can run it to make sure the customer approves before we order.

Johnson: How often are you facing that sort of a process with a new material going on to your manufacturing floor? Is this something

that happens once a week, month, or quarter?

Castro: Not all the time. But when a customer has a special project, probably once a year, I get that kind of requirement for a special solder that we have to use for a project. The customer will provide us information on what kind of solder they want to use, so probably once a year we have that kind of issue. They're going to have a sample for us to run that if it's the solder paste, but we're not doing the qualification build until I see the sample that they provided to us has been tested.

Mechanical and final QC.

Happy Holden: Do you have a specialty area where you have lots and lots of experience and competence that people come to you for? What's the range of complexity of the products put together there?

Malmrose: Green is the real deal. A lot of customers come to us because we do flex. We also do a lot of rigid-flex, and lots of just regular rigid boards. Regarding our capabilities on the component side, we do 01005s. We build products with that small of component. We do flip-chip, so very tight pitches. On the board complexity side, we run a board that might be 320 mils; it's at least 300 mils, and it is about a 20-by-20-inch board, so the thing is a beast. On that board, we will put as many as 15,000 components. It's just crazy.

Holden: Is that done in-house? Is that making flex or assembling flex?

Malmrose: We don't make any boards. We outsource the flex, rigid-flex, as well as rigid, and we just do the PCBA. We do the assembly of the PCB here and then board-level test, box build, system-level test, direct fulfillment, and all that stuff. We do the assembly side. We buy components from all over the world; we buy circuit boards, as I mentioned flex, rigid-flex, and rigid from all over the world, and we do the product assembly and test here.

Holden: Kudos to you if you do flex. I managed the world's second-largest flex assembly facilities in China, and flex assembly can be complicated depending on how it was designed and how much fixturing they're prepared to give you, or you may have to create yourself and how much experience they have in designing flex.

Malmrose: If you were to come into this place, you would see lots of pallets, and it's not easy sometimes. Some products are very, very challenging.

Holden: Especially in the Bay Area. Some of the more creative types can try to do too much with their flex because they don't quite understand its limitations.

Malmrose: We've had a number of customers come in, and with some, we've been successful in modifying their designs, particularly if they're doing flex. Sometimes we can change the layout and turn 100% flex into a rigid-flex to at least make it better for reliability and make the fixturing issues less challenging.

Holden: Even if a product is headed for high volume, your ability to do rapid prototyping and fill in a lot of the holes indicates that you might end up doing a lot of the engineering, but the volume goes offshore once they kind of get past the pilot stage.

Malmrose: About 60–70% of our business is quick-turn prototyping, and we are really fast.

Test and box build.

For some customers, we will do one-day turns on turnkey assembly, and that means making the fab suppliers jump through hoops. We overnight parts. It's very typical for us to do three- to five-day turns, so about 60 to 70% of our business is quick-turn prototyping, and it means really quick. About 30–35% of our business is low- and medium-volume production. We do lots of runs of 500 boards, 1,000 boards—even 6,000 boards is not an uncommon volume for us. But to your point, particularly anything that's consumer-related and where the volumes start getting up to 10,000 a week, we then facilitate offshore production with our customers.

Holden: With that kind of performance and response, you need to have a highly trained and flexible workforce capable of doing a lot of different things. Are you having problems finding that level, or do you have an extensive training program to take the middle of the road worker and turn them into the super flexible type of person you need for your kind of business?

Malmrose: That's our secret sauce! COVID-19 has changed the business a bit, and we're dealing with that, but in any given day pre-COVID-19, sometimes we were running 35 different jobs a day in the shop. And even now, we run not quite the 35, but we're way up there. We're jamming here, and we are cranking with basically 100% of the workforce we had before COVID-19. And with such a high percentage of what we do being quick-turn, everything is different.

On the production side, doing augmented or virtual reality really could be quite interesting for us to take a look at. But on the quick turn side of the business, many boards have ECOs and need special attention, so we wouldn't put together anything that would say let's replicate the build unless it falls into the production side. We do everything in the Bay.

Holden: But you're in the center for all the quick innovations that come out of Silicon Valley, and they can, in less than an hour, probably drive to your place and drop all this stuff on you.

Malmrose: That happens a lot, but what is a little bit surprising, and maybe it's just because we do some cool stuff here, is we have customers from all over the U.S. I'd have to do a geographic segmentation. About 50–55% might be the Bay, add another 10% for Southern California, and we have probably 40% of our business all over the United States. We do a lot of overnight shipping, and so we're beyond just the Bay Area.

Holden: That means that you have a reputation if they come from all over the place for your services. I noticed you are ITAR.

Malmrose: We are. We're ITAR, AS9100, and ISO 13485. We're not TS. We build products for quite a few automotive companies, but we've not looked into the TS certification at this time. Most of the automotive work is prototypes, small runs. A lot of it is sensors and that kind of stuff, and that then moves off to Asia, so we haven't gone there yet.

Feinberg: Do you see any indication of things moving back?

Malmrose: Most customers like the mantra, "We're going to do domestic manufacturing. We're going to do whatever." But at the end of the day, the cost is what drives it.

Feinberg: Is it cost or price? Many people are talking about, "We need the lowest cost," but they're talking about the lowest price. And when you talk to them, you find out their cost is higher.

Malmrose: The motto needs to be the lowest total cost of ownership, so it does need to be a line of cost to wherever your deployment site is; that's where you need to evaluate. We have tariffs, plus labor costs in Shanghai and Shenzhen have escalated year after year for the last 10 years. It's not as cheap as you think. For us, to say you want to bring manufacturing back to the U.S., we're still looking at the total cost of ownership as being the driving factor for our sales pitch with the customers.

Some people say, "We have a competitor in China, and they're $17 ex-factory. You are $21 ex-factory." Throw in the logistics, freight, cost of capital, product on the ocean, and inventory that's going to have to be reworked when it gets here. All that stuff needs to be put into the lowest total cost of ownership landed cost model to really understand what the right thing to do is. Forget about keeping your IP safe when you build your product in China; the IP is going to get lost. One way or another, you're going to lose it.

Play the game however you want. If you're Apple building an iPhone, and you're going to spin it every 6–12 months, that's fine. But if you have a long product life cycle and you care about your IP, you have to build it in the U.S. Be smart about supply chain, and keep your IP.

Johnson: Is there anything else that we should have talked about with regard to reliability and Green Circuits?

Malmrose: It may be no surprise, but most of our reliability emphasis is at the PCBA level. We do thermal shock and temp cycling. Those are device-related accelerated life testing. And we do burn-in, so it's mostly electronics-oriented, trying to accelerate infant mortality and expose latent failures.

On the box build side, I spent a bunch of years at Boyd Corporation, and it was interesting that on the mechanical side, the box build very frequently is the afterthought, where people think, "Now we need to do this." Thermal is another aspect. Also, people say, "We have EMI shielding, and it's not working. Now, how do we fix that?" Then, it's about cost; thus, you get into issues like compression set and what type of foam you should use. There are expensive products out there, so engineers start looking for a Chinese alternative.

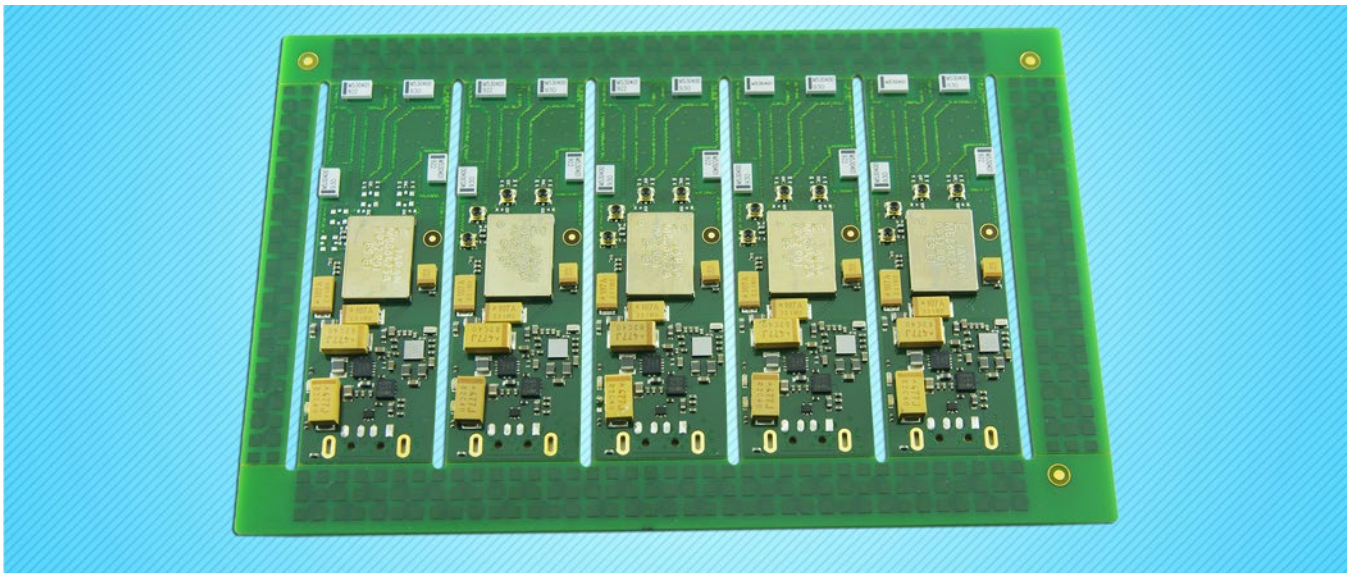
The reliability aspect is really focused on PCBA. We do conformal coating, as well as parylene coating and potting for products. We're in aviation and medical that require special processing. Some people look at mechanicals early in the design process, but in general, we put all the focus on electrical engineering—not that much on the mechanical engineering side unless an engineer says, "I'm going to do the three-meter drop. I'm going to do shock test. I'm going to do the burn-in." We don't see a lot of people concerned about the mechanicals. It's sort of like, "We're just going to do this. We just need you to heat sink this. Put these screws in. No specs."

It's our obligation to make sure our screwdrivers are calibrated, but it's not uncommon just to hear, "Put the box together and just wing it on how tight you should put the bolt and make sure that the star nut is strong enough." There's not a lot of attention to that. Not that we have a lot of returns for that because, again, it's mostly electronics, but it would pay companies well to consider that in their product design and deployment, if they want to have the reputation that their box is indestructible.

Johnson: Thank you both so much. It was nice meeting you.

Castro: Likewise.

Malmrose: I appreciate your time, and I look forward to connecting again. SMT007



Monsoon Solutions: Achieve Greatest Reliability With Optimized Panelization, Part 1

Feature Interview by the I-Connect007 Editorial Team

Nolan Johnson and Andy Shaughnessy speak with Jennifer Kolar and Dan Warren of Monsoon Solutions about common bugaboos they encounter during assembly and what designers should think about if they're considering panelizing their designs to achieve the greatest reliability.

Nolan Johnson: Let's start with a recap of your titles and roles.

Jennifer Kolar: I'm vice president of engineering. Together with the COO, I run the design team. With the CFO, I also run our manufacturing side of the business. I am also responsible for all our power and signal integrity engineering work.

Dan Warren: I'm a principal designer, as well as the director of designer development. I'm in charge of all of our processes and documents, working with the designers to improve their access to tools, training, and anything they need.

Johnson: Tell us a little about Monsoon and your business model.

Kolar: We're a service bureau. We like to say if it has anything to do with PCBs, then we're ready to work with it. We have 30 people. We've been around for 20 years. About half of our company are PCB designers and engineers, and the other half are skilled technical program managers. We also have a small lab in-house. Once somebody has a schematic or something that can be captured into a schematic, then we can handle layout, prototype manufacturing and assembly, box builds, custom kitting, guided functional testing, and things like that.

Johnson: What do project teams need to think about when planning panelization for their design so as to get the greatest reliability at assembly?

Warren: Think about overhanging parts. They always come back and bite us one way or another if you don't document them properly. In the past, we had numerous times where a board would be panelized, parts were assembled, and then they couldn't break the panel

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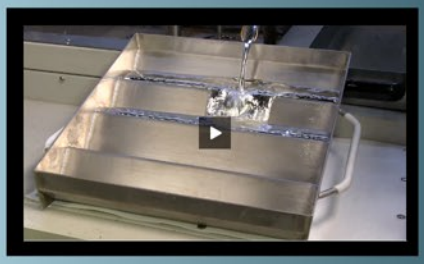

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apart very well. There wasn't a void in the panel where an overhanging part was or, in some cases, they couldn't even install the part because there wasn't a cut-out in the outline where an overhanging part was, especially like a mid-mount connector that encompasses both sides of the board. Those really come back and get you.

As part of our process improvements, we've documented in our fab drawings that it's required to have that information in the drawing, so when they go to create the panel data, those items are taken care of, and consideration is given to overhanging parts and proper pullbacks with the routing channel from those parts. Regarding other issues for panelization, I'm going to defer to Jen because I don't see too much once I pass that data on. Then, I can get a finished panel back.

Kolar: Fab vendors don't think about assembly requirements. We have instilled in our designers that overhanging part input needs to be in the fab drawing because the fabrication shops are never ever going to look at the assembly diagram. Overhanging parts is one concern, and another is where you have break-off tabs. For example, if you have parts really close to the edge of the board and they're fairly fragile parts, or they might be really fine pitch, if you have the breakaway tabs right by those, you risk those connections when the tabs get broken away after assembly. Sometimes, we'll also want to look at calling out whether there can be breakaway tabs or not, or whether it should be V-scoring or mouse bite if we can't really afford any vibration from the breakaway at all. The same is true about calling out where mouse bites are so that they can be filed down. Depending on where it goes into a final enclosure, there may not be an option for any residue left whatsoever.

Those are common issues I've seen. Another thing to consider with the panelization is the thickness of the board and how stable it is. You could get away with a full working panel, like an 18 by 24 panel, and end up with a large array that processes fine in fab depending on the technology. However, if it's a really thin design, that could be really varying and really

Jennifer Kolar

flexible as it goes through assembly. That can cause a lot of risks. The bigger the board going through assembly, typically, the more variation there is in the density of part sizes. As that's going through reflow, the more difficulty they're going to have getting that reflow profile correct so that it will properly solder the entire board.

There are a lot of structural things. You need to be thinking about whether fixturing is required; some connectors and overhanging parts are really heavy. They have to be fixtured, and you want to think about where might that fixture go, and how might you connect it to the board even with the array or out of the array? Where do you need to have cutouts in there?

Even if there are cut-outs, the weight of the board and how the connectors mate might keep it from being flat; this also impacts fixturing. There are a lot of things to think about where I would encourage people to talk to their assembler to gain requirements if they're doing something with particularly heavy connectors and edge mount connectors. When we came up with the requirements that we use in our fab notes, that was one of the things

we did. We talked to our assemblers to ask, "How much pullback do you want from a typical part? If we know it overhangs two millimeters, how much do you want us to call out? How much do you want us to call that there shouldn't be tabs near that?"

Johnson: You're talking about the point where the PCB connects to the rest of the system at the point of interface. This becomes a close conversation with mechanical as well.

Kolar: It's a huge conversation with mechanical. If you're just looking at it from the panelization perspective, you could build just about anything. You just may have to fixture it and do it one up, which adds a lot of cost, time, manual handling, and assembly risk. As you get to large volume production, it may not be practical. That's something for them to think about. We see that people consider, "Do we add a coax cable to a board? Do we do that in a circuit?" That's a trade-off that you may have signal integrity versus manual labor trade-offs.

Johnson: Structural and enclosure issues, as well as cabling, etc., mean you're carefully considering the three-dimensional space into which the electronics go. There needs to be a lot of communication around that. What would you suggest as key guidelines? You have already touched on flex in the board, and that can be an unpredictable source of reliability issues. Again, that may or may not show up in tests until it's in the field. What are some of the design guidelines one should follow?

Kolar: Dan, you've done many of those kinds of designs. A lot of it is knowing what questions to ask the customer, especially for us because we're not the ones that are specifying those mechanical requirements. We need the customer to tell us, "We're worried about shock and vibration. This part will be in this environment, and it's really fragile. We're really concerned about its reliability." We might push back if they're having us put things really close to the board edge, especially like a BGA or something that we're really worried about being right by the board edge. Dan, what thoughts do you have?

Warren: That one's difficult because it's just about years of experience. I don't think about it too much anymore. With a recent design, one of the things that came to mind was the sheer number of connectors and putting too many of them on one edge because you'll end up with a lopsided profile, especially if it's a not lab board. For lab boards, often the customer doesn't really care as long as they can power on one end, and they can access everything easily around the edges. Sometimes, they'll want it all on one edge just for simplicity. But when you explain to them that they're going to have to one-up it and they're not going to be able to panelize it very well because of the profile, the weight, and the thermal profile, a lot of times, they'll come back and say they really don't need that there.

For production, most customers I've seen lately seem to have a lot better grasp than they used to on the ramifications of loading one side versus the other. For this particular board, we're doing the first cut for production on it. All those overhanging connectors are now gone. That was just for the lab board. For the production board, they've taken a much more conservative approach to it so it can be panelized to a larger panel without too much hassle. It is a lot of working with the mechanical engineer. If you see something that just looks weird, question it. Most of the time, they'll say that is how they want it, but it never hurts to verify.

Kolar: And you can also always ask the assembler. On those prototype boards, everybody's pretty good about getting DFM from the fab shop, but they're not so good about getting DFA from the assembler. For larger production builds, that's standard practice that you'll go to both. You'll often have the assembler define the panel that will be used. When we're doing something that's a production build level, the fab shop has usually worked with the assembler, and they've predefined an exact panel drawing and can provide a DXF. We then input

that into the board and put in exactly what they've specified. That's what all their automated testing will be reliant on. Once you get to a production level, you see that coordination and that very careful specification.

Warren: A five-cent difference in cost when you're building a million versus 200 makes a big difference.

Johnson: What are some of the "no-nos" that assemblers are going to point out to you right away? We already talked about overlapping parts.

Kolar: The other thing that's really hard on them is a very different density of parts right next to each other. If you have lots of tiny passives, and then tall shadowing parts next to them, that's an issue. Not only does it make rework almost impossible, but you can't heat the different coppers at the level they need to properly solder. You're either going to get a cold joint on one or have part sliding issues on the other. One is really paying attention to the density of parts as they're near each other and closeness. We do a lot of boards that are below IPC recommended spacing requirements. When you're getting to consumer devices, we have to do that. Again, it's about working with the assembler to see what they're comfortable with.

Warren: One of the things I always come back to is "just because you can doesn't mean you should." Anyone associated with layouts knows that most land patterns have IPC-defined or customer-defined courtyards, but just because you have no DRC errors doesn't mean the two parts should be butted up to where the courtyards are touching. A lot of times, your surface-mount courtyards are set up for cramming in surface mount parts, not against a large through-hole part. I don't know of anyone who has these anymore, but we used to have manufacturing engineers. They would go through the boards and make sure that before it went into being fabricated and assembled, the components were placed properly, and that we didn't have any gotchas or stuff like that. That's fallen mainly on the EEs now and the designers. It's a learn-as-you-go process, unfortunately.

Dan Warren

There's a whole section in IPC about large components, valleys, and shadowing. If you followed that guideline and have a really small product, you might not be able to make that product, so you have to infringe on it. There's where it's really important to include the assembler to get DFA feedback, as Jen said. For me, it's a luxury because we have project managers who handle most of that for me. I just tell them we need DFA, and here's the board. They'll do it, and I'll get a report back. For most places, they don't have that luxury, so designers need to be more proactive, push that with their own internal or external customers, and remember to do it. You have got to be assertive enough to be able to make sure that these get done.

Kolar: Then, it's working with the assemblers. Again, we do a lot of work that ultimately goes to production. In the prototype builds, assemblers, especially prototype assemblers, will just make it work. If there's a panelization issue,

you may not even know about it; they just went ahead and hand-placed something for you and didn't tell you. Something didn't quite fit, or it was really tricky, and they had to go hand-rework things. You may not know if you aren't specifically trying to ask, "Was there any issue with panelization? What could be better? What was different?"

That's another really big gotcha in fab notes, call out to score those tabs. By default, shops do not score them; for production, that is common, but in prototype, it is needed. I don't know how many places still use wave solder, but that's another important issue for where you're placing your surface mount components so that things can properly fit on the pallets to go through wave solder properly. There's a certain clearance you have to have.

Johnson: Like so many functional roles, there used to be a job for this, and the job has gone away. Now, the people doing the job don't have the history, tribal knowledge, or intuition to get it done properly and effectively. Is that a fair statement?

Warren: I would say so. I was lucky enough when I started that I was young and a couple of designers where I worked took me under their wings and taught me the ins and outs. Not everybody has that. It really is up to a designer to make sure that they're paying attention to what's going on and asking the right questions and learning from mistakes for one thing. That's how you're going to get that knowledge, but a lot of it's been lost because those jobs just don't exist anymore for most companies.

Johnson: In this case, it's still important for them to pay attention to it and how it's going to fit into the mechanical enclosure.

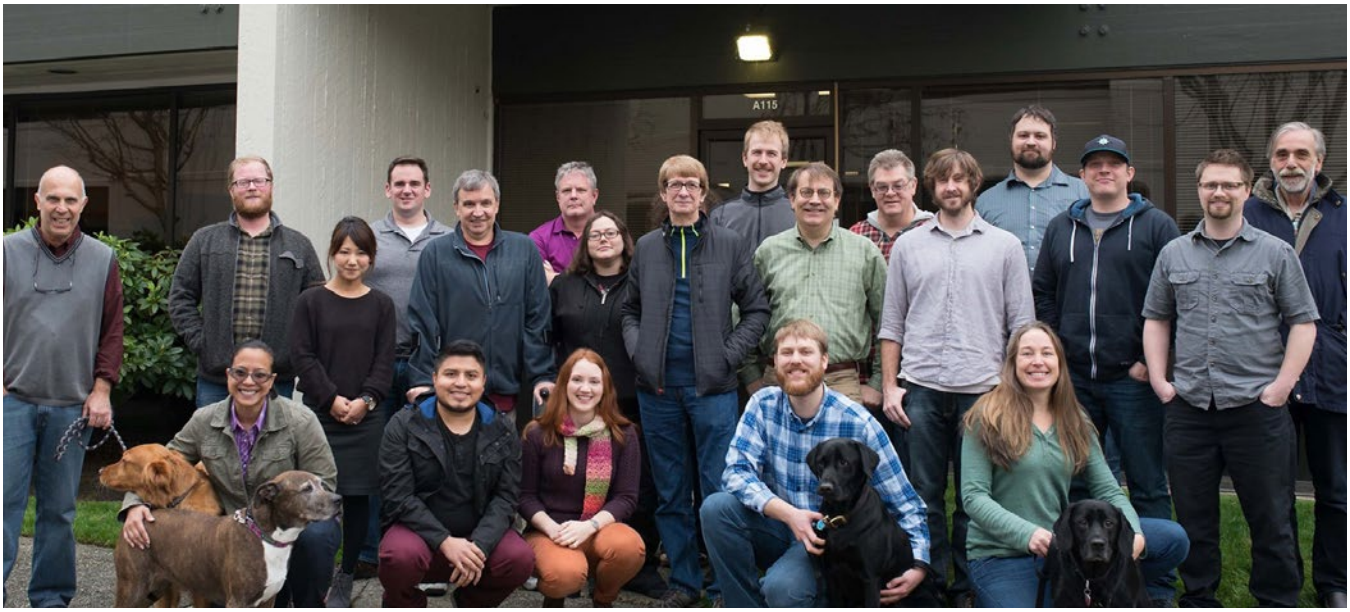
Kolar: It's really an awful thing to find a fundamental mistake once you get to assembly because you've spent so much time and money on the physical boards, you may have used parts that are irreplaceable. It's really awful to find out that information that late in the game. Everything that can be done to proactively look for potential errors and potential issues up front is critical because you're pretty much putting the project on hold and starting over at that point, depending on what issue it is.

Warren: I had a love/hate relationship with our manufacturing engineers in the jobs I worked with, but they saved me I don't know how many times from looking like a complete idiot by catching things that we just didn't notice. As I said, you learn from that process. I learned a lot from manufacturing engineers.

Kolar: And ask as much as possible of the customer. "What is this going to go inside of? What does this mate to? Depending on the tool, can I get a 3D model that I can put into the tool, overlay it, and see if there are any clearance issues? Can I get a DXF of the enclosure? Can I find out what it is mating into?" The tools these days are sophisticated enough to do multi-board checks.

Andy Shaughnessy: What advice would you give to designers as far as things they could do to make things easier at the assembly level? From what I understand, most designers don't really think much about assembly until they get up into the million parts.

Kolar: One is making sure that they have a good assembly diagram that has all of the polarities and PIN1s called out. Especially once you get to production, most production boards don't have silkscreen, so it is really critical the assembly diagram is good. For ones that have it, cleaning up their silkscreen. We get a number of customer boards that have silk overlapping parts, and we have to tell the vendors to trim it off in fab because the customer's designer just didn't even bother to pay attention to it. All those things make the assembler's life a lot harder. They do use that silkscreen during the QA process. Then, think about, "How big is this board? How densely are you placing things to make rework possible, especially if it's an earlier generation of a board? Are you adding test points? Are you making some recommendations that make it easier to test?"



The team at Monsoon Solutions. (Source: msoon.com)

Warren: Test points are a big one. Ask early because putting test points in after the fact is a nightmare and can really mess things up.

Kolar: Another can be thinking about whether, ideally, all the through-hole parts to be soldered can be soldered in from one side instead of both. Looking at, as they can go through SMT and reflow, minimizing the number of passes they have to do. You may not always have that option, but trying to minimize the number of processing steps can be a big one.

Warren: From a designer's point of view, for any new designer out there who doesn't have as much experience, IPC is a good starting point. Use IPC as a guide. I can't say that enough. It's not a hard written rule; it's a guide. When you use it as such, it can get you off to a decent start. My biggest complaint is that the standards are huge. You really need to go through them and make a cheat sheet. We took the IPC placement guide information and condensed it down to a fraction of its original size. For anything that doesn't fit within the IPC guidelines, you can work with your customer and work with the assembler. If you do that, for the majority of the time, you're going to have a pretty producible board with a minimum amount of problems.

Shaughnessy: I hear fab and assembly people say designers get all the crazy signal integrity stuff right, but they'll put connectors too close to something on the board, and you can't get the cables in. It's the simple mechanical stuff that gets them.

Kolar: In fairness, the designers these days, depending on who you're working with, may be working on a project for a big company where they have dedicated mechanical engineers, and they have dedicated people providing that info. For a lot of other cases, you're pulling teeth to get the mechanical requirements. You don't know how the cables are trying to connect there. The customer's saying to just do it. For a lot of designers especially, people that are one- or two-person shops, or if they're working with smaller customers, getting the mechanical stuff right is really hard.

Shaughnessy: Do you think the average designer out there communicates with their assembly provider?

Kolar: I doubt it. I would expect that most just create the package, I doubt that many communicate in advance. Unless they're handling fab or assembly themselves, then they're creating

a package, handing it back to their customer, and their customer is handling fab and assembly. No, I wouldn't expect they would. That's one of the neat things with our model of how interconnected both our PMs and designers work together. Right now, everybody's pretty much working from home, but our designers still have a lot more visibility than the typical designer might. It's about emphasizing communication and being proactive, as we talked about with the fab stuff. If you're doing something that might be a little out of the ordinary or might be risky, it's pretty easy to just email the assembler in advance and ask, "Do you see any issue with this?" One thing I found assemblers really like is if you will give them the full ODB data, that makes their life so much easier than just giving them pick-and-place files, as well as the outer paste layers or outer copper layers. It really helps them both because ODB data is smart, and you can search through it by part. Often, you can find and answer your own PIN1 and polarity questions, but it allows them to have all of the different copper layers so that they can plan their profile better. Only giving them the outer paste layers and not letting them have the outer copper layers makes their life a lot harder because that really impacts the reflow profile.

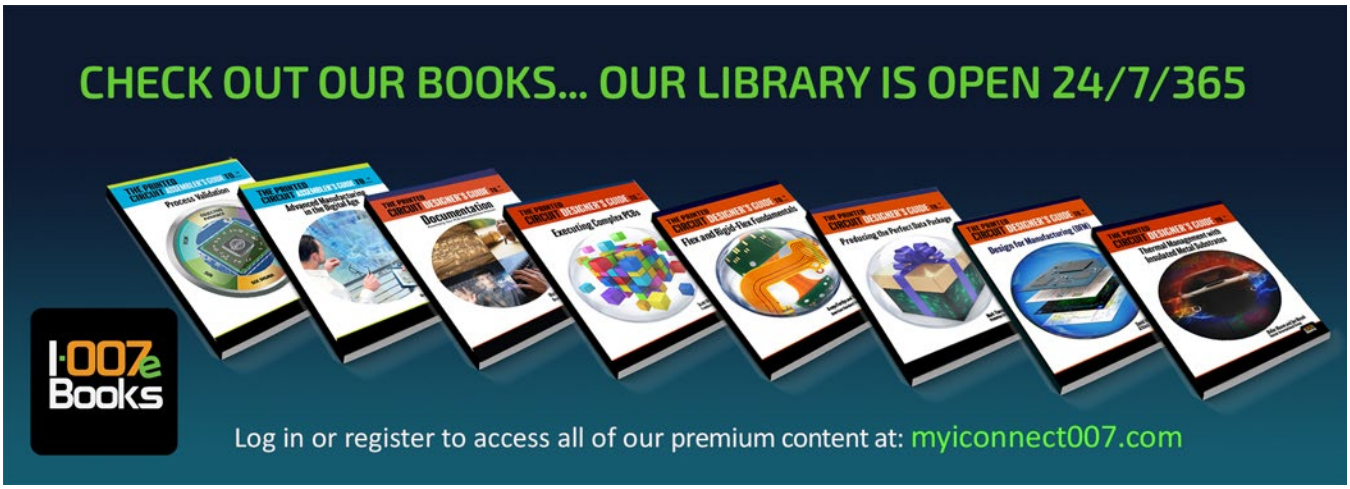
Johnson: Dan, you said you kind of disliked having a mechanical engineer working for you on past projects, but are they worth their money and their trouble?

Warren: A good mechanical engineer can make a designer's life so much easier. A bad one can make it so much rougher. I haven't worked with a bad mechanical engineer for a long time. Most of them really seem to know what they're doing. Those that know their product line are invaluable. At another company where I worked, one man had been there for 30 years. He knew the "gotchas" and would let you know upfront. That made my job a lot easier.

With the customers we have now, I've worked with some really good mechanical engineers. Some of them have better inputs than others. The more complete the input, the easier my job is. I don't have to pull the information out of somebody. But I've had stuff drawn on paper where half of it was on a computer, and half was by hand. I had an input drawn on a napkin with a picture taken with a cellphone and sent to me. I will work off that, but I'm not going to guarantee it's going to work as well as a nice mechanical input.

Shaughnessy: That's great information. Thank you. **SMT007**

Editor's Note: Stay tuned for Part 2 of this conversation, wherein Kolar and Warren give details on successful strategies for multiple-board panels.



Electronics Industry News and Market Highlights

AEM Elevates Capabilities in Automation Fixtures by Acquiring DB Design ▶

AEM Holdings Ltd.—a global leader offering application specific-intelligent system test and handling solutions for semiconductor and electronics companies serving advanced computing, 5G, and AI markets—announced that it acquired 100% stake in California-based DB Design Group Inc.

Keysight Technologies, Cambridge Industries Group Accomplish Inter-Operability Testing of O-RAN Radio Units ▶

Keysight Technologies Inc.—a technology company that helps enterprises, service providers and governments accelerate innovation to connect and secure the world—announced inter-operability development testing (IODT) of O-RAN radio units (O-RUs) in collaboration with Cambridge Industries Group (CIG), an original design manufacturer (ODM), headquartered in Shanghai, China.

Bosch Launches Longevity Program for Industrial, IoT Applications ▶

Bosch Sensortec is launching a longevity program and expanding its product portfolio to meet the specific needs of industrial applications. By ensuring products will be available for 10 years, this new program will give customers peace of mind, as well as access to high-performance, robust sensors and increased purchasing flexibility due to smaller reel sizes.

DuPont's Bryan Barton Named Kavli Foundation Emerging Leader in Chemistry Lecturer ▶

Bryan Barton, Ph.D., was selected to present The Kavli Foundation Emerging Leader in Chemistry Lecture at the American Chemical Society (ACS) Fall 2020 Virtual Meeting & Expo. The meeting will take place on August 17–20 with the theme of "Moving Chemistry From Bench to Market."

Hewlett Packard Enterprise Unveils 5G Lab to Accelerate Adoption of Open, Multivendor 5G Solutions ▶

HPE 5G Lab will be the catalyst that unlocks a new wave of open, interoperable 5G innovation, as telcos prepare for mass adoption of 5G.

TT Electronics Receives Grant From Innovate UK ▶

TT Electronics, a global provider of engineered electronics for performance-critical applications, announced it would receive Innovate UK funding for furthering innovation in the nation's civil aerospace industry. These funds have been awarded to participants in the Aerospace Electric Propulsion Equipment, Controls & Machines (AEPEC) project led by Safran.

Taiwanese Supercomputing Center Advances Real-Time Rendering With NVIDIA RTX Server ▶

As the stunning visual effects in movies and television advance, so do audience expectations for ever more spectacular and realistic imagery. The National Center for High-Performance Computing, home to Taiwan's most powerful AI supercomputer, is helping video artists keep up with increasing industry demands.

Cambridge: AI-Based 'No-Touch Touchscreen' Could Reduce Risk of Pathogen Spread From Surfaces ▶

A "no-touch touchscreen" developed for use in cars could also have widespread applications in a post-COVID-19 world by reducing the risk of transmission of pathogens on surfaces.

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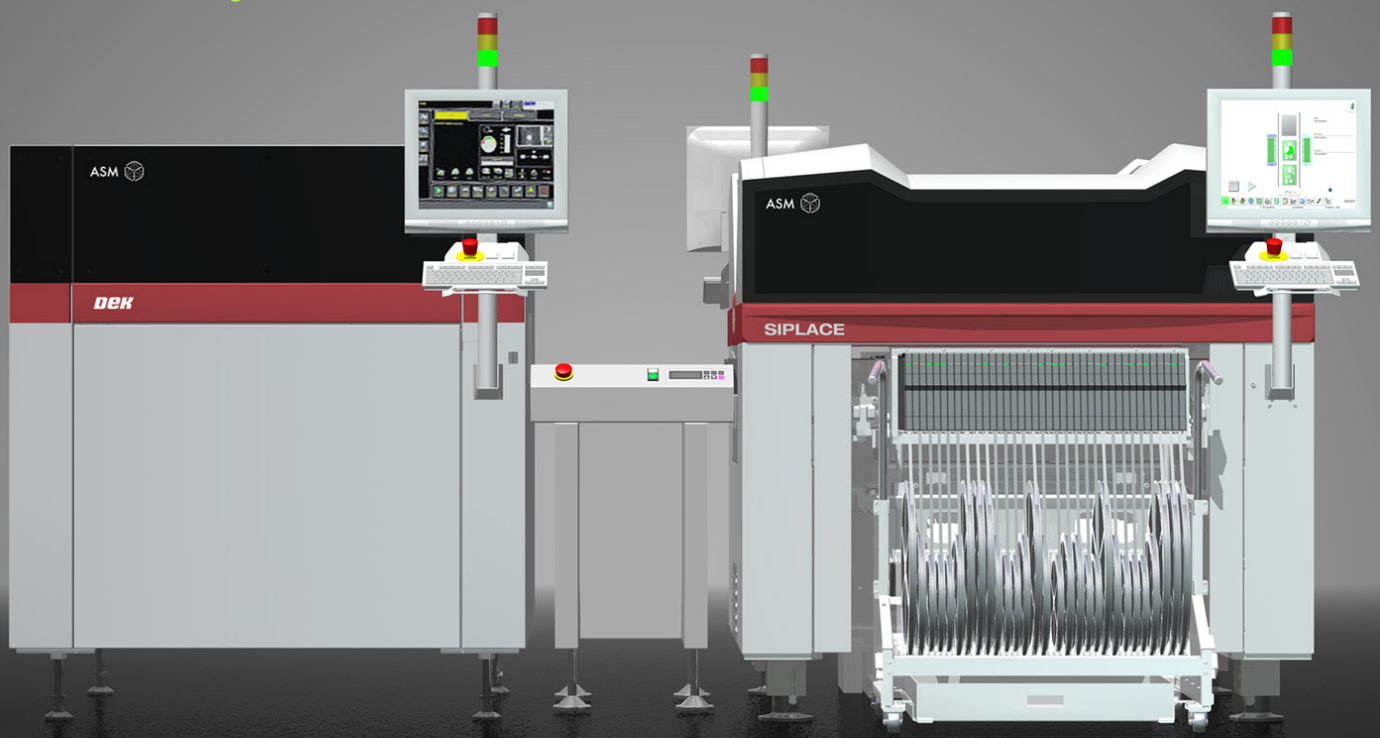

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90% Solder Dross Recovery: Eliminate Waste, Save Money

Interview by Nolan Johnson
I-CONNECT007

The impact of 90% solder dross recovery can have a substantial impact on reducing waste and increasing cost savings. I recently spoke with Jay Hardin, MS2® product manager at P. Kay Metal, about the process and benefits of efficient solder dross recovery, as well as product roadmaps, the soldering machine market, and raw materials supply chain for solder alloy manufacturing. As Jay says, "For many companies, the savings are in the thousands or millions" of dollars.

Nolan Johnson: Hi, Jay. Could you tell us a little about yourself and P. Kay Metal?

Jay Hardin: I'm with P. Kay Metal, Inc., headquartered out of Los Angeles, California. I'm the product manager for the company. Since 1978, we've been a tin-lead alloy and chemical manufacturer, which includes fluxes and our specialty product called MS2.

Johnson: With a product mix like that, do you primarily sell into both fabrication and assembly?

Hardin: Yes. Primary customers are based in Mexico and the Western United States. The specialty product, MS2, became a global product in 2006. It has been used by most major contract manufacturers and assemblers in the world, including the largest ones. We have contracts with many of the facilities around the world and can supply them all from our headquarters in Los Angeles.

Johnson: The MS2 product is a little different. Can you explain MS2 and what it does?

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MS2® molten solder surfactant being poured onto the surface of the solder bath.

Hardin: Our company is a solder manufacturer, but our history has always been in dross recycling. Solder dross is a waste that's formed in the through-hole assembly process of PCB manufacturing—a large solder pot of the solder is constantly in motion, forming a gum called dross, which is removed from the process and sold back to companies like us. We recycle that solder dross back to usable metal and can then sell it back to the customer. The MS2 product was developed when everything was becoming lead-free, and prices of solder went from being $2 a pound to up to $30 a pound. The cost of dross became a huge problem once everything went lead-free.

We thought that the product we used to recycle solder dross could be re-blended and, in a pure form, sold to the producers of the dross globally to eliminate both the solder dross problem and cost. The solder dross that customers generate from the wave soldering machines represents about 60–80% of the total waste that they generate in their facility. It also requires them to purchase new solder bars. About 80% of the new solder bars that a customer buys is to replace the solder dross that they're removing from the process. If we're able to eliminate that waste and help the customer to become 95+% efficient with the solder they buy, all they have to do is implement the MS2 process into their lines.

Johnson: What did they do with the solder dross before your product was available?

Hardin: There are manufacturers out there that also sell solder bars, and we buy the solder dross back from the customers. The way the cycle typically works is we sell it to the customer over an LME price, which is the cost of metal plus manufacturing. It's what all customers are going to pay for when they buy solder bars. Now, when they generate their solder dross, they're getting a third of the value of the metal cost. If they're just sending solder dross out the door, 80%, more or less, of the solder that they're buying is replacing that dross that they're then selling and shipping off as hazardous waste—but getting paid about 30–40% of the actual value. They're losing 60+% every time they send dross out the door.

Johnson: That must drive the actual average purchase price of the solder way up. If they use your product to do on-site dross recovery, then they get something more like 95% efficiency?

Hardin: Exactly. 95% of the solder bars that they buy from a solder manufacturer, whether it's from us or anybody else, ends up under their product versus 80% of that being shipped out the doors as hazardous waste.

Johnson: Help me imagine what a setup is going to look like for using MS2. What equipment do you need? How do you put the product to work? To achieve such a reduction in solder waste is pretty significant.

Hardin: For many companies, the savings are in the thousands or millions. We're constantly adding new companies each quarter and significant companies globally, and they all see huge savings. One thing I can always say about MS2 is once the customer has gone down that path by taking the time to help us implement it inside their process, it never leaves. We don't see companies start to buy from us and then go away. Once they're a customer, they're always a customer because they see the savings right away.

The process varies depending on the size of the customer as well. We have setups for a company that has, maybe, 1–3 wave solder machines. In the warehouse we put up a melting pot with a mixer and a drain valve that molds. When you're done recycling your solder dross, you make your own solder bars, which could be added back to your solder pot.

The other advantage of doing this offline is when you have multiple solder alloys in your processes, which many companies do. Some companies will have lead-free and then tin-lead processes. Some might have multiple lead-free processes or lead-free alloy lines. With this process, we're able to take a solder sample from your vats before you make your own bars. You can send them off either internally or send it to us so we can analyze the solder bars before they go back in your process to verify that they're within specification. The number of machines depends on the size of the line, size of the customer and how many wave solder machines they have. Most large contract manufacturers will have three lines—the tin-lead line and maybe two lead-free lines. Each unit is about the size of a washing machine and they're fully enclosed. They have a ventilation system and temperature controls, which allow a customer to process each machine at about 300–400 kilos of solder dross per shift and per operator.

Johnson: Is there a waste byproduct after using MS2 and reclaiming the solder from the dross?

Hardin: That MS2 chemical combines with the oxide, and when it's all done, it thickens up like mud. That has been removed, which turns to a solid and can then be returned to your solder dross recycler, or to us. We always take that back. The weight reduction is about 90–95% less than what you have with your solder dross.

Johnson: There's still something that P. Kay can buy back and work with further.

Hardin: Exactly. The chemical renders some of the oxide of the solder dross. It does contain some metal, which has a slight value to it.

Johnson: Does MS2's acceptance with customers cut into the revenue for P. Kay?

Hardin: That's a great question, and it's something we ask a lot. If we were a large global company that sold solder bars globally, then this would impact us. Because we're a smaller solder manufacturer, we just supply Mexico and North America. For example, if we had a customer that was a long-time solder bar buyer, and they went to MS2, we would be losing money to that customer. The goal obviously with MS2 is to be global. We can't be selling solder bars all around the world because of freight. Freight's the killer.

Jay Hardin

Johnson: As a regional supplier of solder, that's one thing, but as a global supplier of dross recovery, that's an entirely different market.

Hardin: Right. For example, if we were Nihon Superior or one of these global companies, and we knew about MS2, we wouldn't be selling it.

Johnson: Instead, you are selling a dross recovery system so manufacturers can be more efficient with Nihon's product. That makes a lot of sense. You alluded earlier to testing the recovered solder so that it stays within spec. Is that much of an issue?

Hardin: No, but new customers want to verify that the process hasn't changed. They call it process modification or improvement as the engineers push to get it approved as a process within their facility. As they start to implement the process, they're going to look even closer at how it affects the quality of the product and the product defect—product defects per million opportunities that they measure across their normal process of soldering. Part of that process, and what they also want to monitor, is whether it changes the alloy, or the purity, of a solder pot. That's the one thing that takes

some convincing to the customer, but we're always able to prove to them that it does not. Your process and quality do not change. If anything, we've even been told that they see improvement.

Johnson: That would seem to be rather critical given what's going on in the industry right now—for example, microvia issues, challenges with packaging, solder adhesion and wetting. These topics are on the minds of the assemblers. A new process like this, which is not only more efficient but also keeps customers inside spec, is going to be critical.

Hardin: Yes. From our many years of experience working with each customer hands on, this is the first hill that we climb—we have to prove it to them, and we're willing to do that. We come in as a team. We don't just send products throughout the world. We're either seeing the customer ourselves or it's one of our partners/distributors whom we personally trained. If you're the customer, we prove the process out and look at those numbers with you. We help you gather them, and we prove that your process is not going to be affected in any way, except that you're going to be saving boatloads of money.

Johnson: Let's walk through what a customer demo, verification, validation, and engagement looks like.

The Akila off-line solder recovery unit.

Hardin: We carry what we call a little "demo pot." It looks like a little tiny crockpot, but it's an industrial version. It's also a miniature version of what the process looks like, but it's something that we can hand-carry in there. We ask the customer to collect 10–15 pounds of their typical solder dross, and then we set up and recycle that together. It takes about two hours to set up the equipment.

We'll take a sample from the solder pot that the dross came from and call that our "before" sample. Then, we remove the dross from the solder pot and weigh it. We put it into our offline process line melting pot. We melt it, and then add the required amount of MS2 needed for 10–15 pounds, depending on the weight. We mix it for about 10 minutes, and then everything returns to metal. We take a sample from that pot and pour out the bars, which is a big selling point to the engineers and to the customers. When they see dirty solder dross, it's like dirt going into a melting pot; and at the end, when we're done, we're pouring out brand-new shiny bars.

That's when it really hits home to them that this works. We weigh everything, showing them how we put in 10 pounds of dross and got out nine pounds of solder bars. We recovered 90%. We know what recovery to expect going forward, do some simple math right there, and we tell them, "Based on your current solder bar purchases price and what you're getting paid for your dross, here's your value."

In the end, we take those solder samples from the solder pot—from the wave solder machine that the dross came from—and then we have the sample from our offline unit from recycling the dross. It shows customers that there's no change to the alloy. Whatever the alloy is inside the wave solder machine is identical to the alloy that you're getting out in your solder bars.

Johnson: Because all you've done is separate out the oxide.

Hardin: Correct. It does not affect the alloy in any way. It acts like a soap or a degreaser.

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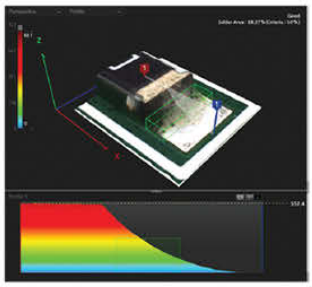

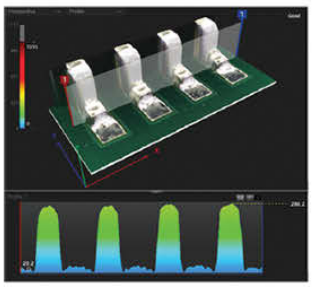

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It breaks the bond between the oxide and the metal and purifies it. Now, you have a solder bar that has no oxide impurities in it.

Johnson: Is the MS2 a reagent in this process, or is it a catalyst?

Hardin: It's more of a reagent. There's no bond at all between the alloy itself and MS2, so all it's doing is sequestering the oxide. When it does that, the oxide is what's kind of bonding up the dross, making the metal stick to the oxide. By sequestering the oxide, it releases the good metal.

Pure solder bars are formed when the solder cools.

Johnson: Soap works because one end of the molecule is hydrophilic, and the other end of the molecule is attracted to oils; therefore, you connect the oil on one end, the water in the other end, and the dirt washes out. At that point, you probably have a sale.

Hardin: When I go into a customer, and we get to that point where we are with the right people at the management level—the people that care if we're saving money—they are going to want to use it. And it works for all types of alloys.

Johnson: What do you see going on in the market right now? There are still issues about lead solder, tin-lead solder, lead-free solder, and the like.

Hardin: The only time we see tin-lead right now is with military or some specialty automotive safety stuff. It took a while, but right now, everything's pretty much lead-free. Even in China, I saw some tin-lead stick around for a little bit longer, but that has gone away. The real struggle right now is people trying to work in a safe environment. The economy's down, so consumer electronics are down. Many factories, especially in Mexico, were shut down. Some are still only running at half capacity. Like the rest of the economy and world right now, it's a little unstable. People have to save their money.

Johnson: Do you find that facilities are more interested now in talking to you about the dross recovery product?

Hardin: There was a two-month dry spell where there weren't really any engineers at the facilities because they were all working from home. But now engineers are back to work, and the drive we see is, "How do we save money? How do we reduce inventory? How do we reduce lead times?"

Johnson: What do you see over the horizon for the solder alloy market? Are there some dynamics in play that could change things?

Hardin: Yes. Over the last few years, the wave soldering industry has died down quite a bit. They've gone to a more efficient process called selective soldering. That type of soldering has a lot less waste. The old-style wave soldering machine would have a 2,000-pound solder pot constantly under turbulence, producing probably about four to five pounds of dross an hour. Nowadays, the new machines produce five pounds of dross in a day. There's an objective to be more efficient and reduce costs, and that's one way to do it. We're also here to say, "No matter what equipment you have, if

you're generating solder dross, we have a solution for you."

Johnson: It has been interesting in the past year to follow the wave solder machine market because, depending on who you talk to, there's a question as to whether that's still solid or on the decline.

Hardin: Wave soldering machine purchases are on the decline. If anything, people are going more toward selective in replacing older and larger machines. They take up a lot more space, but as far as throughput goes, there are still a lot of companies out there that are doing thousands of power supplies every day. Doing power supplies, you're going to have through-hole and need a lot of production, so wave soldering is the only way to do it.

Johnson: They're not going to go away. Like many things, there's going to be a particular application that needs wave solder.

Hardin: Power supplies will be a long industry for the through-hole.

Johnson: What's on the development roadmap? What's over the horizon for P. Kay?

Hardin: Our focus has been more on the metal side, but we have a lot of parts of the business. We're in the electronics industry, the industrial radiator industry, the ammunition industry, and that's where our focus has been from a corporate level. Right now, the ammunition industry is a very strong market for us, but at the same time, we're always right there with our electronics focus. As far as the industry goes, we have our own dedicated team that runs that side of the business, and they're always trying to help customers save money.

Johnson: Given that multiple industries are competing for the same raw materials, and some of them are large, global industries, you still see ammunition growing. What other industries seem to be competing for the same materials?

Hardin: Battery manufacturing uses many of the same elements as the electronics industry, in addition to ammunition. As everyone knows, battery manufacturing and technology is at a high point right now, so that's another strong industry for us.

Johnson: We're talking about how well the mining industries are able to keep up supply. What can you share about the market for getting your raw materials?

Hardin: For the electronics industry, you're talking tin, silver, copper, and some lead, but not too much. Lead has gone way down. The tin market has been down quite a bit—it's probably down 30% from where it was two years ago. Silver is holding pretty steady, and copper is bouncing all over the place right now.

Johnson: Is that pricing or production?

Hardin: Both. They go hand in hand, especially with those metals. Silver has been pretty steady for a while. As far as mining goes, all those materials are used in lead-free alloys for the most part; 80+% have to be a special grade, which is directly from a mine and triple the impurity levels.

Johnson: You don't see production issues out of the mining industry at this point?

Hardin: Correct.

Johnson: Good. That means that there is a part of the supply chain that may be relatively robust.

Hardin: One of the few.

Johnson: Jay, thanks for such a thorough briefing.

Hardin: It was a great conversation, and I appreciate the time. SMT007

Supplier Highlights

Indium Corporation Featured AuSn Precision Preforms at Space Tech Expo ▶

Indium Corporation featured its precision AuSn preforms for high-reliability aerospace applications during the Space Tech Expo Connect virtual exhibition on August 10–13.

Koh Young Collaborates With Mentor to Further Simplify Inspection System Programming ▶

Industry leader Koh Young announced it joined forces with Mentor, a Siemens Business, to deliver an enhanced programming solution, which will benefit the PCB assembly market.

Saki Corporation Opens Solution Center in Europe ▶

Saki Corporation, an innovator in the field of automated optical and X-ray inspection equipment, announced the expansion of the new EMEA regional head office in Prague (Czech Republic) with the opening of a brand-new solution center.

Electrolube Introduces Key Products for Battery Thermal Management ▶

Electrolube, a global leader in protective electrochemical solutions, developed key thermal management and encapsulation resin products for battery protection.

CyberOptics to Present Technical Paper at SPIE Optics + Photonics 2020 Online Conference ▶

CyberOptics® Corporation, a global developer and manufacturer of high-precision 3D sensing technology solutions, was scheduled to present at the SPIE Optics and Photonics Online Conference in August during the SPIE Optical Engineering and Applications Symposium's verification and alignment session.

Manncorp Boosts Ability to Buy Online ▶

Manncorp is now offering the convenience of online purchasing with added benefits of support from equipment specialists and online-buying discounts that may not be available from alternative sources.

KIC Announces MB Allen to Retire by March 2021 ▶

MB (Marybeth) Allen has been a dedicated and valued part of the KIC family since 1999. MB spent decades leading our team with her technical expertise and sales experience. This—along with her work ethic, outstanding contributions, devotion to clients, and many industry achievements—has positioned MB as the face of KIC for many years.

MacDermid Alpha to Present Advantages of Solder Paste in Shingling Interconnection at SNEC PV Power Expo ▶

The Assembly Division of MacDermid Alpha Electronics Solutions, a world leader in the production of electronics soldering and bonding materials, will be presenting a technical paper on the "Advantages of Solder Paste in Shingling Interconnection" during the SNEC 14th (2020) International Photovoltaic (PV) Power Generation and Smart Energy Exhibition & Conference in Shanghai, China.

Creative Materials Launches New Insulating Adhesive ▶

Creative Materials introduced 813-76, a two-component room temperature curing thermally conductive and electrically insulating adhesive. This product is designed for assembling heat-sensitive components on PCBs, and it develops strong adhesive bonds and excellent thermal transfer.

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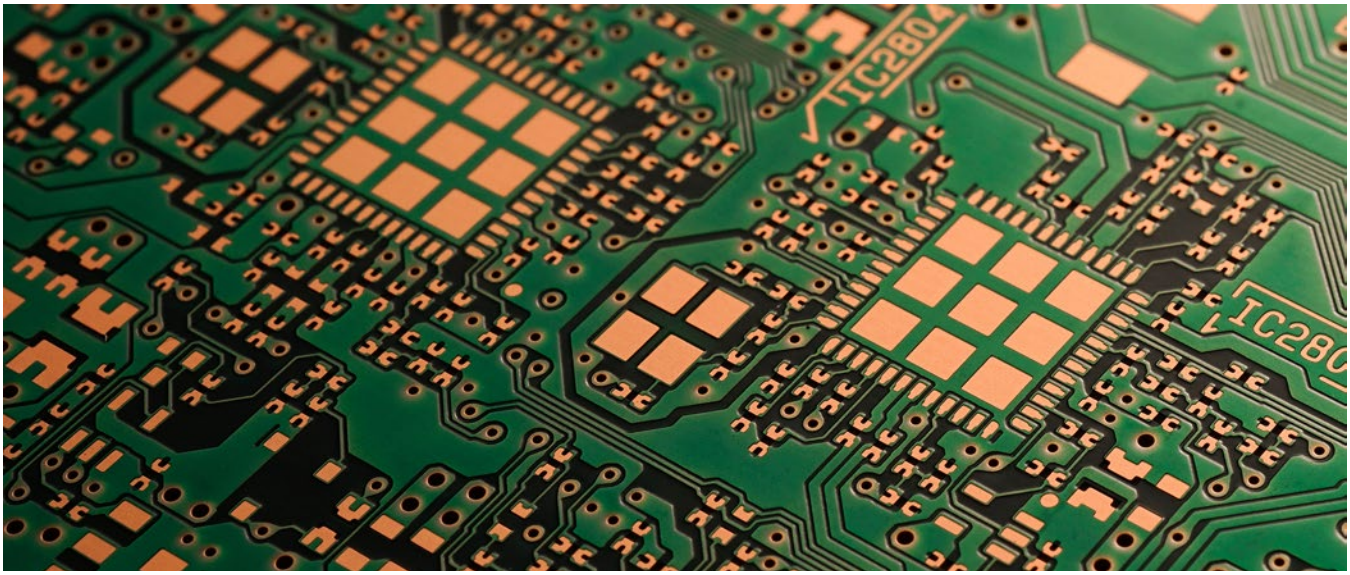

Can All Liquid Fluxes Work Well on A Reflowed OSP Pad Finish?

Article by Ansuman Das
MACDERMID ALPHA ELECTRONICS SOLUTIONS

Introduction

Organic solderability preservative (OSP) is an ultra-thin organic final finish coating for copper pads on PCBs, which provides protection from oxidation under a wide range of conditions. Several advantages—such as lower cost, easier processing, and excellent coplanarity compared to metallic finishes—has made OSP an attractive choice to PCB fabricators and assemblers. Solder joints formed on OSP have a negligible tendency of electromigration, as they do not contain any metallic impurity coming from other finishes.

OSP finish is being used on over 60% of all PCBs made today, and it has proliferated into high-reliability markets like automotive, which have traditionally used metallized finishes. However, OSP coatings suffer from a few drawbacks as well. After exposure to one or more thermal excursions, OSP coatings can become more challenging to solder, especially during wave and selective soldering applications. For example, a thick multi-layered double-sided PCB coated with OSP that has been exposed to one or more SMT solder paste reflow cycles may experience reduced solder wetting or hole fill by the assembler when wave soldered. This poses a huge challenge to all the assemblers, especially for Pb-free processes using SAC alloys with higher operating temperatures.

Solutions suggested by engineers and researchers to mitigate poor soldering performance on pre-reflowed OSP were limited to PCB and component design improvements or optimizing soldering process parameters. Some groups suggested using more active fluxes, but these fluxes tend to leave corrosive residues and compromise the electrical performance of the assembly. Keeping this in mind, we have tried to understand the chemical changes OSP coatings undergo during thermal excursions and identify elements of soldering flux, which will interact with such thermally exposed OSP to convert them into a clean copper surface, which will result in better wetting performance.

Characterization of OSP Coating

OSP coating is achieved by dipping specially treated copper surface into a solution containing active OSP chemicals. During this process,

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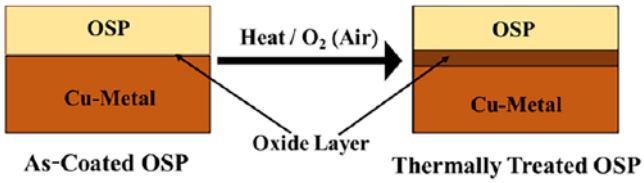

Figure 1: Schematic diagram of oxide thickening at the Cu-OSP interface.

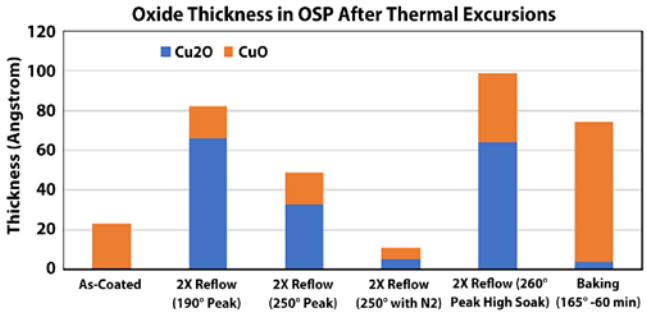

Figure 2: Oxide thickness in OSP coating after different thermal excursions.

OSP molecules attach themselves to the copper surface by forming coordination bonds with surface metal ions, as well as by electrostatic attraction. When OSP-coated copper pads undergoe thermal exposures (baking or reflow), the oxide layer at the metal-organic interface gets thickened depending on the nature of the exposure (Figure 1).

The oxide layer formed under different thermal conditions was quantified using sequential electrochemical reduction analysis (SERA). The results showed that the oxide layer consists of both Cu_2O and CuO, and it increases with the increase in exposure temperature or time (Figure 2). The study also indicated that there might be a temperature range above which OSP coating softens and changes its morphology. During this transition, the coating becomes less protective and allows external gas (oxygen) to penetrate through it, which increases the oxide layer thickness.

We have studied this morphology change of OSP coating by atomic force microscopy (AFM). Three-dimensional AFM images (Figure 3) showed that the as-coated OSP surface consists of an extensively large number of fine-grained micro-peaks, which largely disappeared after Pb-free reflow with the appearance of larger grain-like features. This morphology change is not noticed when coupons are exposed to 165°C or less, independent of exposure duration. These observations reinforce the hypothesis of coating softening above 165°C as suggested in SERA study.

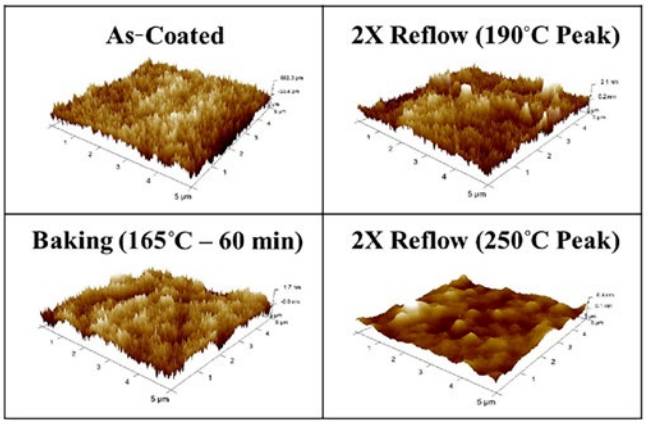

Figure 3: Three dimensional AFM images of as-coated and thermally treated OSP coating.

The obvious question here is, "What types of changes in the organic layer result in larger grain morphology after OSP is exposed to higher temperatures?" Images obtained from field emission scanning electron microscopy (FESEM) showed the presence of small-size random grains present on the surface of the as-coated OSP, which was converted into elongated fiber-like structures upon standard Pb-free reflow (in air or nitrogen) (Figure 4). The formation of such fiber may be attributed to the supramolecular structure formation of substituted benzimidazole molecules.

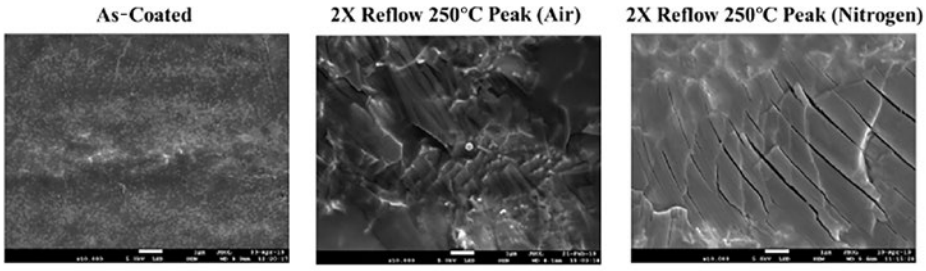

Figure 4: FESEM images of as-coated and a thermally treated OSP coating.

From these results, it can be summarized that when OSP-coated PCBs undergo thermal excursions, two main changes take place: (1) oxide layer at the organic metal interface thickens and (2) active OSP molecules get rearranged to form supramolecular fiber-like structures. Oxide thickening requires both heat and oxygen, while fiber formation is affected by the elevated temperature alone.

OSP Flux Ingredient Interaction

Now, with our understanding of the changes in OSP after thermal excursion, we wanted to find out which chemicals, often contained in liquid fluxes, could overcome the effects of these changes. In the soldering flux industry, few organic solvents are loosely termed as OSP cutters because of their ability to dissolve OSP coatings. We studied the relative OSP cutting efficiency of a few such solvents.

As-coated and 2x reflowed laminates of fixed dimensions with ENTEK Plus HT finish were dipped in a fixed volume of each of these solvents (at 70–80°C) and 5% HCl. OSP coating dissolved in solvents was quantified by measuring the UV absorption of the resultant solutions. 5% HCl was known to dissolve as-coated ENTEK Plus HT completely, and the absorption value of this solution was taken as 100% OSP concentration. The absorption value of other solutions was converted into a relative percentage of OSP dissolved (Figure 5).

From the absorption plot, it is easily understood that most of the solvents taken can easily dissolve as-coated OSP, but solubility decreases drastically once the coating undergoes two reflows. Only solvent SOL1 and 5% HCl can dissolve 40–50% of the pre-reflowed coating under the experimental conditions. Solvent SOL1 is one of the strongest organic solvents and can break down the supramolecular arrangement in pre-reflowed OSP. On the other hand, HCl can react with benzimidazole (which is a base by nature) and remove it into the solution.

If inorganic acids can dissolve thermally treated OSP, can organic acids do the job? To confirm this, a 1% solution of two organic acids was prepared in SOL3 (having poor performance on reflowed OSP), and a dissolution study was carried out as earlier. Results showed that both of the acid solutions could dissolve ~80% of the as-coated OSP. But for the pre-reflowed OSP—while solvent can dissolve only 5–10% of the OSP layer—activator solutions showed better efficiency, dissolving 20–30% (Figure 6).

However, dissolving the organic layer is only half of the job. For solder to wet and form a joint, the oxide film beneath the organic layer needs to be removed. Historically, organic or inorganic acids, halides, halogens, etc.—collectively known as activators—are used for this purpose. To understand how they react with oxides, differential scanning calorimetry (DSC) was used.

Commercially available, analytical-grade cuprous, or cupric oxide, was mixed with an activator (90:10 ratio) by dry mixing and was heated in a DSC pan at 10°C/min ramp

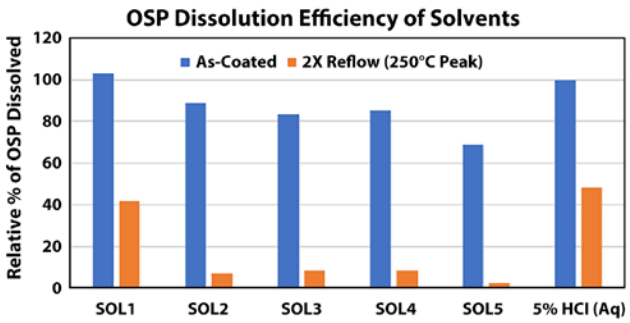

Figure 5: Relative percentage of as-coated and reflowed OSP dissolved in different solvents.

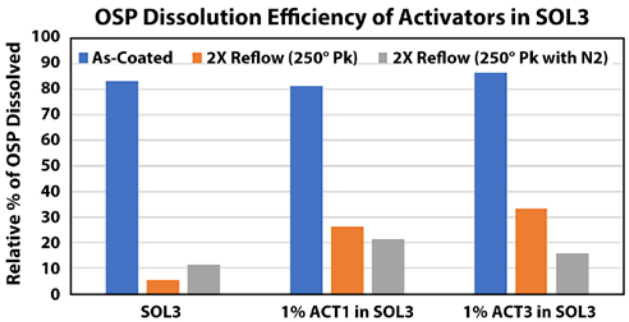

Figure 6: Relative percentage of as-coated and reflowed OSP dissolved in solvent and activator solutions.

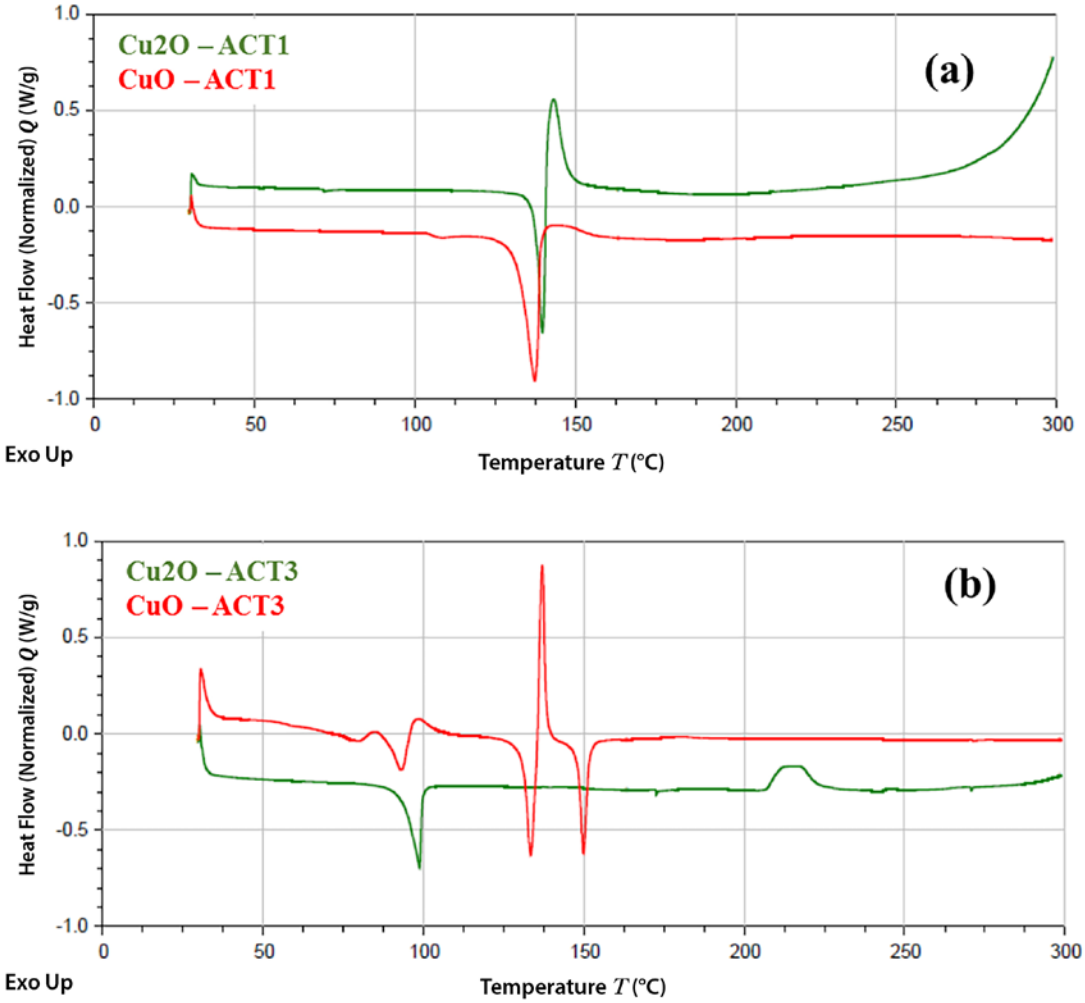

Figure 7: Representative DSC thermogram of activator copper oxide mixtures.

from 30°C to 300°C. A baseline DSC study of the only activator was carried out to discover whether the activator undergoes any heat change during this thermal ramp. Representative DSC thermograms are shown in Figure 7. DSC results reveal endothermic peaks for only the activator runs corresponding to the melting point of the activators. Additional exothermic and endothermic peaks are observed for oxide-activator mixtures. These additional peaks we believe are resulting from the reaction between activators and copper oxides.

A closer look at the thermogram also reveals activator ACT1 reacts with cupric oxide just after it melts around 140°C, while the other, ACT3, reacts with cuprous oxide at a similar temperature after melting at 100°C. ACT3 also showed a smaller reaction exotherm around 220°C with cupric oxide. This indicates each of the activators reacts with a particular oxide at a particular temperature range. Thus, a multi-component activator package, where different constituents will react with different oxides at different temperature ranges, will be efficient to remove all the oxide from OSP coating.

Wetting of Solder on OSP

Now, with the knowledge on the flux ingredients required to remove thermally treated OSP, we wanted to evaluate their efficiency to wet solder. A few activators and solvents selected from the aforementioned studies were short-listed, as shown in Table 1. A wetting evaluation was carried out on ENTEK Plus HT coated OC-3 coupons using Malcomtech SWB-S2 wetting balance tester fitted with SAC305 solder bath. Wetting data were collected on both as-coated and 2x Pb-free reflowed coupons

Ingredients	Combination No 1 Wt%	2 Wt%	3 Wt%	4 Wt%	5 Wt%	6 Wt%	7 Wt%	8 Wt%	9 Wt%	10 Wt%	11 Wt%
ACT1	2.0				2.0	2.0	2.0	2.0	1.0	1.0	1.0
ACT2		2.0									
ACT3			2.0						1.0	1.0	1.0
ACT4				2.0							
ACT5					0.5					0.5	0.5
ACT6						0.5					
SOL1							10.0				10.0
SOL3								10.0			
IPA	98.0	98.0	98.0	98.0	97.5	97.5	88.0	88.0	98.0	97.5	87.5
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Table 1: Details of solvent activator combinations for wetting balance study.

with solder bath temperature at 260°C. Solder score (S) for each measurement was calculated using the equation, $S = [3.5 - T_0] + [4 - T_{2/3} - T_0] + [F_{max} \times 10]$, where F_{max}, T_0, and $T_{2/3}$ stand for maximum force, time to zero wetting, and time to reach two-thirds of the maximum force, respectively. T_0, $T_{2/3}$, and F_{max} values were obtained from the instrument, and solder scores (S) for each run were calculated using that data.

A solder score plot (Figure 8) shows that all solvent-activator combinations except 7 have

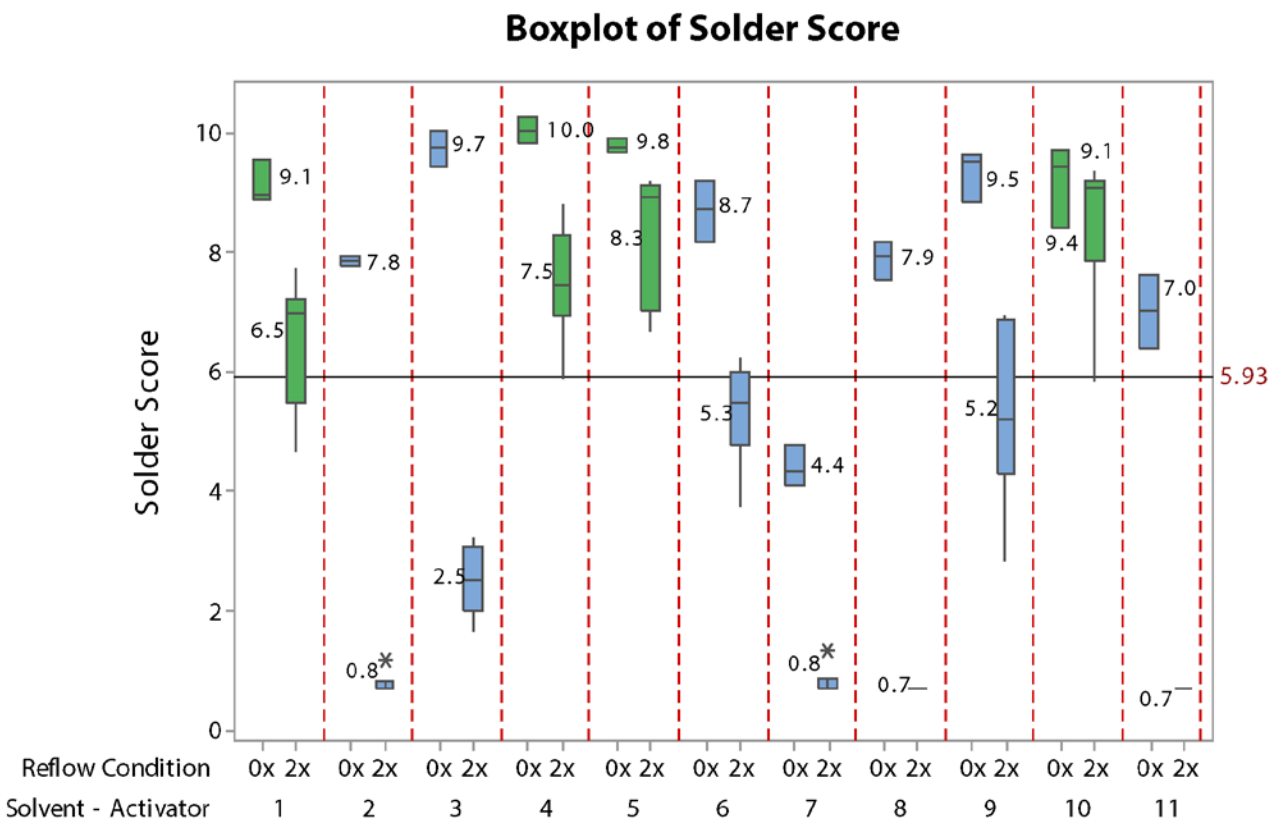

Figure 8: Solder score plot for solvent-activator combinations.

excellent wetting properties on the as-coated OSP. All these combinations have a solder score above 5.93, a requirement for the sample to be called as AA-class per IPC J-STD 003C. However, when tested on 2x reflowed OSP coupons, solder scores for only a few combinations remained above 5.93, indicating that only these combinations were able to remove the pre-reflowed OSP coating effectively. Solder score data obtained from such simple wetting experiments helps flux formulators to shortlist ingredients to develop new products with best-in-class wetting on pre-reflowed OSP.

Another interesting observation from this experiment is that whenever a secondary solvent is used, solder scores of those combinations have declined. Combinations 7 and 8 contain the same activator as combination 1 with the addition of two different secondary solvents, and combination 11 has the same activator as 10 with a secondary solvent. We have seen in the earlier section that these solvents help to remove thermally treated OSP.

The author assumes this anomaly of results between two sets of experiments is due to the partial drying of the coupons due absence of a preheat system in wetting balance. Whenever a partially dry coupon is dipped in the solder bath, volatiles present in coupons dilute the activator system and also cause spattering, disturbing and delaying the wetting process. Wetting balance is an excellent tool to screen the efficiency of activators, but it may not be the most reliable method to compare flux performance, especially for fluxes containing secondary solvents to preserve their activity at higher temperatures. They require more complex evaluation processes like wave or selective soldering to compare the activity and other properties.

To verify this, we selected few commercially available liquid fluxes containing some of these activator-solvent combinations. Details of the solvents and activators present in the fluxes are described in Table 2. The wave soldering performance of these fluxes was benchmarked on a 2.4-mm 6-layer PCB having ENTEK Plus HT finish. PCBs were subjected to 2x reflow before the wave process. Wave soldering was carried out on an ERSA PowerWave machine using an SAC305 bath at 265°C. Flux loading for all the fluxes was controlled in such a way that activator amounts on the board remain constant. Wetting performance of the fluxes was evaluated by comparing the x-ray images of the PCI connector barrel filling (Figure 9).

Flux	Solvent - Activator Combination Used
A	Combination 3
B	Combination 5
C	Combination 5
D	Combination 6
E	Combination 5 + SOL3
F	Combination 11

Table 2: Details of activators and solvents present in commercial fluxes taken for wave soldering performance.

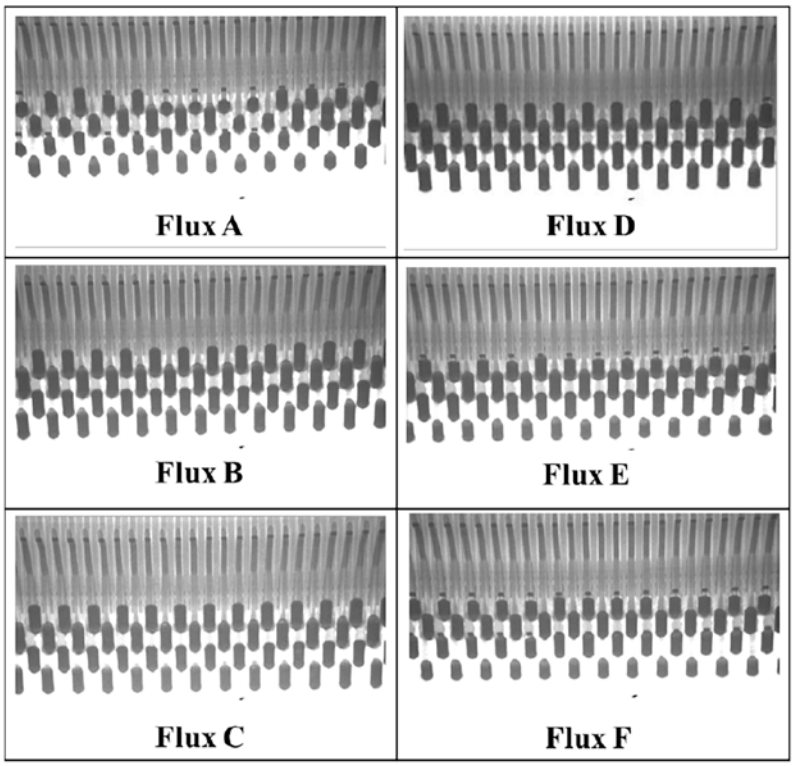

Figure 9: X-ray images of PCI connectors showing the barrel filling for different fluxes.

From the barrel fill images, it is very clear that Flux A containing solvent-activator combination 3 has the worst performance among the fluxes. Flux B and C with combination 5, and Flux D with combination 6, showed excellent barrel filling. Wave soldering performance of these fluxes corroborates the results obtained in wetting balance experiments. Additionally, Flux E having solvent SOL3 and activator combination 5, and Flux F with combination 11, demonstrate soldering performance equivalent to Flux B, C, and D. For Fluxes E and F, secondary solvent helps the flux to remove the thermally treated OSP, thus assisting in the solder wetting process. In many Pb-free capable fluxes, secondary solvents help to dissolve OSP and also preserve the activity for soldering at higher temperatures.

Conclusion

The study showed when OSP-coated copper pads undergo thermal excursions, two major changes take place. Copper oxide film at organic metal interface thickens due to the formation of Cu_2O and CuO. In addition, the organic layer becomes compact as substituted benzimidazole molecules rearrange them to form elongated fiber-like structures via intermolecular attraction. This organic layer of pre-reflowed OSP can be dissolved by some solvents or solutions of organic acids in these solvents. Flux activators can react with the oxides and remove them at elevated temperatures. Different activators, found to react selectively with one of the oxides at different temperature ranges, indicate the necessity of a multi-activator package for soldering flux.

The wetting balance method was found to be very useful in screening activators that may effectively remove pre-reflowed OSP, but the results may sometime lead to false failure, especially where a secondary solvent is used in addition to IPA to make the activator solutions. Thus, for fluxes with a secondary solvent, it is advisable to compare the flux activity using wave or selective soldering processes. Results obtained from both wetting balance and wave soldering experiments, however, confirm the effectiveness of fluxes with multi activator packages achieving superior wetting on thermally treated OSP. SMT007

Ansuman Das is an R&D manager at MacDermid Alpha Electronics Solutions, Bangalore, in India, working on new product development in the area of soldering fluxes and pastes. He joined MacDermid Alpha in 2004 and has 25 years of experience in chemical and materials research.

How Airplanes Counteract St. Elmo's Fire During Thunderstorms

At the height of a thunderstorm, the tips of cell towers–and other tall, electrically conductive structures–can emit a flash of blue light, known as a corona discharge, or St. Elmos' fire.

Scientists found that corona discharge strengthens in windy conditions, glowing more brightly as the wind further electrifies the air. Now, aerospace engineers at MIT have found that wind has an opposite effect on ungrounded objects, such as airplanes.

In a storm cloud, friction can build up, creating an electric field that can reach all the way to the ground. If that field is strong enough, it can turn neutral air into a plasma. This process most often occurs around sharp, conductive objects, such as cell towers and wing tips.

The MIT team wondered about a sharp, ungrounded object, such as an airplane wing. They fabricated a simple wing structure out of wood and wrapped the wing in foil. The team subjected the wing to increasingly higher velocities of wind, up to 50 meters per second, and varied the amount of voltage that they applied to the wire.

They found that the strength of the corona discharge and its resulting brightness decreased as the wind increased—a surprising and opposite effect from grounded structures. (Source: MIT News)

How to Audit OEM-EMS Assembly Capability, Part 1

SMT Solver
by Ray Prasad, RAY PRASAD CONSULTANCY GROUP

If you are one of the long-time readers of *SMT007 Magazine*, you probably know that there was a print version for decades known as *SMT*. I was one of the columnists for the print version, starting in the mid-1980s. I was looking at some of the columns that I wrote almost a decade ago to see how things have changed over time. It should be no surprise that there have been significant changes in many areas but practically no changes in others.

For example, there has been practically no improvement in the percentage of yield despite decades of industry experience in high-volume manufacturing. Obviously, some companies are better than others in achieving higher and consistent quality than others, but overall the yield has not improved in percentage terms over the decades. Less than 10% of companies, OEM or EMS, have over 90% first-pass yield (see my June 2019 column).

At a macro level, there are many reasons for this. For example, to keep up with Moore's law, there has been significant shrinkage in size and pitches of packages while still dealing with old packages, including through-hole on the same board. This increases board complexity. In addition, during the past two decades, there has been a tremendous increase in outsourcing by OEMs to EMS companies, which also results in a decrease in yield. This is not because EMS companies are not good at what they do, but as I have explained in previous columns, EMS companies don't have control over some of the key contributors of defects, such as DFM and in many cases incoming material quality.

What I want to do in this column and the two follow-up columns is to look into how to assess the manufacturing capability of any company—OEM or EMS. When I say manu-

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facturing capability, I am only talking about assessing or auditing, if you will—the capability of a company to produce consistent quality over time. In this column, I will provide an overview of the audit process. In future columns, I will delve into the details of questions that should be asked to assess the major areas, such as technology, manufacturing, and the quality of the company being audited.

Audit Process: An Overview

We need to begin with defining the complexity of the product that needs to be built. Not everyone has the expertise to build all types of products, especially complex mixed-assembly boards. Also, they may not have skilled and experienced technical personnel. Even the best companies will find it challenging if the product requires the assembly of packages, such as fine-pitch, BGA, BTC, 0402, 0201, or 01005 discrete devices—especially when that board also has legacy components, such as J lead, gull wing, and even through-hole components. Add to this lead-free BGAs in a tin-lead process, which is very common in products for military applications.

Not everyone has the expertise to build all types of products, especially complex mixed-assembly boards.

Keeping the complexity of the product in mind, the first thing to do before an audit is to prepare a detailed questionnaire for the audit. The questions should be targeted to assess not only the manufacturing capability for tin-lead and lead-free products but also the basic SMT infrastructure of the company, which is essential in building products with consistent quality over time. The answers to these questions will supplement the findings of the audit during the visit. The objective of the questionnaire is also to give the company being audited a heads up as to what you may be looking for during your visit.

Some questions may be considered confidential or not applicable, and the company may choose not to answer them. You can draw your own conclusions on whether those questions are confidential or not applicable.

If possible, the company should return the completed questionnaire to the auditor a few days before the site visit. Along with the completed questionnaire, it may be appropriate to ask for the following documents to review before the visit to make the on-site visit very productive, especially when you have limited time for the audit:

1. Company-specific design for manufacturing (DFM) used to build your products. DFM means different things to different people (I will explore the details in the next two columns), but for now, we want to know the rules and guidelines in DFM for things such as component selection criteria, paneling considerations, fiducial requirements, land pattern design, solder mask consideration, via hole location, design for test, and anything unique to your design.
2. Company-specific manufacturing process document(s), such as adhesive and paste application, pick-and-place, reflow, wave, cleaning, repair, etc., that are used to build your products. These documents are not dependent on the types of equipment being used in the line. They are essentially a recipe the company uses to build the product. An example would be targets for peak temperature and TAL, no matter which oven is being used.
3. Equipment operating procedures. This is equipment specific document. The objective of this document is to ensure all operators use the same procedure when operating the machines on the line.
4. Handling and storage procedure for moisture-sensitive components. This becomes even more critical for lead-free. Very few companies have good control on this issue.

5. Typical wave and reflow profiles showing peak, TAL, and variations of different components seen in wave and reflow soldering.
6. The sum of all defect data collected from ICT, functional, AOI, and visual inspection for some of your key products. The defects should be summarized in four subcategories to help you analyze field failure potential and related consequences of these defects.
   a. Shorts
   b. Opens
   c. Insufficient
   d. All other

In one recent audit, I asked for this defect data on assemblies made in China. The company responded that it had zero defects and, therefore, nothing to provide. With peak reflow temperature of 255°C and TAL of over two minutes, would you have zero defects? Since products were failing in some of the stress testing, you can draw your own conclusions.

It is important that some products be built during the site visit so that you can get a realistic view of a typical production day. On the last day of the visit, findings of the audit should be presented to the company in an interactive and informal format. I find it most useful to give feedback face to face. All personnel who participated during the audit process and management should plan to attend the presentation. In some cases, a written report is necessary and can be provided a few days after the audit.

It may be obvious, but it is important to confirm the details of your visit, including the dates of travel, dates of the audit, and the people you will meet. If possible, you may also want to have a brief teleconference with the people before the visit to agree on the format and expectations of the audit. The questionnaire can be very lengthy (I use a 30-page questionnaire, which I will summarize in a future column) and focus on the following areas:

- **Overview Questions: A Broad Overview of Your Manufacturing Capability in Both Tin-Lead and Lead-Free**
  - General company and contact information
  - Types of components and products being built
  - Training program for engineers and operators
- **Technology Questions**
  - DFM documentation and control
  - Laminate
  - Surface finish
  - Components
- **Manufacturing Questions**
  - List of all assembly equipment (make, model, and year of purchase)
  - Materials management
    - Component procurement
    - Component storage and handling
  - Tin-lead and lead-free assembly
    - Assembly materials (paste, adhesive, flux, cleaning)
    - Paste printing
    - Reflow soldering
    - Wave soldering
    - Rework
    - Inspection and test
    - Repair
- **Quality Assurance Questions**
  - Materials assembly database
  - Quality monitoring and reporting database
  - Field returns
  - Materials declaration
- **RoHS Compliance**
  - RoHS compliance assurance system (CAS)
  - Tests or procedures used to ensure RoHS compliance
  - Supplier reliability and selection of raw materials and components
  - Evidence and documentation
  - Staff training and experience

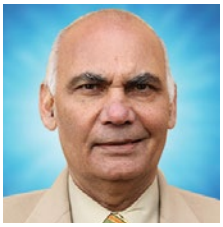
If you do not have a chance to review the various design and process documents (noted earlier) before the visit, you certainly want to

review them during the visit. It is also important to review the training procedure as part of the audit and to talk to the engineers and technicians responsible for design and processes. And do not forget to spend time on the line alone, talking to the operators and inspecting some of the boards being built. If you only spend time in the conference room with the quality manager, you will never get the complete story.

Asking the Right Questions

Building good quality products requires not only the right type of equipment but a solid infrastructure of skilled personnel, extensive documentation and process control, and equipment characterization. Characterization of process and equipment, which is necessary for higher yield, requires an investment in engineering resources that have not been made by all companies.

In my future columns, I will discuss specific questions that should be asked to correctly assess the capability of the company in building the products that meet your specific requirements. SMT007



Ray Prasad is the president of Ray Prasad Consultancy Group and author of the textbook *Surface Mount Technology: Principles and Practice*. Prasad is also an inductee to the IPC Hall of Fame—the highest honor in the electronics industry—and has decades of experience in all areas of SMT, including his leadership roles implementing SMT at Boeing and Intel; helping OEM and EMS clients across the globe set up strong, internal, self-sustaining SMT infrastructure; and teaching on-site, in-depth SMT classes. He can be reached at smtsolver@rayprasasd.com and has an upcoming SMT class in October (remotely by Zoom). More details at rayprasad.com. To read past columns or contact Prasad, click here.

Lean Digital Thread: Data-Driven Decisions and Micro-Solutions in Manufacturing

by Sagi Reuven
Siemens Digital Industries

People and factories have been collecting data, verifying it, and translating it into reports for a long time, but context always makes a difference. People will sometimes interpret and challenge the outcome; other times, they will try to validate and verify the accuracy of the data (smart and required, but it's a slippery slope). However, some will create additional reports, detect the root cause of the problem, remove the outliers, and improve, or even use the data to innovate. In this column, I'll discuss the next level—changing the mindset from reporting to analytics and focusing on making small improvements. (To read the full column, click here.)

Sagi Reuven is a business development manager for the electronics industry, Siemens Digital Industries. Download your free copy of the book *The Printed Circuit Assembler's Guide to... Advanced Manufacturing in the Digital Age* from Mentor, a Siemens Business, and visit I-007eBooks.com for other free, educational titles.

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PCB Rework of 0201 Packages

Knocking Down the Bone Pile

by Bob Wettermann, BEST INC.

As electronic passive components continue to shrink in size, methods for their rework need to be developed by electronic manufacturers to maintain and support PCB assembly processes. The 0201 package—only 20 by 10 thousands of an inch in size—is one of the components requiring a higher degree of rework skill compared to other larger packages. IPC-7711 and IPC-7721 on the "Rework, Modification, and Repair of Electronic Assemblies" [1] for these resistor and capacitor sizes outlines a variety of methods in sections 3.3.X. Here, I will compare and outline a few of these rework methods.

While the 0201 package size has been in the mainstream for several years, assembly soldering defects are common. Tombstone defects, common for this package type, are commonly caused by the pads heating up at different rates. A thermal mass imbalance may cause one of the pads to heat at a different rate compared to the other. For example, if one of the 0201 pads is connected to a thermal ground plane and the other pad is not, the unconnected pad will heat at a faster rate—all others being equal. This thermal imbalance will cause the tombstoning defect as the molten solder pushes up one side of the component.

It is well understood that lighter and smaller components are more susceptible to this tombstoning phenomenon. A similar result is realized if the pads are not the same size, as the larger pad will heat at a slower rate. The pad sizes influence the defect rate; smaller pad sizes result in higher defect rates [2]. The component placement offsets in the X and Y direction are one of the largest contributors to the post-reflow defect rates of these packages. This means that the assembler needs to control these parameters by placement consistency through proper placement programming, nozzle maintenance, and placement pressure. In addition, the very small pad geometries of the 0201 packages make solder paste printing consistency a challenge, which can also cause defects.

A Conductive Soldering Rework Technique

The most common technique used to remove and replace 0201 body style components is through the use of a conductive hand soldering system. This hand soldering rework technique calls for the removal of a passive component by employing a micro body tweezer or a micro hoof soldering tip. For part removal using a micro hoof tip, make sure to first tin

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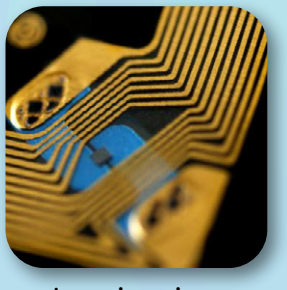

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the flat surface of the tip as this will aid in heat transfer. For placement, apply the proper liquid flux to the pads and hold the 0201 down with the tip of a tweezer and touch the hoof tip for 2–3 seconds to one side of the pad to allow the solder to reflow. Finish the attachment by doing the same operation on the other side.

An even faster hand soldering method uses a micro tweezer hand piece. These tweezers can reflow both ends of the 0201 simultaneously for component removal or replacement. The tips themselves are fragile structures and are easily damaged, which means care needs to be taken by the soldering technician. Because of the small geometries involved, the skill and patience of the soldering technician need to be at an advanced level. The site preparation process post component removal, regardless of the tip used, requires great care by the rework technician as the very small pad surface area means that the propensity to damage or lift pads is high. While hand soldering is the fastest method for the removal and replacement of the 0201, it requires a high degree of operator skill and dexterity.

Hot Air Rework

Another reflow method employed by soldering technicians for the rework of these small passive devices is by using a hot air source. Both controlled (closed-loop rework systems) and uncontrolled hot air sources (hot air guns or handpieces) can be used to reflow 0201s. These hot air sources must be designed with low airflow capability so as not to disturb the solder joint or blow the component off the pad. A controlled heat source has limited throughput compared to the hand soldering rework method as there are several process steps, which takes time. A split vision rework system, which assists the operator in aligning the part to the pads, reduces the degree of skill required to rework these small packages.

The downside of using a hot air reflow source is that components neighboring the component of interest can also be reflowed during the soldering or desoldering process. To prevent the hot air source from disturbing these neighboring components, they need to be thermally masked from the heat source. This further extends the rework process time. When using a hot air rework system, the removal of the component is accomplished by using a hot air nozzle specifically designed to push out low airflow. For replacement of the 0201 component, a high-resolution camera, combined with precision X-Y adjustments of the rework system, means device placement can be more precise and repeatable vis-à-vis the hand soldering approach.

Using an IR Reflow Source

While the hand soldering of 0201 packages requires highly-skilled soldering technicians and the hot air rework sources can easily disturb the solder or placement location of the lightweight 0201s, the use of an IR reflow source is a good alternative approach to reworking these packages. Infrared rework systems do not use any airflow as part of the reflow cycle, thereby preventing the problems associated with the hot air rework sources. The IR heat source can quickly heat these small component body style types before their removal.

Magnification, as part of the rework system—along with a micro vacuum nozzle—can then remove the component once a liquidus state has been reached. Through the use of an IR BGA rework system and the high skill and dexterity level required for rework of these 0201 packages, without the downside risk of the positive airflow from the hot air source, makes the IR reflow source ideal for these components. **SMT007**

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1. IPC, "IPC-7351 Generic Requirements for Surface-Mount Design and Land Pattern Standard," Bannockburn, Illionis, 2015.

2. Paul Neathway, et al. "A Study of 0201's and Tombstoning in Lead-Free Systems," Proceedings of SMTAI, 2014.

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[1] IPC. (2017). Findings on the Skills Gap in U.S. Electronics Manufacturing.

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SPECIAL EVENT COVERAGE

From the 2020 IPC High-Reliability Forum

2020 IPC High-Reliability Virtual Forum Review

Edited by Happy Holden
I-CONNECT007

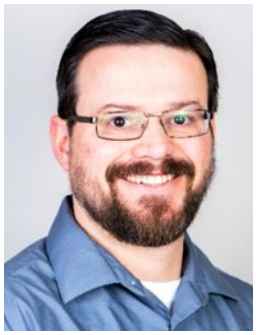
Introduction

The IPC High-Reliability Forum planned for May 2020 in Hanover, Maryland, was rescheduled as a virtual conference in July because of the COVID-19 pandemic. This is the third annual event, and, like the past two, it continues to grow with more than 150 in attendance. The forum focuses on electronics for critical military, aerospace, automotive, and medical applications required to function without interruption for an extended lifetime where downtime is not acceptable.

This event covered a broad range of topics related to reliability and an opportunity to share expert knowledge and experience in determining and understanding the causes of failure and selecting the best design rules, materials, processes, and test methods to maximize product reliability. The other objectives of the forum were to discuss the industry's best efforts to date to mitigate weak-interface microvias through recently adopted design parameters, test protocols, and product sorting, and to solicit attendee support for the various sub-teams of the IPC Weak Microvias Task Group.

Day 1

John Perry



To begin, IPC's John Perry, director of printed board standards and technology, greeted everyone and opened the virtual conference. He also introduced Dennis Fritz as the opening speaker.

Dennis Fritz

Fritz is a technical consultant with Fritz Consulting, chairman of the IPC V-TSL-MVIA Weak Microvia Interface Committee, and an I-Connect007 columnist. The theme of his presentation was "An Introduction From the Microvia Task Group." In this context, microvia holes constituted the focus of this forum.

In his introduction, Fritz made it clear that there was no intention to scare designers and users away from microvias; they remained a reliable PCB interconnect construction when properly formed and screened by IPC methods. But there was a valuable opportunity to discuss a potential reliability issue primarily associated with multiple levels of stacked microvias. He stressed that staggered or even single-level microvias still needed to be manufactured carefully and tested to IPC standards.

Additionally, Fritz included a review of the background and history of the problem, as described in the IPC-WP-023 white paper, and an introduction of the panel members and their interest in this problem. A big fishbone diagram illustrated the complexity of the subject, defined the project categories, and nominated the working teams.

The obvious long-term objective was to provide design, material selection, and processing guidance to enable the industry to achieve reliable higher density structures. Fritz implored delegates to support the work of the IPC V-TSL-MVIA Weak Interface Microvia Failures Technology Solutions Subcommittee, contribute relevant data with the assurance that sources would not be disclosed, and join one of the working teams investigating

this perplexing and currently expensive PCB industry problem.

Next, Fritz showed many real examples of microvia failure since microvia challenges and reliability issues have become a great concern to the PCB manufacturing industry. He provided updates on the work of members of the IPC V-TSL-MVIA Weak Interface Microvia Failures Technology Solutions Subcommittee and opportunities to learn about the latest developments in methods to reveal and explain the presence of latent defects, identify causes and cures, and consistently and confidently supply reliable products.

The IPC-V-TSL-MVIA Subcommittee is working with IMEC in Europe on its European Space Agency (ESA) microvia reliability study. IPC is using its test vehicle to test stacked microvias on a typical high-Tg laminate, and D-coupons are being fabricated for IPC.

James W. Fuller, Jr.

The next speaker was James W. Fuller, Jr., VP of engineering and technology development at Sanmina Corporation. He discussed the use of a smartly designed test vehicle, coupled with a unique IST test protocol, that provided the company with the tools to improve microvia robustness quickly and definitively.

One key challenge included, "How can the technical team evaluate lot-to-lot differences using current test protocols?" Next, the project was to identify and implement an effective combination of a coupon and test that allows for a significant differentiation of product processes by making the coupons more sensitive and make the test more aggressive and test to failure.

Their IST system was utilized to create a new, more aggressive test coupon at new temperature extremes. The new coupon had 4-, 5-, and 6-mil microvias with these via constructions:

1. L1-14 through via and L2-13 buried via
2. L1-2-3 and L14-13-12 stacked via offset from buried L2-13
3. L1-2 and L14-13 blind via stacked on buried L2-13
4. L1-2-3 and L14-13-12 stacked via on buried L3-12
5. The experimental results for stacked microvias resulted in Table 1.

The results of Sanmina's work provides a platform that allows for actionable data from site-to-site, simple evaluations of electroless process control and selections, the evaluation of material choices, and the differentiation of laser equipment, noting the influence of desmear and glass etch, as well as comparisons of design considerations.

Bill Birch

Bill Birch, president of PWB Interconnect Solutions Inc., and **Hardeep Heer,** VP of engineering and CTO of Firan Technology Group (FTG Corporation), were the next speakers. Their presentation, "Reliability of Microvias: Troubleshooting MV Failures," addressed their findings from recent WMI DOEs. They discussed various contributing factors causing microvias to fail and what has been done to make microvias more reliable. Their findings for Type 1 10-layer microvias board are presented in Tables 2 and 3. All the testing was

Four Coupons Per Cell		Process A "On"			Process A "Off"		
		N+1 mil	N mil	N-1 mil	N+1 mil	N mil	N-1 mil
Process B "On"	N+1 mil	132			126		
	N mil		22			48	
	N-1 mil			4			9
Process B "Off"	N+1 mil	254			3		
	N mil		80			0	
	N-1 mil			19			0

Table 1: Experimental results, stacked microvias, IST cycles to failure.

done after 6X pre-conditioning at 245°C before thermal cycling for 250 cycles at 190°C for micro-vias. The resulting failure mode was confirmed as the interfacial separation between the electroless copper and the target pad copper foil.

DOE #1

DOE #1 focused on specific process variables associated with:

- Post laser ablation micro-etch pre-treatment (single pass-double pass)
- Hold times between laser ablation and loading into the electroless line (level 1: zero hold time; level 2: two-hour hold time)
- Electroless copper thickness (0.8–1.0 microns)
- The influence of coupon position within the test panel
- 36 coupons were related for reliability testing.

Using a series of case-history examples, illustrated by a combination of optical microscopy and X-ray with scanning electron microscopy and energy-dispersive for failure analysis, showed all failure was electroless lifting.

Panel #	1	3	5	7	9	11	13	15	17
IST Cycles	Unstable	14	10	24	9	7	3	8	13
	2	18	Unstable	27	11	3	3	10	15

Panel #	2	4	6	8	10	12	14	16	18
IST Cycles	10	Unstable	2	11	Unstable	Unstable	2	9	23
	14	Unstable	11	Unstable	6	4	Unstable	3	23

Table 2: Test results for panels and the number of cycles completed before 10% resistance change; all failure was electroless lifting.

Unstable Failures by Location		Unstable Failures by Cu Deposit		Unstable Failures by Hold Time		Unstable Failures by Micro-Etch	
U/L	1/10	0.8	7/16	Zero	3/16	1X	4/16
MID	5/17	1.0	9/16	2 Hr.	5/16	2X	4/16
LR	2/7						

Up to 5 Cycles to Failure by Location		Up to 5 Cycles to Failure by Cu Deposit		Up to 5 Cycles to Failure by Hold Time		Up to 5 Cycles to Failure by Micro-Etch	
U/L	4/10	0.8	7/16	Zero	8/16	1X	9/16
MID	8/17	1.0	9/16	2 Hr.	8/16	2X	7/16
LR	4/7						

Table 3: Coupons with unstable results and those failing below 5 IST cycles. All failure was electroless lifting.

Micro-Section A				Micro-Section B				Micro-Section C			
Conventional No Flash				Conventional With Flash				Vertical Plating With Flash			
Coupon	Cycles	% Change	Results	Coupon	Cycles	% Change	Results	Coupon	Cycles	% Change	Results
P1-1	250	3.4	Passed	P3-1	250	0.9	Passed	P5-1	10	10	Failed
P1-2	173	10	Failed	P3-2	250	1.1	Passed	P5-2	Unstable	10	Failed
P1-3	250	0.8		P3-3	250	1.9	Passed	P5-3	250	1.1	Passed
P1-4	250	0.3		P3-4	250	1.2	Passed	P5-4	3	10	Failed
P1-5	250	0.7		P3-5	250	1	Passed	P5-5	49	10	Failed
P2-1	125	10	Failed	P4-1	250	1.8	Passed	P6-1	2	10	Failed
P2-2	250	7.7		P4-2	250	1.5	Passed	P6-2	6	10	Failed
P2-3	250	1.8		P4-3	250	1	Passed	P6-3	46	10	Failed
P2-4	250	1.5		P4-4	250	1	Passed	P6-4	2	10	Failed
P2-5	250	2.1		P4-5	250	1.9	Passed	P6-5	62	10	Failed
125 cycles to failure				Passed 250 cycles				Unstable (pre-cycle failures)			

Table 4: DOE #2 IST test results.

DOE #2

DOE #2 involved the impact of the electrolytic process to improve reliability (Table 4):

- Conventional copper deep tank line with mechanical agitation with/without a copper flash plating

DOE #3

DOE #3 was a referee test to repeat DOE #2 with 21 panels (Table 5):

- Conventional copper deep tank line with mech agitation with/without a copper flash plating
- HDI copper filling using only the conventional line

DOE #4

DOE #4 was a comparison to the production electroless line with 21 panels (Table 6):

- 16 panels use production electroless line
- Five panels use the new electroless line
- The current production electroless line all survived the 250 cycles to 190°C
- The IST testing discovered the 10 failures of the new electroless plating line

Coupon	IST Cycles	Micro-Section
36-1	14	
36-2	123	
36-3	24	A
37-1	81	
37-2	16	B
37-3	Unstable	
38-1	17	C
38-2	90	
38-3	No Test	
39-1	124	
39-2	10	D
39-3	No Test	
40-1	132	
40-2	Unstable	E
40-3	No Test	
41-1	9	
41-2	24	F
41-3	No Test	
42-1	20	G
42-2	Unstable	
42-3	No Test	

13 coupons failed before a maximum of 124 cycles.

Table 5: DOE #3 IST test results; low performance consistent with DOE #1.

Electroless Copper Line	Coupon	IST Cycles	HDI % Change	Micro-Section	Coupon	IST Cycles	HDI % Change	Micro-Section
Prod	36-1A	250	0.2		36-1B	250	1	
Prod	36-2A	250	0.3		36-2B	250	1.0	
Prod	36-3A	250	0.11		36-3B	250	0.3	
New Line	37-1A	8	10	A	37-1B	3	10	
Prod	37-2A	250	1.1	B	37-2B	250	0.9	
Prod	37-3A	250	1.3		37-3B	250	1.0	
Prod	38-1A	250	0.1		38-1B	250	0.4	
New Line	38-2A	4	10	C	38-2B	1	10	
Prod	38-3A	250	0.1		38-3B	250	0.3	
Prod	39-1A	250	0.1		39-1B	250	0.3	
Prod	39-2A	250	0.1		39-2B	250	0.7	
Prod	39-3A	250	0.2		39-3B	250	0.1	
Prod	40-1A	250	0.5		40-1B	250	0.3	
Prod	40-2A	250	0.4		40-2B	250	0.5	
New Line	40-3A	19	10		40-3B	1	10	D
Prod	41-1A	250	0.4	E	41-1B	250	0.4	
New Line	41-2A	4	10	F	41-2B	Unstable	10	
Prod	41-3A	250	0.5		41-3B	250	0.5	
New Line	42-1A	69	10	G	42-1B	15	10	
Prod	42-2A	250	1.1		42-2B	250	0.6	
Prod	42-3A	250	0.9		42-3B	250	0.4	

The current production electroless line all survived the 250 cycles to 190°C. The IST testing discovered the 10 failures of the new electroless plating line.

Table 6: DOE #4 IST test results (low).

Conclusions from the DOE tests indicate that electroless copper deposits are responsible for the majority of weak microvia interface failures and that the newly released IPC-6012E does not require extended testing or micro-sections, creating a risk of positive results.

Gerry Partida

Gerry Partida, field application engineering manager at Summit Interconnect, presented on "Current Concerns Over Microvia Failures." He reviewed concerns regarding the reliability testing of microvias, provided an overview of HDI processes, and presented the use of current test methods. In particular, he emphasized the superiority of testing with IPC-D-coupon and IPC-TM-650 test methods 2.6.7.2 and 2.6.27. Gerry also presented data that showed that traditional thermal testing using IPC-2.6.7.2 will pass coupons that fail reflow. IPC-TM-650-2.6.27B found 17% of the coupons that passed the thermal cycling test failed the SMT reflow test in the first few reflow cycles.

Failure analysis indicated that the failures occurred near the center of the coupons. Test runs were repeated using lower blind via aspect ratios and larger laser drill diameters, and all coupons passed the reflow tests 100%. It is critical that tests be performed on microvias using production materials, design rules, stackups, and pre-/post-clean processes using the IPC-TM-650-2.6.27B test method before products are shipped to customers.

Dr. Maarten Cauwe

Maarten Cauwe, Ph.D., team leader of advanced packaging at IMEC-CMST, explained "Microvia Technology Assessment for Space Applications." Dr. Cauwe is a member of the IPC Special Committee on the weak microvia interface problem and a frequent contributor to his work with the ESA at IPC APEX EXPO and SMTAI.

The work presented is part of the ongoing ESA project on high-density PCB assemblies, led by IMEC and with the aid of ACB and Thales Alenia Space Belgium. The goal of the project is to design, evaluate, and qualify HDI PCBs that can provide a platform for assembly and the routing of small-pitch area array devices (AAD) for space projects. Two categories of HDI technology are considered: two levels of staggered microvias (basic HDI) and up to three levels of stacked microvias (complex HDI).

Within the project, various test methods for evaluation microvias are assessed. Interconnection stress testing (IST) and reflow simulation combined with traditional thermal cycling is currently the method of choice in ESA's ECSS-Q-ST-70-60C standard for qualification and procurement of PCBs. Alternatives as

convection reflow assembly simulation (IPC-TM-650 2.6.27B) and current-induced thermal cycling (CITC, IPC-TM-650 2.6.26A) are explored in this study.

Dr. Cauwe began by updating the results of Phase I testing in the ESA program. The results indicated that for the three build-up layers, the semi-stacked inside (L1-L2/l3 stacked) was superior (no failures) compared to the semi-stacked outside (L1/L2-L3) construction for both the 0.8-mm pitch D-coupons and for the 0.5-mm D-coupons using polyimide materials. The modified high-Td epoxy SI materials passed at both pitches, but he noted that the single-prepreg used was 25 microns thinner. This was verified in failure analysis that the high Td SI materials strain was 9960 ppm at 190°C compared to the polyimide's 11340 ppm at 210°C. Theoretically, it is 22% lower than the polyimide due to CTE-Z and thickness, verified by modeling. Also, IMEC used finite element analysis to help determine the effects of microvia interfacial stress.

Jerry Magera

What was the source of the weak microvia interface? According to Jerry Magera, senior staff principal engineer at Motorola Solutions, it all began with the microvia target pad in his presentation on "The Complete Path to Least Resistance." He focused on the often maligned electroless copper process and proclaims that the IPC-6012E performance specifications for metallization for PCBs of "sufficient for subsequent plating" is too vague, sets low expectations for deposit quality, and is the reason optical microscope views of well-formed electrolytically copper filled microvias fracture during solder reflow thermal excursions.

Continuous resistance measurements during component reflow assembly revealed thermally induced microvia failures that were subsequently located by cross-section analysis at and in the vicinity of that electroless copper deposit. The fascinating elegance of electroless copper is not appreciated, relegated today as a transient step in the copper metallization process, with function reduced to a conductive liner within the laser-ablated microvia cavity that bridges the target pad to the adjacent copper layer to support electrolytic copper fill plating. However, it must form a metallurgical bond between the target pad and electrolytic copper plating to survive reflow assembly. Four-wire resistance measurements of microvia daisy-chains confirmed substantial chain to chain variation attributed to the electroless copper deposit in the microvia.

The results of four-wire resistance measurements completed on simple L1L2 and L3L4 microvia daisy-chains at ambient temperature are presented for samples prepared with production-ready processes by PWB manufacturers. The measurements objectively revealed the actual variation in the quality of the electroless copper deposit lining the microvias that was missed by weight-gain and backlight assessments. Published electroless copper deposit thickness ranged from 0.3–3.0 µm for immersion times of 4–30 minutes, depending on the process implemented.

Structural variations exist in microvia field-failure interfaces on products that had passed existing IPC and OEM validation tests and micro-section inspections but had retroactively failed IPC 2.6.27A testing and been investigated using micro-sections produced by focused-ion-beam (FIB) trench-machining techniques. These revealed defects that had been missed by conventional optical microscopy. Three modes of interface failure had been observed: between electroless copper and target pad, between electrolytic copper fill and electroless copper, and within the electroless copper. There was often a mix of all three failure modes.

Scanning electron microscope (SEM) examination of the surfaces of target pads after laser drilling and electroless copper showed some interesting variations in grain structure, which Magera explained in terms of the different rates of growth of (100) and (111) planes in the face-centered cubic crystal structure of copper. The evidence suggested that substrate morphology,

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chemistry, and process control all affected the copper deposit structure.

Magera recommended further FIB, SEM, and X-ray diffraction studies of microvia target pads (as laser-drilled, before catalyst predip and after electroless copper, correlated against process control data to identify critical control variables) to determine the conditions required to produce consistent interface structures and identify the appropriate copper crystal lattice structure for best practice. And it was proposed that IPC-6012E 3.2.6.1 be updated to better define the requirements for electroless copper.

Day 1 Q&A

John Perry then read questions sent in by attendees, followed by an open session for the speaker panel, with questions like, "What is needed to achieve and ensure reliable microvia structures?" The ensuing discussion was lively and interesting. Many topics were discussed, and the panel went 30 minutes longer than scheduled.

Day 2

Chris Mahanna

Day 2 opened with a presentation by Chris Mahanna—president, owner, and technical manager at Robisan Laboratory Inc.—titled, "We Experienced a Microvia Failure; Now, What Do We Do?"

Chris opened with the statement, "With all the publicity around weak microvia interfaces and the horrible functional failures caused by them, it is easy to become overwhelmed by their notoriety and the complexity of the problem. Effective action needs to be taken to understand and mitigate risk, but where does one start?"

His presentation provided a framework for the failure analysis, variables to the related risk, corrective actions, and quality assurance to limit and quantify the risk. The three starting steps are:

1. Verify: Confirm that you have a weak interface microvia failure and not a simpler failure. Isolate the failure to specific microvias.

2. Assess: Keep it simple by concentrating on three variables: (1) the density of your microvias; (2) the Tg of your laminate; (3) and the susceptibility of your circuits to a marginal increase in propagation delays through the interconnects.

3. Take action: Take steps to dramatically reduce future risks by changing the design. Consider your fabricator's capabilities and/or install screening immediately.

Lance Auer

Lance Auer, an Engineering Fellow at Conductor Analysis Technologies, discussed "Performance-Based Microvia Reliability Testing: What You Need to Know." Auer discussed the implementation of a performance-based reliability test methodology:

- Test sample (coupon) must match production board, holes and lands, staggers, spacing, fill, signal/plane layers, and solder mask
- Convection reflow assembly simulation per IPC TM-650 2.6.27B
- Air-to-air thermal shock per IPC TM-650 2.6.7.2C

Both test methods are examined in detail with respect to the requirements of the test system:

- Control and performance
- Data acquisition
- Documentation and reporting

Auer summarized the recommendations for performance-based acceptance testing, which was agreed at the IPC APEX EXPO 2020 committee meetings must represent the boards being manufactured and the time/surface temperature of reflow. He demonstrated the thermal profiles for reflow simulation and thermal shock testing and showed examples of change-in-resistance measurements cor-

responding to microvia failures. Again, Auer reinforced the IPC microvia warning that traditional inspection techniques utilizing thermally stressed micro-sections and light microscope alone are no longer an effective quality assurance tool for detecting microvia-to-target plating failures.

Kevin Kusiak

Speaking with many years' experience of reliability testing and failure analysis, Kevin Kusiak, electronics engineering senior staff at Lockheed Martin Space Systems, gave a comprehensive presentation on "Microvia Reliability Testing Utilizing D-Coupons to Understand Best Design Practices." This session detailed a project Kusiak is leading to design and test coupons, which will give LMS insight to best practice design variables of PCBs utilizing microvias.

The test vehicle will be:

- Multiple via structures of varying microvia diameters across 54 different D-coupons
- 37 coupons for plated hole evaluation through micro-sectioning and SEM-FIB analysis
- Four peel strength coupons with embedded microvias
- 5-, 6-, and 7-mil diameter; 0-, 5-, 10-, 15-, and 20-mil pitch (center to center)
- Fabricated by two different vendors recording bath parameters during the processing of panels

He also explained the IPC-TM-650 2.6.27 reflow cycle, 12x reflows at 260°C using OM testing followed by IPC-TM-650 2.6.7.2 100 thermal shock from -55–205°C and failure criteria, and the via failure mode that will be observed as an open or measurable resistance change at or near the peak temperature.

Marc Carter

Marc Carter, president and owner of Aeromarc LLC, as well as an I-Connect007 columnist, addressed "Stacked Microvia/ Weak Interface Reliability Study Project." For over a year, a committed group of companies and individuals has been developing a reliability modeling study. This study combines empirical confirmation structures and testing protocols with advanced reliability simulation in a three-phase, three-year iterative study (simulate, test, refine, and repeat). The goal is to provide an urgently needed enabler of greater miniaturization in the form of increased complexity "stacked microvias" currently limited by an incomplete understanding of the forces and mechanisms (click here for background information).

While several company-specific studies have generated excellent proprietary data, these do little to benefit the wider industry. In part, this project aims to begin to raise the capability level and understanding of those in the electronics manufacturing supply chain for high-reliability, critical applications not privy to the proprietary studies.

The mutually agreed test vehicle is characterized by:

- 12-layer high-Td laminate with three build-up layers of various stacked and staggered microvias over buried TH vias fabricated by shop A vs. shop B
- Microvia formation methods of mechanically drilled vs. laser-ablated (UV/CO_2/UV)
- Alternative metallization of direct metallization vs. electroless copper
- 17 different D structured coupons
- Reflow simulation of eutectic (230°C vs. lead-free 260°C)
- Analysis by test lab A vs. test lab B

Figure 1: (Top) 2017 Reliability Forum.

Figure 2: (Right) 2018 Reliability Forum.

Michigan Tech University, with the help and software from ANSYS (Sherlock), will do the statistics and attempt to correlate results with simulation. The completion time is estimated at nine months, and the report/results will be made public once finished.

Final Q&A

The wealth of knowledge and experience generously shared by the presenters provided an excellent background for a panel discussion on weak-interface stacked microvia reliability, moderated by John Perry. Although the attendees did not have the opportunity to network and catch up on old times, the last Q&A roundtable session was robust. The success of this virtual conference was confirmed by the scheduled 30-minute session lasting over 90 minutes with abundant conversations on these topics and additional questions. The only thing missing from this virtual event was face-to-face networking from previous IPC Reliability Forums (Figures 1 and 2).

I can't speak for everyone who attended, but I believe it was an extremely rewarding experience for all 150+ participants. IPC also provided the entire two-day transcript for all attendees. SMT007

Happy Holden has worked in printed circuit technology since 1970 with Hewlett-Packard, NanYa/Westwood, Merix, Foxconn, and Gentex. He is currently a technical editor with I-Connect007.

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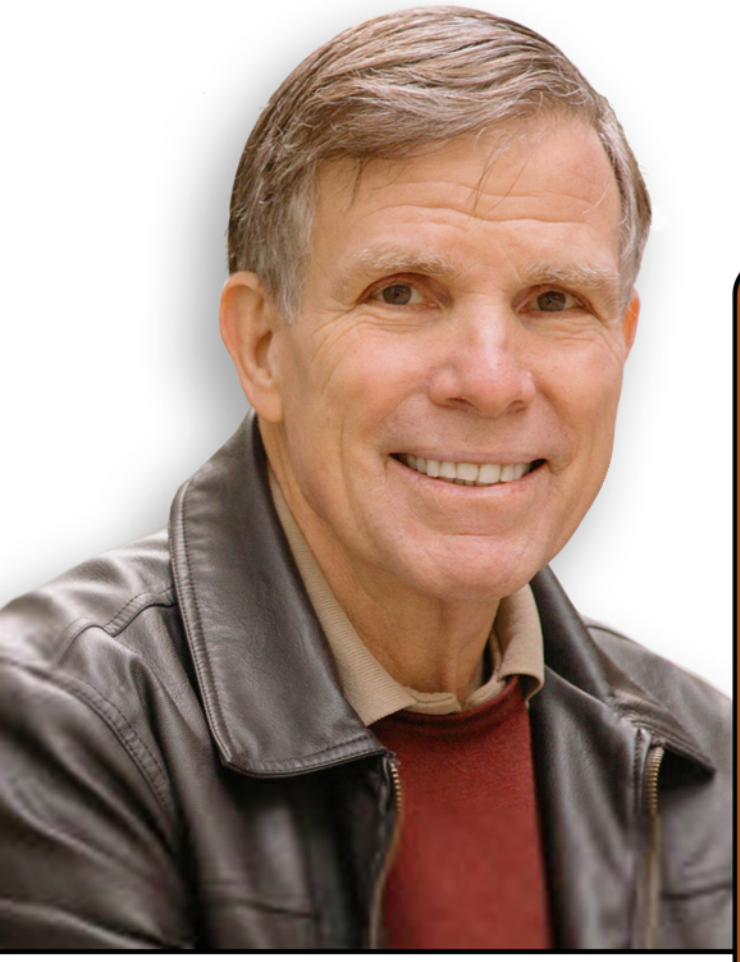

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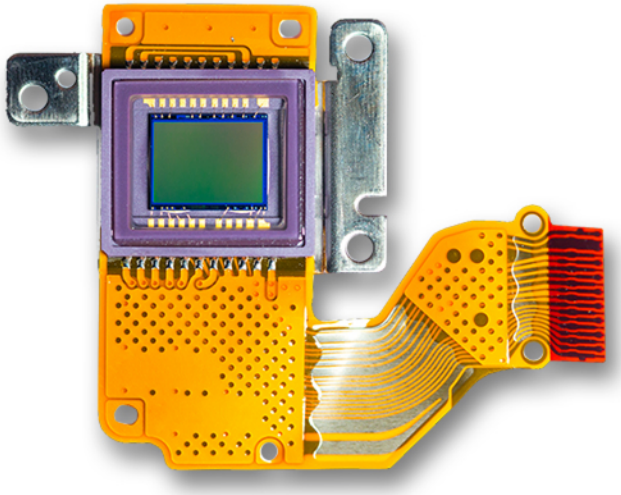

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Denny Fritz Unpacks Weak Interface and Stacked Microvia Reliability

Edited by Happy Holden
I-CONNECT007

On the first day of the IPC High-Reliability Forum, Denny Fritz gave a presentation on weak microvia interface and stacked microvia reliability.

Denny Fritz was a 20-year direct employee of MacDermid Inc. and is a retired engineer after 12 years as a senior engineer at SAIC, supporting the Naval Surface Warfare Center in Crane, Indiana. He was elected to the IPC Hall of Fame in 2012 and is now the head of the Hall of Fame Council of Fellows. Denny has also been involved with the weak microvia team for a couple of years and has participated in many technology roadmaps, better component activities, and standards for board fabrication—particularly Pb-free Electronics Risk Management (PERM). Currently, he is president of Fritz Consulting, as well as an I-Connect007 columnist who writes "Defense Speak Interpreted" on military and defense industry topics and applications.

Here, I have assembled the highlights of Denny's presentation, including the transcript, which has been slightly edited for clarity.

Denny Fritz

Today's Purpose Tomorrow

We certainly do not want to scare away any new designers. Microvias remain a reliable interconnection construction as long as you do things according to IPC test methods and observe practices that will come out in the presentations. However, we do want to alert you to a reliability issue that has been around for a couple of years publicly and maybe as many as 10 years. From some of the stories we've heard, many people thought that they were the only ones who had this problem until they compared notes with other companies that fabricate and use microvias. We are trying to find the root causes of the phenomenon, and we would certainly like any data that you can contribute. If you are not willing to contribute data, please support the working effort of our IPC teams. Where we stand today is to mitigate this microvia problem through design parameters, etc. The Weak Microvia Team is not here to specify product acceptance test methods but to work on the problem itself, so you'll get plenty of information in the presentations on the test methods.

Our objective is to give you a background on the problem, understand the causes, and help guide the efforts of individual companies and consortiums to find answers. This will give you an idea of the teams that are under the Weak Microvia Group, especially because this is on a test program that IPC is participating with IMEC and ESA.

Certainly, the overview explains how to prevent escapes from the fabrication process by understanding the capacity and yield impacts

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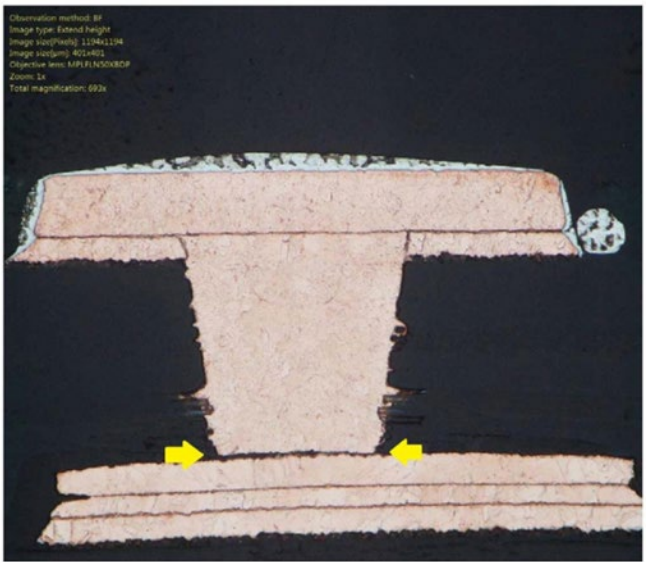


Figure 1: Older microvia failure due to contamination on the landing pad.

of sorting. Currently, we encourage people to avoid higher stacks, so you will see a Motorola presentation on that company's requirements for its own product. The IMEC testing on the test methods will be referred to as TM-650 2.6.26 and 2.6.27A; they involve multiple reflow cycles simulating assembly with continuous resistance monitoring.

Microvia Failures

When I first heard of this problem, I thought, "This is just a common problem out there of microvia failures." Figure 1 is a roughly 10-year-old slide, showing a one-stack microvia that obviously did not include a well-cleaned landing pad in the separation between the microvia fill; the internal layer is obvious on this cross-section. This is not the simple problem that we encounter today.

In Figure 2, a cross-section from Motorola Solutions shows an unpolished cross-section of a three-stack microvia on the left. On the right, with reflow and careful micro-edge, it is possible. You can see a line there, but this is a functional resistance that shows up in the testing. And you might pass this just with optical cross-section. It is an almost invisible problem because it's subtle—and that really bugs us. Figure 3 shows the methodology of using instrumentation to find these problems.

Figure 3 shows the instrumentation involved in finding these weak microvias. The two graphics on the left show thermal cycles. Against that, the resistance of the microvia sections is included in the daisy chain. On the third thermal cycle, the resistance went up infinitely, and the microvia opened. However, you can also see in all the cases the resistance comes back down after the end of the thermal cycle. In Motorola's case, with this data, when they stagger their microvias on the right, the thermal cycles did not change the resistance of the microvia daisy chain, and those are shown as good microvias.

With information from Raytheon (Figure 4), further analysis shows that there was no single

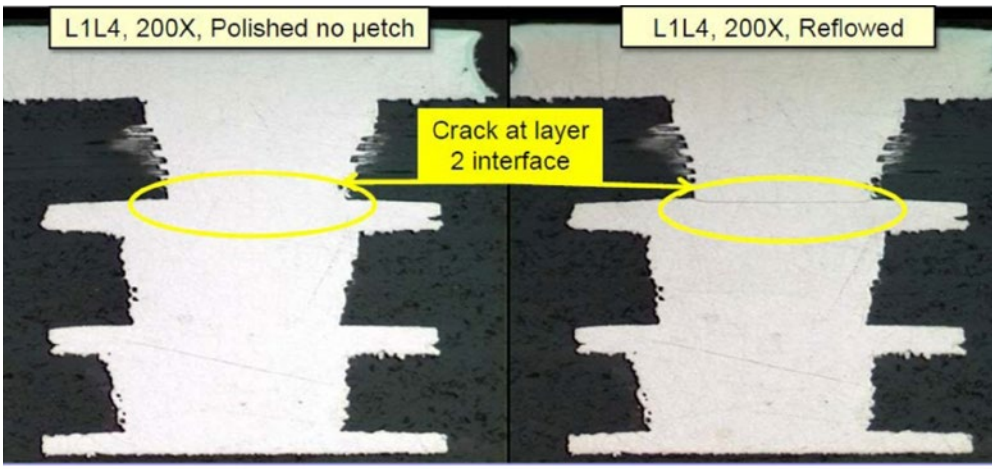


Figure 2: Two microvia stacked constructions with the typical microsection on the left, where the problem is invisible, compared with after reflowing, where it is almost invisible. (Source: Motorola Solutions)

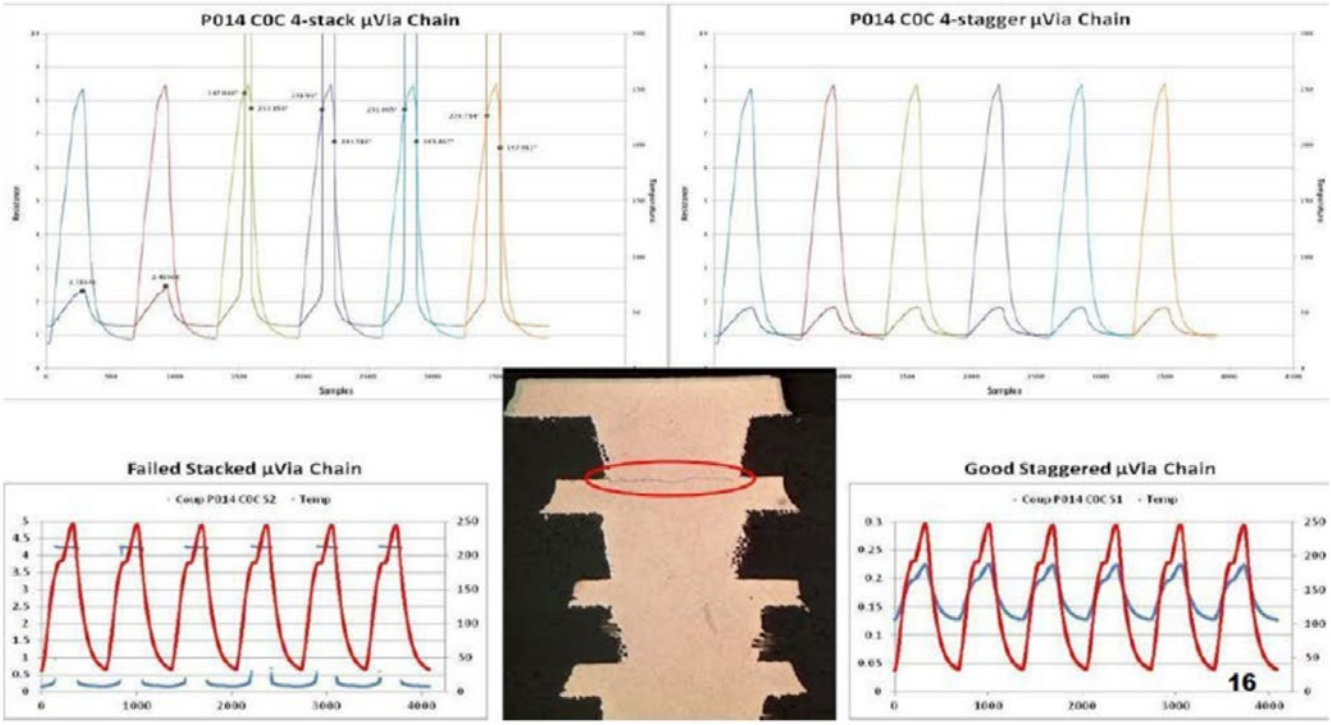
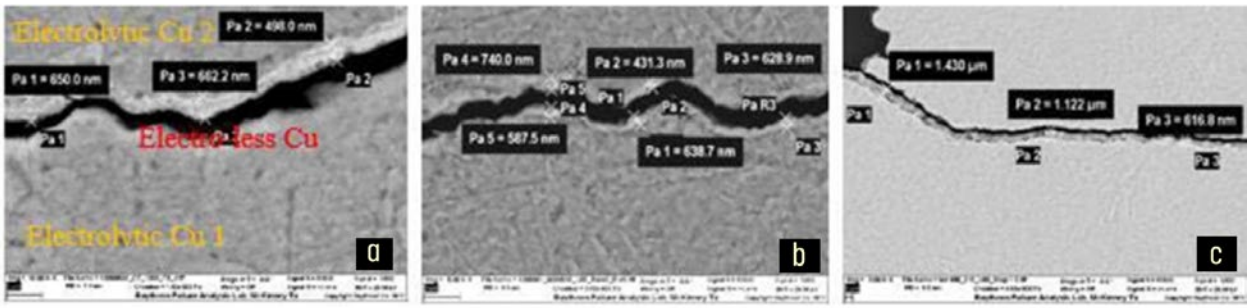
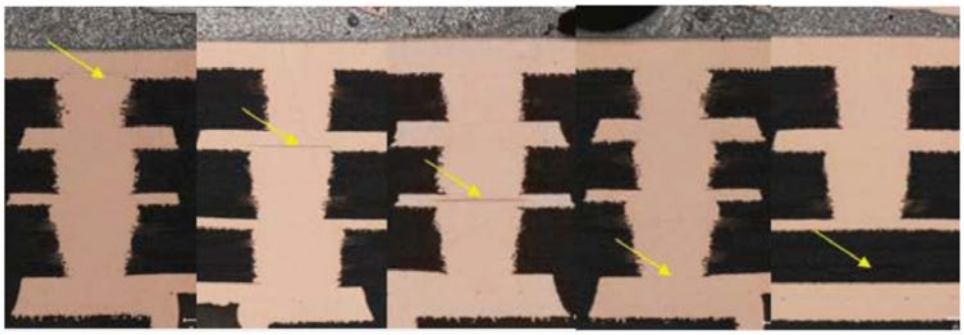


Figure 3: Two sets of three-level microvias, left-stacked, thermal cycled to reflow temps, opened, and then closed when cooled. Right-staggered and no-open/resealed connections. (Source: Motorola Solutions)



Microvia fractures propagated below (a), within (b), and above (c) electroless Cu region and oxidized, which is indicative of a mechanical intergranular fracture.



Microvia "partial" fractures found throughout stacked electroless Cu interfaces, as well as within the laminate resin, which indicates CTE-z stresses essentially the same at all levels.

Figure 4: Mechanical intergranular fractures of stacked microvias. (Source: Raytheon)

interface that was guilty all the time. The one on the left shows the interface between the electrode copper, and the landing pad within the electroless copper deposit is in the center; on the right is between the electroless copper and the fill. It does not necessarily occur on one stack. Although, you will see that there is currently more stress found in the deepest microvia.

The product characteristics are intermittent. They open more at hot temperature versus cold temperatures, and this self-healing effect is a real problem in intermittency. The failures occurred after the finished product was stored for weeks or months; it passed test at the time of fabrication and initial assembly but dropped out after storage. A failure after field deployment is the costliest of all failures. This is an unpredictable reliability issue that needs to be resolved.

Table 1 shows the structure of the IPC Weak Microvia Failure Committee Sub-Teams, including simulation and modeling. The two groups (1b and 1d) are in yellow, as we are melding the characterization and test methods team with the construction design elements team.

Weak Microvias Subcommittee Structure Adopted Early 2019
1A. Simulation and Modeling
1B. Characterization and Test Methods
1C. Laminate Materials
1D. Construction Design Elements
2A. Chemical Processes and Metallurgy
2B. Hole Formation
3. Data Collection (Reactivate After IPC Testing)

Table 1: IPC Weak Microvia Failure Committee Sub-Teams.

There is a laminate sub-team, a chemical processes and metallurgy team, and the whole formation team, which were highly active. A year ago, after formation and trying to collect field data (which was not forthcoming), this committee was inactive. It will reactivate after IPC test data from the test program that we outline is disseminated.

You might ask, "What can cause weak microvias?" Figure 5 shows a fishbone diagram

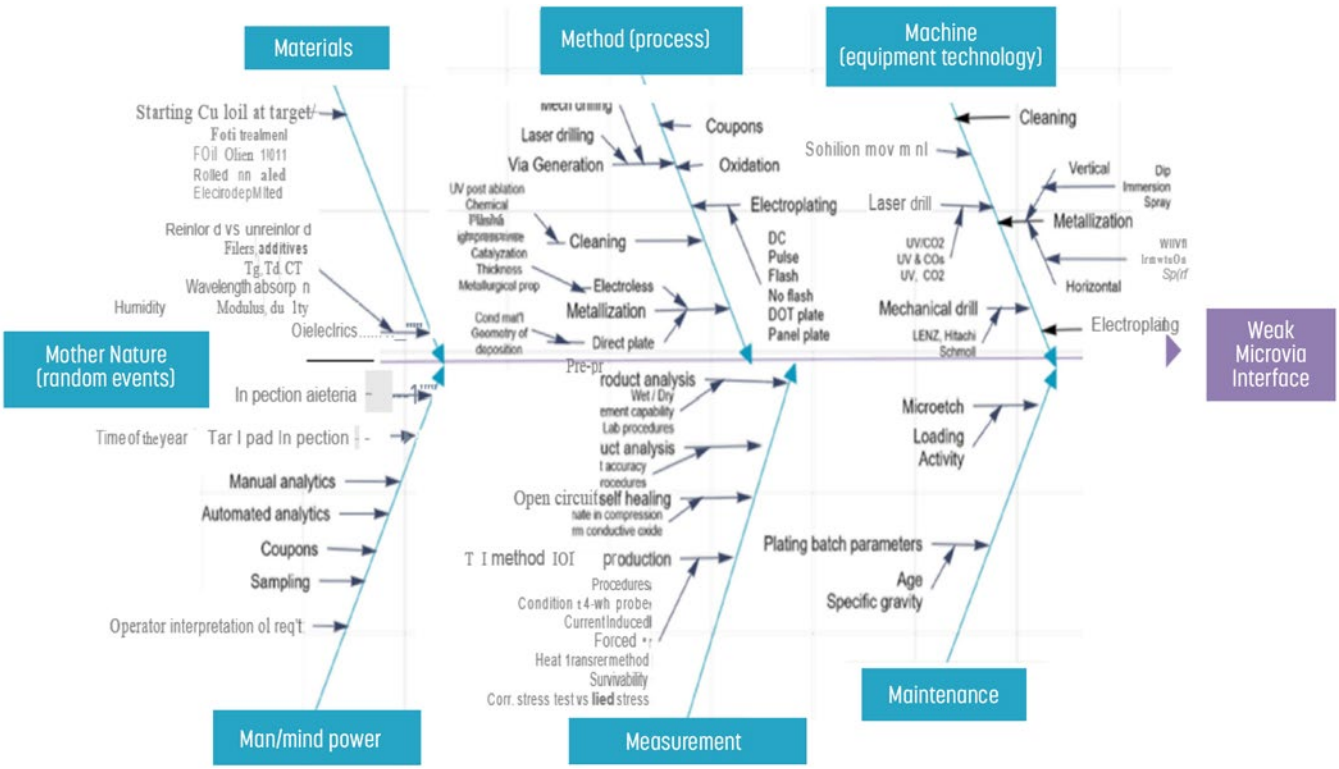


Figure 5: Various factors in the understanding of weak interfacial bonds for microvias.

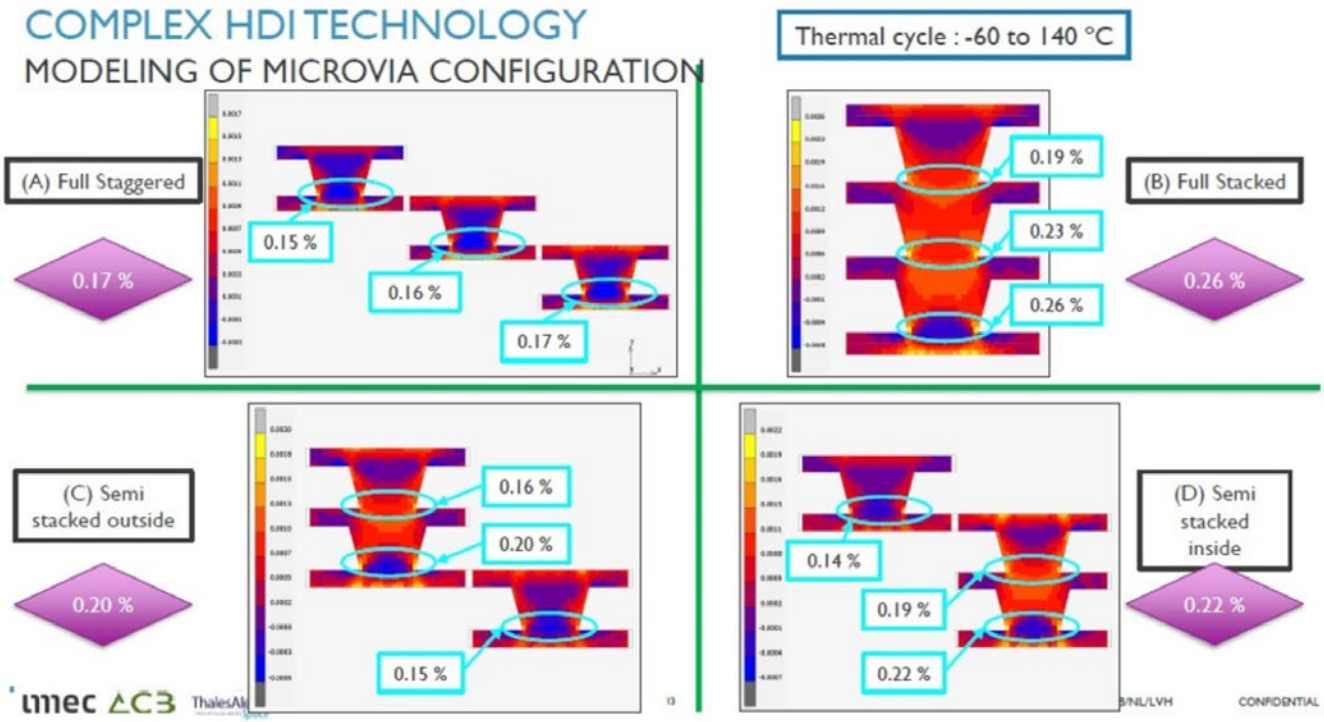


Figure 6: IMEC and ESA test simulations with actual builds and thermal stresses.

assembled by the team after just two months together. You can see that materials, methods, machines, maintenance, measurement techniques, and human inputs can all contribute to some aspect of the weak microvia team. It is a very thorny problem. To sort all of these out would be an immense undertaking for some kind of test design. These presentations review the efforts to determine the germane causes of weak microvia interfaces.

Figure 6 is from IMEC and ESA, which shows stress simulations from internal evaluations. On the upper left, you see staircase microvias. On the upper right, you see a three-stack of microvias, as well as semi-stacked "two over one" or "one over two" microvias.

You see that the most stressful situation is in the stack microvia. Unfortunately for us, that is the configuration that takes up the least space on the board; it's the most desirable from an interconnection density standpoint but the most likely to fail. Figure 7 shows IMEC graphics between a three-stack staircase and staggered microvias. They found that the staggered microvias have slightly less stress than the staircase microvias, at least in our simulation. You will see that most of these designs occur in some of the presentations of future work.

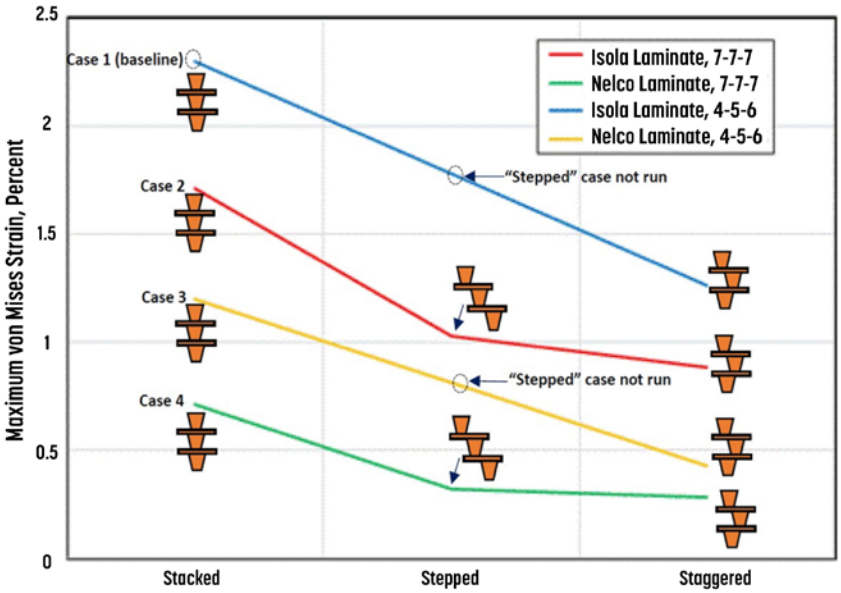


Figure 7: The effect of varying microvia configurations shows stacked as the most strained and staggered as the least strained. (Source: Raytheon)

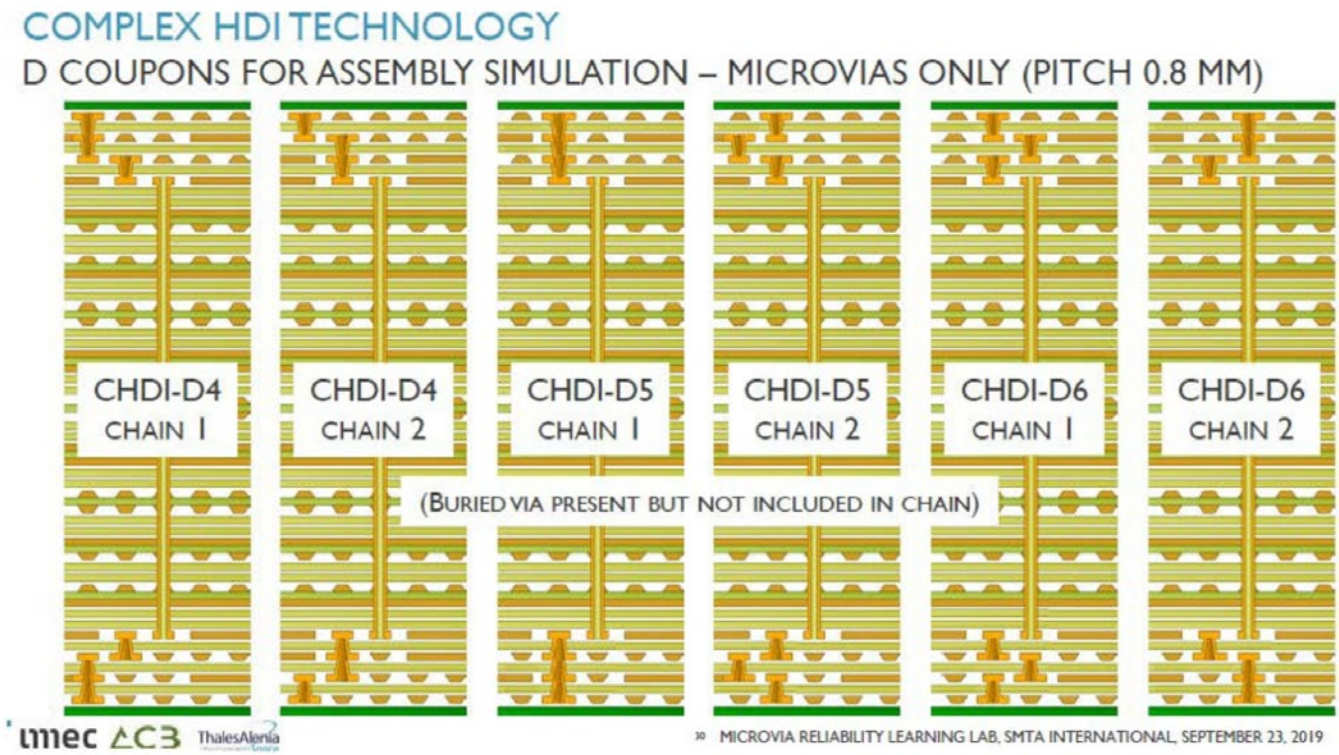
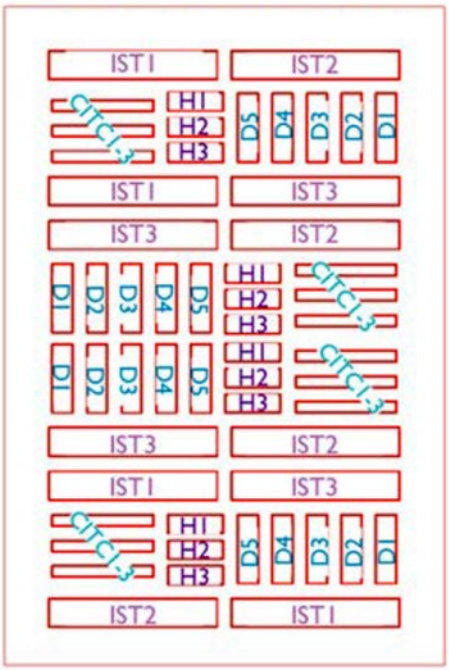


Figure 8: The modified ESA microvia test panel for the IPC reliability testing using the Hitachi high-Tg laminate. (Source: IMEC)

The test board that IPC has selected is from the ESA program (Figure 8). The chessboard—with a purchase order issued by IPC to participate with IMEC and its board fabricator, a CBF in Europe—uses this design of daisy chains. There are six different chains, and Figure 9 shows where they are placed on a panel.

Figure 9 is the panel that IPC is contracted to have fabricated at the EU fabricator, duplicating ESA.

These will be constructed in Hitachi 679F laminate, which is an epoxy qualified at CB and most similar to the North American constructions of microvia. It will use four different test coupons, depending on the instrumentation for the analysis of the D-coupon to the HATS to two other coupons. The CITC coupon, which is the old IBM-developed method, was carried forward by i-3 and possibly TM and the IST coupon.



	Hitachi 679FJ				
D coupon	D1	D2	D3	D4	D5
Per panel	4	4	4	4	4
Three panels	12	12	12	12	12
Six panels	24	24	24	24	24
Total	60 - 120				
HATS[2]	H1	H2	H3		
Per panel	4	4	4		
Three panels	12	12	12		
Six panels	24	24	24		
Total	36 - 72				
CITC					
Per panel	4	4	4		
Three panels	12	12	12		
Six panels	24	24	24		
Total	36 - 72				
IST coupon	IST1	IST2	IST3		
Per panel	4	4	4		
Three panels	12	12	12		
Six panels	24	24	24		
Total	36 - 72				

Figure 9: Layout and number of the four coupons on the IPC test panel. (Source: IMEC)

Year	%Yield
2014	83.8%
2015	86.9%
2016	87.5%
2017	94.4%
Total	90.1%

Construction	%Yield
1 Layer HDI	98.5%
2 Layer HDI	95.7%
3 Layer HDI	85.0%
4 Layer HDI	62.3%

Table 2: Composite test results from years of testing microvias by reflow coupons containing a staggered chain and a stacked chain for each HDI construction type. (Source: Motorola Solutions)

Table 2 shows Motorola's results. When Motorola put in its sorting protocol, it showed yields from 2014–2017. These went up significantly with the protocol, and they learned that there was a breakdown after three-stack or a force that showed in their results anyway. Since the time this was initially presented, Motorola has had no failures.

Motorola has gone from preferred to unacceptable, and the preferred is staggered microvias and then two-stacks and with caution on a two-stack or three-stack construction. They require a management sign-off if you need three-stack microvias.

In summary, stacked microvias and even some others can fracture at a metallurgical interface, particularly during reflow and thermal cycling simulations. The failure level is not predictable with what we are doing today and how we understand the process. The test methods, like visual cross-section, are not effective in detecting the failures. The technique duplicates reflow assembly and potential problems.

T-type testing is the most widely used equipment today. You can minimize failures with design, and our team hopes to release a white paper design guide within a year. Is there more than one cause of this? If our industry was not in containment right now, we would have discovered the answer already.

Please understand that our team has been operating for over two years, working to identify the root causes. We are not particularly working on product acceptance. Try to help IPC. We certainly want higher reliability and high-density structures with four stacks or more. Join our working teams and contribute. SMT007

Gerry Partida Emphasizes Current Concerns Over Microvia Failures

Edited by Happy Holden
I-CONNECT007

Gerry Partida

At the virtual IPC High-Reliability Forum, Gerry Partida, field application engineering manager at Summit Interconnect, covered concerns regarding the reliability testing of microvias in his presentation titled "Current Concerns Over Microvia Failures." He also provided an overview of HDI processes and discussed current test methods. Here, I share Gerry's presentation transcript, which has been slightly edited for clarity.

Current Concerns Over Microvia Failures

I'm going to share the knowledge that our team has accumulated over 20 years of making microvias, as well as information on what can be done to test your microvias for acceptance as it applies to today's IPC standards. Have you ever had to hold your finger down on a component to make it work, and when you let up, it stopped working (Figure 1)? It might be the reason why you are here today.

Figure 2 shows a quote from an IPC news release warning about microvia reliability.

The industry has experienced failures of microvias after the boards have been completed and shipped to the customer, either at assembly or during thermal testing of a finished product. Customers have experienced failures that occurred even later. There is a way to check your microvia and ensure that you have a good microvia that will meet the assembly reflow process, as well as when doing thermal shock.

Why do we test and then look? We don't see a lot of commercial companies; we see a lot of high reliability. The military-aerospace sector is more interested in this than U.S. commercial companies, and there is a reason for that. When they build a lot of these space products, they can only put the component down one time. It cannot be reused. If it's a custom ASIC chip with 1,400 I/Os on a BGA, or an ASIC

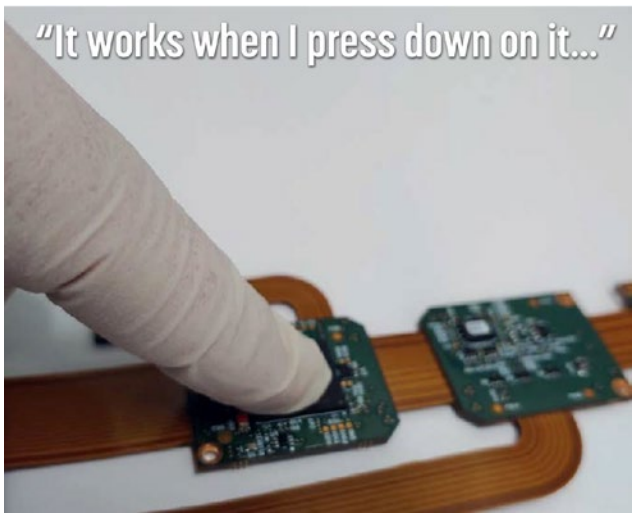


Figure 1: A finger pressing down on a component to make it work.

> "There have been many examples of post-fabrication microvia failures over the last several years. Typically, these failures occur during reflow; however, they are often undetectable (latent) at room temperature. The further along the assembly process that the failures manifest themselves, the more expensive they become. If they remain undetected until after the product is placed into service, they become a much greater cost risk and, more importantly, may pose a safety risk."

Figure 2: IPC microvia reliability warning press release.

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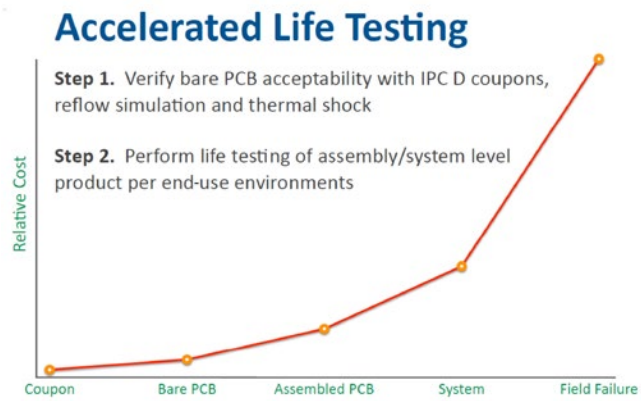


Figure 3: Why are we testing for reliability?

where that one component can cost $100,000, then you don't want to build a board and put a couple (or five or six) $100,000 components on a space board only to find out that the vehicle instructions are not reliable.

It is better to just test this coupon using a little bit of real estate. Put the same geometries, drill sizes, land sizes, and vias—whether they are stacked or staggered—in designs, build a coupon with planes and signals, and find out before you commit the components to the assembly. Now, you can test whether that structure can sustain the reflow you expect to do to the part.

You need to test that coupon for acceptance before you commit the parts. Many people have not tested with reflow temperatures, measuring resistance at reflow to find out what is going to happen. With OM testing and IPC TM650 2.6.27, you can measure the resistance at reflow and find out whether these boards will go through assembly safely. And you do not want to assemble the serial number that coupon came from. As seen in Figure 3, the cost of any failure goes up with time.

All of my testing is IPC 2.6.27 for real-world validation for today's demanding PCB design. I'm going to review the current evaluation methods that are required by a PCB fabricator and talk about the different temperature methods. Why did some methods not provide us a true assessment in some cases? And how does OM testing provide a real-world evaluation of your finished product by testing the coupons?

In our current evaluation methods, we take A-B coupons and thermal stress them, depending on the temperature. If it's tin-lead to 230°C or 260°C, then we evaluate the cross-sections and look at what we have after we micro-etched a polished coupon.

Our shops are required to do monthly performance testing. I will talk about that, as well as what happened to a board at electrical test, and why it does not really tell us whether we have weak microvias. I'll also show some real-world builds in which the D-coupon testing catches a non-conforming via when the resistance caught it, as well as it being non-conforming to IPC-6012 for internal evaluation.

Why did the older methods seem to fail us? When we do a micro-section on A or propagated B coupons, we begin by baking. We solder float them and then grind them. In the as-polished condition, we look for separations. If we do not identify the separation of a microvia evaluated at 200x, and if we do not notice anything, we will take a Q-tip with micro-etch and rub the coupon that has just been polished (Figure 4).

We see this result in Figure 5, especially the different layers of copper plate in the starting foil. There's a plated layer and layer two. In this example, the flash plated microvia plated shut. Then, we do the final calculating, but all the evidence is now gone, so it's kind of a moot point. We polish and look; if we don't see any-

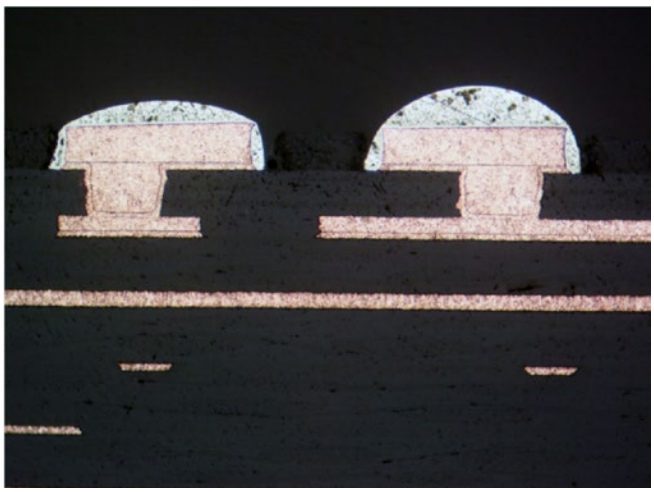


Figure 4: Micro-etched cross-sections hide small separations found in the polished condition.

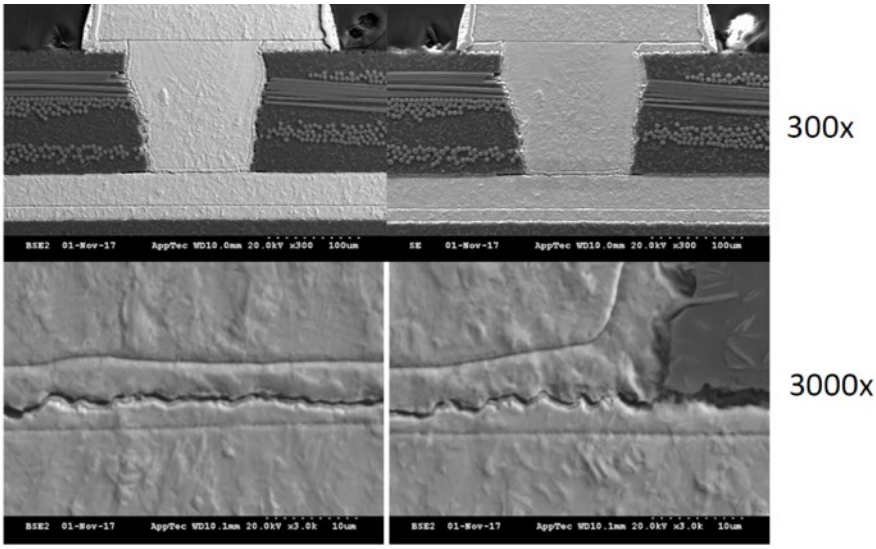


Figure 5: IPC-6012 requires examination from 200x up to 500x.

thing at 200x, we micro-etch, which is where we can no longer see any separation.

But if we go to a higher magnification, we see what it looks like after micro-etching. The top picture of Figure 5 is at 300x. IPC requires that we start at 200x for a microvia, and if there is something that's questionable, go up to 500x. If we can't identify anything, it's deemed acceptable. But if we take those same pictures and go to 3,000x, we can see that separation is taking place. Our standards for what's required from a fabricator may not identify this separation, which leads to problems. They pass all of the cross-section evaluations and get shipped, but nobody did a thermal test of the D-coupon to show that there were weak microvias in the build. Instead, it will be found in assembly when your fingers are pushing down on the component.

Figure 6 is an example of the as-polished condition. On the left, you can see the three stack microvia, and there is no separation. Right after this point, when somebody evaluates it, they are going to take a micro-etch and look. The center picture shows a 2X tin-lead reflow, which is about 230°C, and it's a lot less stressful on the specimen. You can't really see a separation, but there might be a separation between the top and the middle of microvia on the target path. On the far-right column, you can see a separation occurring at the target pad on layer 2 to the microvia between one and two.

At that point, it should be deemed an unacceptable condition and non-conforming. It is so thin and slight that it could be missed. Once they ship, you are not going to see this demarcation.

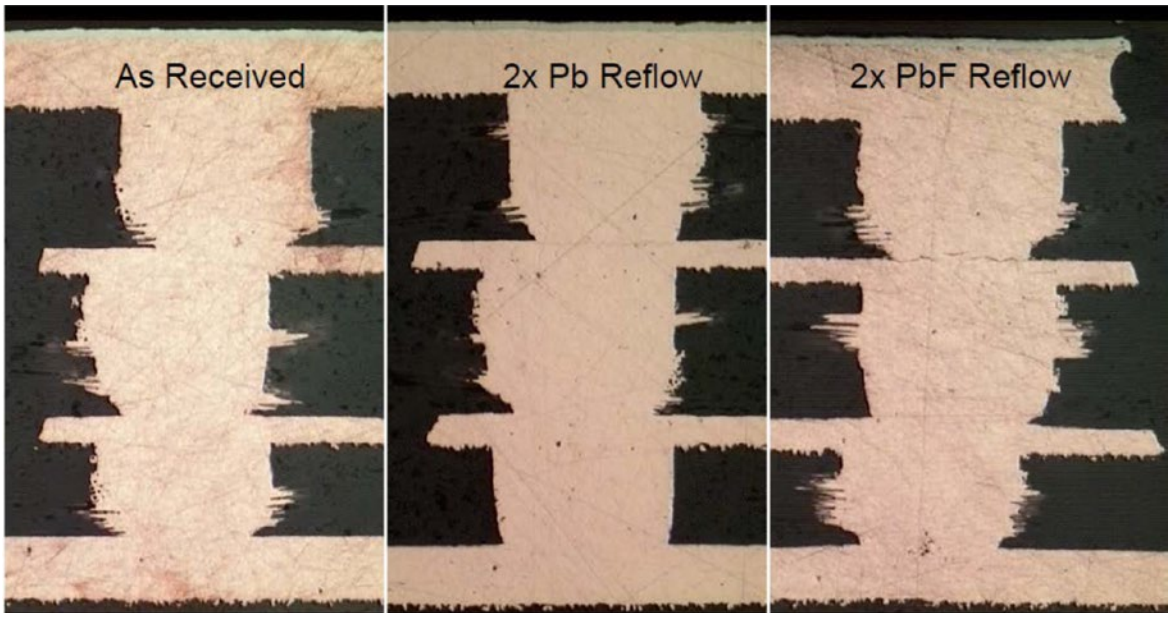


Figure 6: How older methods fail us.

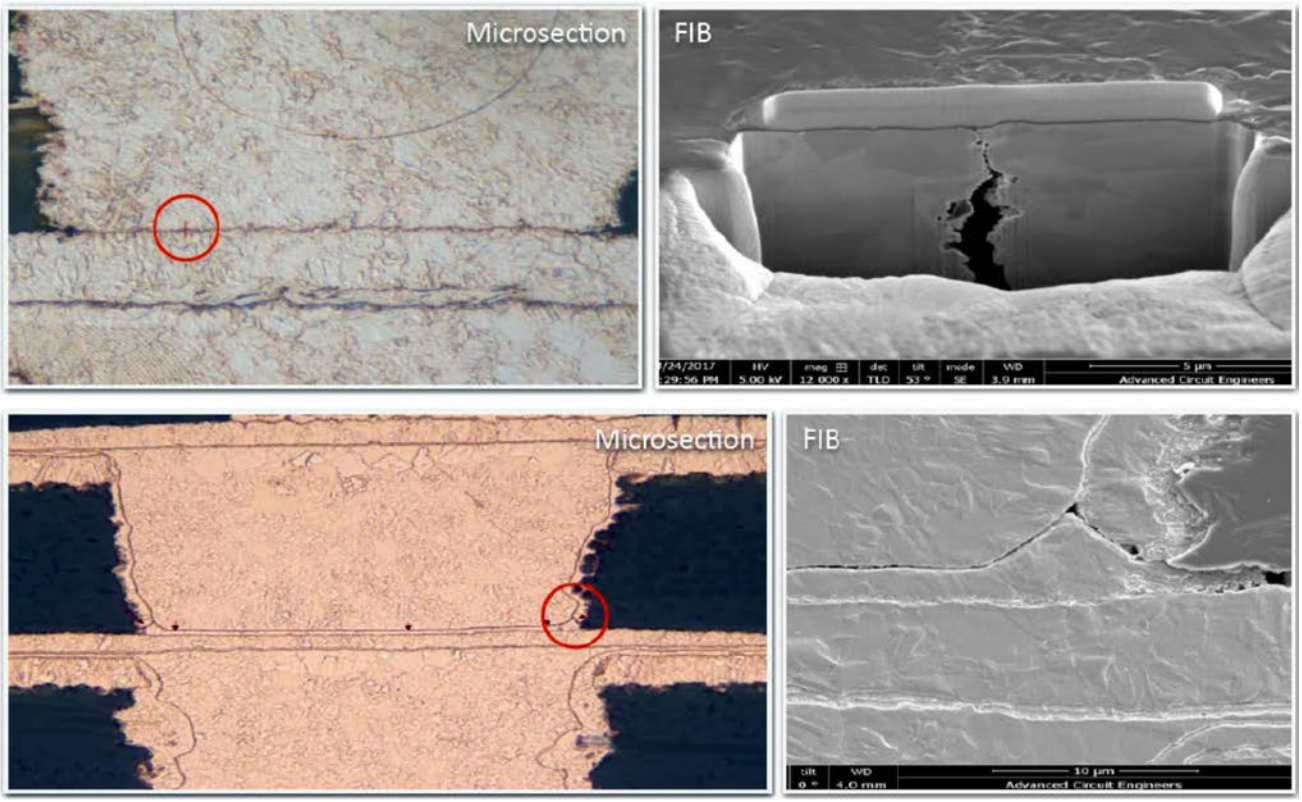


Figure 7: The older methods fail at detecting weak microvia defects.

If we were to take a specimen after microetch and everything was fine (Figure 7), we would focus on ion-beam milling and look inside it. You can find a crack; in some cases, there are failures. You find these cracks in the board, and now everybody's in a panic about whether these boards are going to work. I have seen many customers who have had 1,400–1,600 I/O BGAs using four-stacked microvias. I told them we were not going to build the boards. They said, "You build all our hardest boards." But I knew that this board was not going to get through their assembly.

Six months later, I was in their quality lab with two Ph.D.s. They were looking at a board, and I said, "Let me guess. When you put your finger down, they work." Their response was, "How would you know?" I was not going to build that board because they have this type of failure in them due to the four-stack migrations. They are only detectable by using very expensive, very sophisticated focused ion beam milling.

Another requirement these board fabricators have is monthly quality conformance testing for Class 3 suppliers. All we have to submit is the most complex board we built in that month to testing. The test checks rework simulation, bond strength, peel strength, dielectric with standing voltage, and moisture installation. But there's no way to test whether the board shop can actually produce microvias reliably.

When we've finished building a PCB, we test the electrical circuit boards at ambient room temperature. But a weak microvia still has enough connection and will not fail an electrical test, especially when the electrical test threshold is typically at a 10 ohms resistance value and anything under 10 ohms in a net is considered a connection. Therefore, the weak microvia is not going to be detected.

A funny story about testing at ambient room temperatures over the last five or six years is we've been working with reliability reflow testing of the coupons since the very beginning. In that time, some customers would not do the coupon testing and, therefore, had assembly problems. Typically, there were three- or four-stacked microvias involved. We shipped the boards. They called us and explained how they wanted to retest the boards after putting

Figure 8: Electrical testing at ambient temperatures will not find weak microvia interfaces.

them through a reflow oven six times. Now, they want us to retest on our testers to see if we have an open that occurs.

Again, this is at ambient room temperature. We were never going to find any weak microvias, even though they passed it through a reflow of six times. A customer might say, "I want to retest these boards, I will pay you for it." But when I look at the designs, I typically find that it was a three- or four-stacked microvia, which we highly recommend not doing (Figure 8).

In most cases, if you have a defective microvia only at reflow, then only resistance is open. In this example, you can see the six peaks. This is the resistance at each reflow cycle. The red line is a 5% threshold that we cannot exceed; if we do, it is a bad panel, and it is going to get rejected. Typically, you do not hear board shops saying this, but if we have a bad serial number, I do not want you to build with it. Rather, I want to throw it away. I do not want you to have failures. I will reject it. I will be happy that you are not getting bad products.

As you can see in Figure 9, the little line that goes over the 5% red line threshold is a defect. The resistance at reflow at the peak of reflow temperature went over the 5% threshold, but only as it cooled down. You will notice that the resistance went away, and it is now connected, or self-healed, at ambient room temperature. This gives that false hope that everything is fine. But you can detect these, in many cases, only at reflow with actual reflow temperature.

Traditional thermal testing with thermal shocks uses the chamber in which it normally cycles from a very cold temperature (-60°C) to 160°C. Originally, it was thought that you didn't have to check if the resistance changed after every reflow. The thinking was you just had to exercise through the six reflows. Then, you put them on the tester, and a whole measurement of resistance was only done in the thermal shock temp chamber (Figure 10).

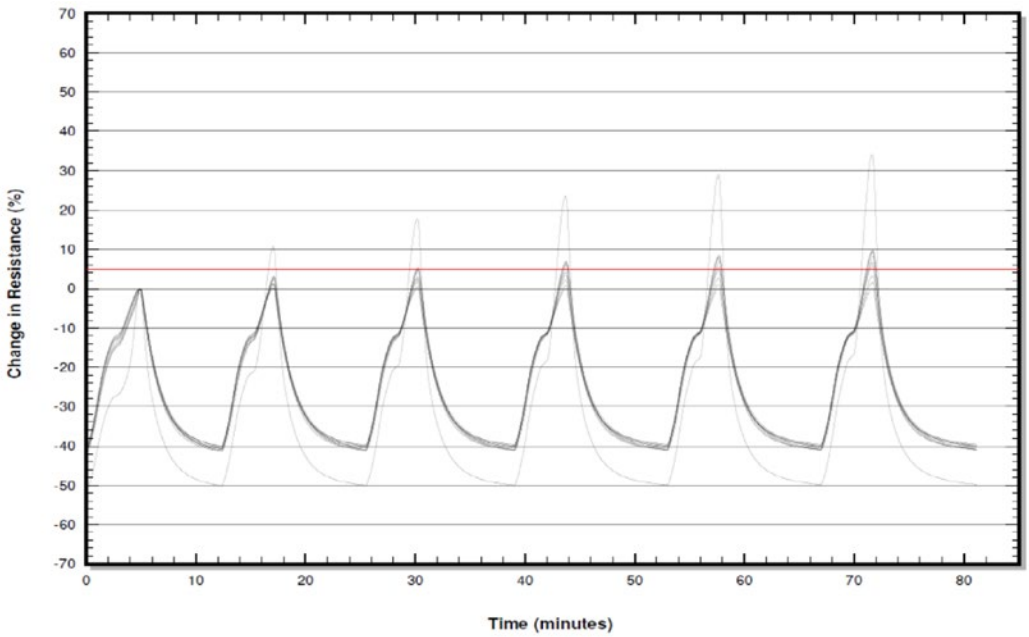


Figure 9: OM testing with four-wire resistance from ambient to reflow temperatures.

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 175C (ohms)		Cycles to 5% Change		Change after 100 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	1.138	0.717	1.693	1.070	>100	>100	0.3	0.1
2	1.150	0.739	1.738	1.118	>100	>100	0.5	0.7
3	1.163	0.606	1.750	0.913	>100	>100	0.5	0.1
4	1.069	0.657	1.661	0.993	>100	>100	1.5	0.6
5	1.034	0.695	1.568	1.046	>100	>100	4.0	0.6
6	1.045	0.700	1.578	1.048	>100	>100	1.3	0.4
7	1.069	0.622	1.629	0.930	>100	>100	0.5	0.1
8	1.143	0.659	1.736	0.992	>100	>100	1.6	0.4
9	1.019	1.145	1.517	1.698	>100	>100	0.3	0.3
10	1.170	1.207	1.741	1.792	>100	>100	0.1	0.2
11	1.105	1.167	1.645	1.741	>100	>100	0.1	0.3
12	1.122	1.067	1.670	1.585	>100	>100	0.1	0.2
13	1.060	1.154	1.573	1.713	>100	>100	0.3	0.5
14	1.125	1.212	1.683	1.807	>100	>100	0.2	0.1
15	0.135	1.256	0.204	1.876	>100	>100	0.4	0.2
16	1.121	1.100	1.687	1.650	>100	>100	0.4	0.1
17	0.203	0.336	0.311	0.513	>100	>100	-0.2	-0.1
18	0.218	0.281	0.333	0.428	>100	>100	-0.2	-0.3
19	0.208	0.264	0.317	0.402	>100	>100	0.1	0.4
20	0.201	0.300	0.311	0.460	>100	>100	0.1	0.3
21	0.196	0.326	0.300	0.497	>100	>100	-0.2	-0.1
22	0.203	0.280	0.310	0.424	>100	>100	-0.1	0.0
23	0.210	0.304	0.321	0.463	>100	>100	-0.0	0.2
24	0.183	0.273	0.280	0.414	>100	>100	0.1	0.1

Figure 10: Examples of how thermal shock alone will pass coupons that fail at reflow.

Figure 11 is a report. If you just looked at the thermal shock on some coupons, and look toward the right, you will see yellow lines. The first two pairs of columns are how many cycles it went past 100 cycles. The requirement was 100 cycles. But when you did an OM test with reflow measuring, the resistance at reflow was followed immediately by thermal shock. The reason these are marked in yellow is that every one of the yellow-marked tests failed during reflow in that the resistance went over the 5% threshold.

If you just use the thermal shock, and if that is the only test you did, you would have declared all the parts as good. They passed

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 230C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	1.117	0.708	1.905	1.210	>6	>6	0.2	-0.3
2	1.135	0.734	1.979	1.279	>6	>6	0.4	-0.2
3	1.147	0.591	1.990	1.039	>6	>6	1.7	0.3
4	1.063	0.649	1.885	1.136	>6	>6	2.6	0.0
5	1.017	0.689	1.782	1.197	2	>6	Open	0.2
6	1.030	0.693	1.790	1.189	3	>6	Open	0.3
7	1.072	0.615	1.845	1.055	>6	>6	1.1	0.0
8	1.119	0.652	1.969	1.124	5	>6	Open	0.5
9	1.006	1.126	1.700	1.903	>6	>6	0.5	0.5
10	1.157	1.192	1.955	2.011	>6	>6	0.5	0.5
11	1.092	1.150	1.855	1.967	>6	>6	0.2	0.6
12	1.108	1.052	1.880	1.780	>6	>6	0.2	0.2
13	1.044	1.135	1.766	1.950	>6	2	0.3	Open
14	1.106	1.192	1.903	2.038	>6	>6	0.6	0.2
15	0.133	1.237	0.230	2.120	>6	>6	0.4	0.3
16	1.102	1.086	1.915	1.872	>6	>6	0.4	0.0
17	0.202	0.334	0.355	0.585	>6	>6	-0.1	-0.3
18	0.217	0.280	0.377	0.485	>6	>6	-0.2	-0.2
19	0.208	0.263	0.357	0.456	>6	>6	0.2	0.3
20	0.201	0.298	0.354	0.524	>6	>6	0.2	0.5
21	0.195	0.325	0.341	0.563	>6	>6	-0.3	-0.2
22	0.203	0.278	0.352	0.483	>6	>6	0.1	-0.3
23	0.210	0.301	0.363	0.524	>6	>6	0.3	0.6
24	0.183	0.272	0.315	0.464	>6	>6	0.2	0.2

Figure 11: Same load from previous figure except these are reflow statistics.

thermal shock. But if you did reflow—which is this slide, plus the thermal shock—you would say, "No, I don't want to assemble those four serial numbers because they actually went open at reflow, even after thermal shock. They are still connected, and maintaining their connection those boards that have failed could lead to problems out in the field later."

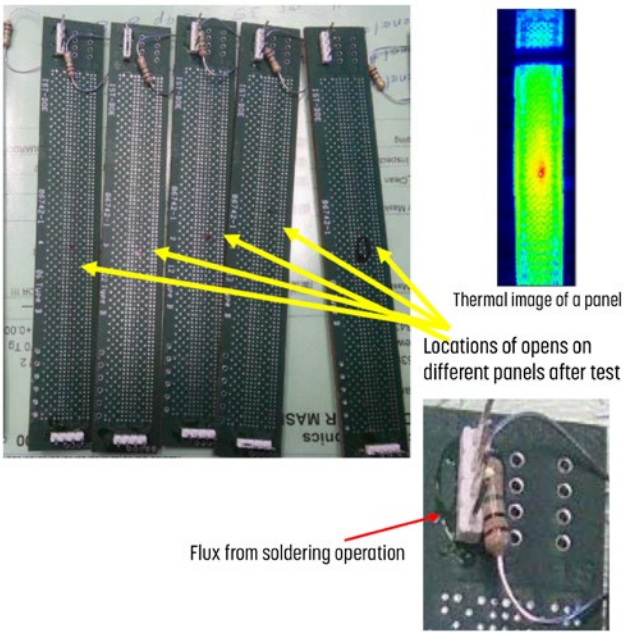
There is also the ability to evaluate using IST coupons and current to induce heat in the specimen to evaluate whether the structure is strong. It's a great system to compare changing one process to the other, and I highly agree with that. It's a good comparison system to say these are stronger than those, but it doesn't take the coupon to reflow temperatures across the board, like we do with an actual board in assembly.

On the bottom right in Figure 12, what you see is the thermal image of a coupon, and a current is flowing through the daisy chain. The hottest point in the coupon is in the dead center, which is going to have the most stress. The connector is soldered on there. It is not as if it had reflowed the coupon and was going to reflow to have the problem with the connector. The actual coupon itself did not reflow across the whole coupon, just like your board is going to get reflow across the entire board. Then, there's the example with the arrows.

You can see the little black dots where the arrows are pointing, where every failed microvia was on five different coupons. They are all in the center, where the heat's the strongest. By the way, these all come from different panels and positions on those panels. I do not have the ability to make the weakest microvias in the middle of a coupon specifically over again when they are all the same geometries. It is a good comparison test to validate your process. But it does not take your coupon, which should have the same structures as your board and takes the reflow temperature just like your portal experience.

IPC-TM-650 2.6.27A comes to the rescue. What we are using is a D-coupon, which is approved by IPC. The coupon can be built by anybody by going to Conductor Analysis Technology and building your own D-coupon that meets the IPC requirements. When you generate your coupon, you have generated it just like your board. You need to know the diameter of your microvia or mechanical or buried vias and use the same land size.

You specify whether there is a plane layer on layer two or if it is a signal layer. You build the coupon exactly like your board so that it tests a structure just like your board. It is critical that you have the distance between the drill laser and the mechanical drill at the same distance,



- In some test methods, coupons are not thermally cycled at actual reflow temperature. The connector is soldered to the coupon and, therefore, cannot be reflowed.
- Coupon is a heating coil with five amps of current through a microvia daisychain. The temperature is theoretical, not measured. The greatest heat is at the center of the coupon as seen in the thermal image shown.
- OM coupons use the actual recorded temperature readings.

Figure 12: In IST testing the greatest heat is in the center of the coupon.

land size to land size; pad to pad size is meaningless. Instead, the edge of the laser drill to the edge of the mechanical drill, as they get closer to each other, start to fail at a higher percentage; the farther they go away, the safer they become. Again, you can use production house technology and generate your own coupons, and I highly recommend that the OEM checks the coupons that are generated by the board fabricator to make sure everything is correct. Again, the D-coupon matches the structure of your PCB. You are going to evaluate your structures in your process and the coupon that matches your product. If the coupon passes, your boards will be good in assembly.

The coupons go into a chamber. The OM tests are currently a 24 position test. You have coupon positions and can define different strategies of interconnects. In some cases, you may need two or three different coupons to do all of the different drill spans you have designed into your board. Each coupon can only have two different nets. If you have propagated vias of various configurations, you may need multiple coupons on the panel that goes into the chamber and is tested.

A real-life test is shown in Figures 13 and 14. It is kind of embarrassing, but this really hap-

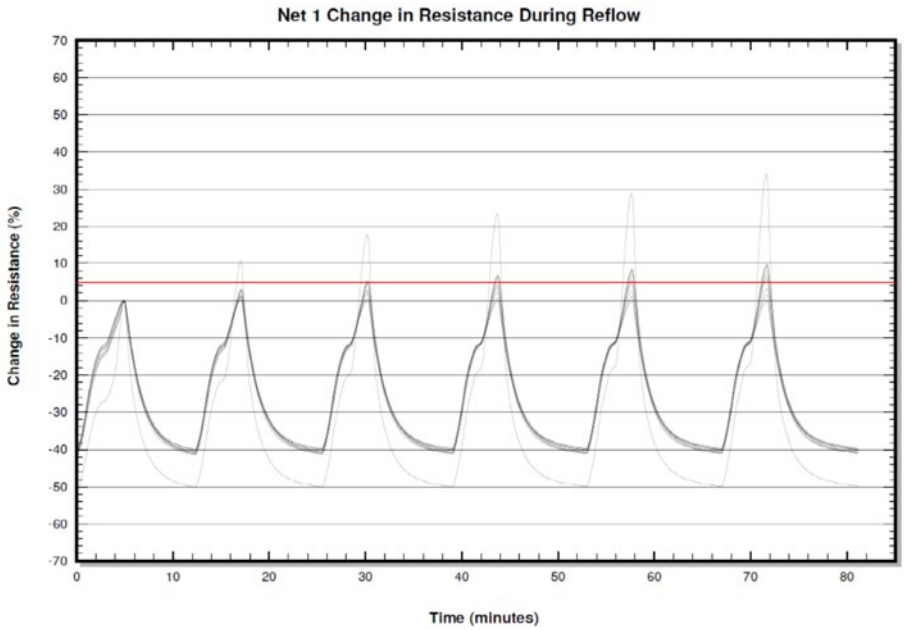


Figure 13: Example of test results.

Reflow Statistics

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 230C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	0.695	0.683	1.201	1.148	4	>6	8.2	0.1
2	0.674	0.671	1.146	1.127	5	>6	6.7	-0.1
3	0.725	0.731	1.235	1.222	6	>6	5.8	1.3
4	0.691	0.669	1.169	1.098	3	>6	9.8	0.2
5	0.715	0.737	1.205	1.204	4	>6	9.2	0.1
6	0.694	0.687	1.179	1.121	3	>6	9.6	0.2
7	0.674	0.698	1.123	1.160	>6	>6	1.6	0.0
8	0.710	0.714	1.180	1.184	>6	>6	-0.1	-0.0
9	0.692	0.700	1.167	1.166	>6	>6	3.2	0.0
10	0.659	0.647	1.351	1.093	2	>6	34.2	2.9

Notes:
1. Resistances greater than 15 ohms are "open".
2. Reference resistances greater than 3 times their initial room temperature resistance are "open".
3. Reference resistances are based on cycle 1 at high temperature.
4. Cells highlighted in red indicate failures.

Figure 14: OM test reflow statistics.

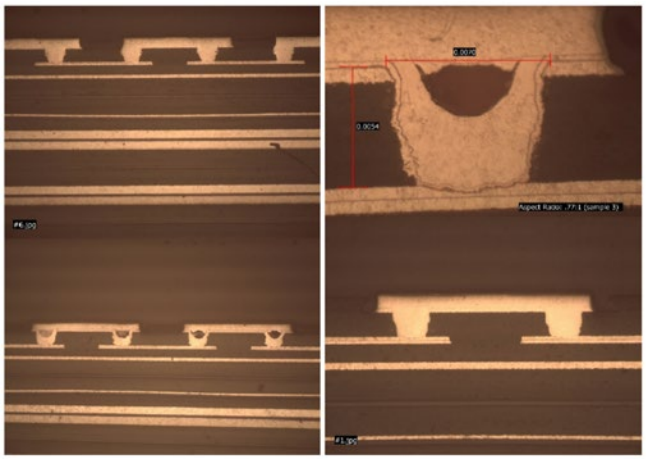


Figure 15: Example of WMI failure caught by OM testing.

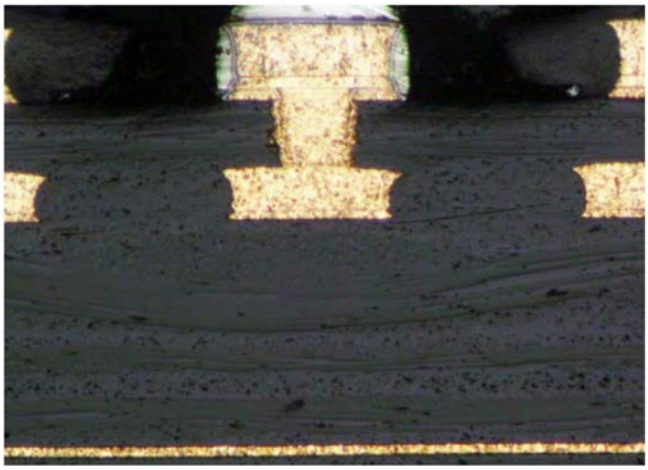


Figure 16: A microvia at 0.005″ with an aspect ratio of 1:1 and a dielectric target of 0.0045″.

pened. We built these boards, and every one of the reds failed reflow testing. Three of them passed.

Therefore, as seen in Figure 15, we had a void in the microvia at the cap plating. The one on the bottom right passed. When you build them right, they pass; but if you have problems, they will fail.

This is a real case study (Figure 16). I had a new CAM planner that planned for a 5-mil microvia; because of the price at five, it is a five-mil laser via, and the aspect ratio was high. I highly recommend 0.75:1.0.

Figure 17 shows the test cycle at 245°C. The black line is the actual temperature on the coupon. Here is what happened during the routine first reflow. It looked like it was okay, but then we started having failures at the second reflow, and it happened more and more as we got down to the sixth reflow cycle (Figure 18).

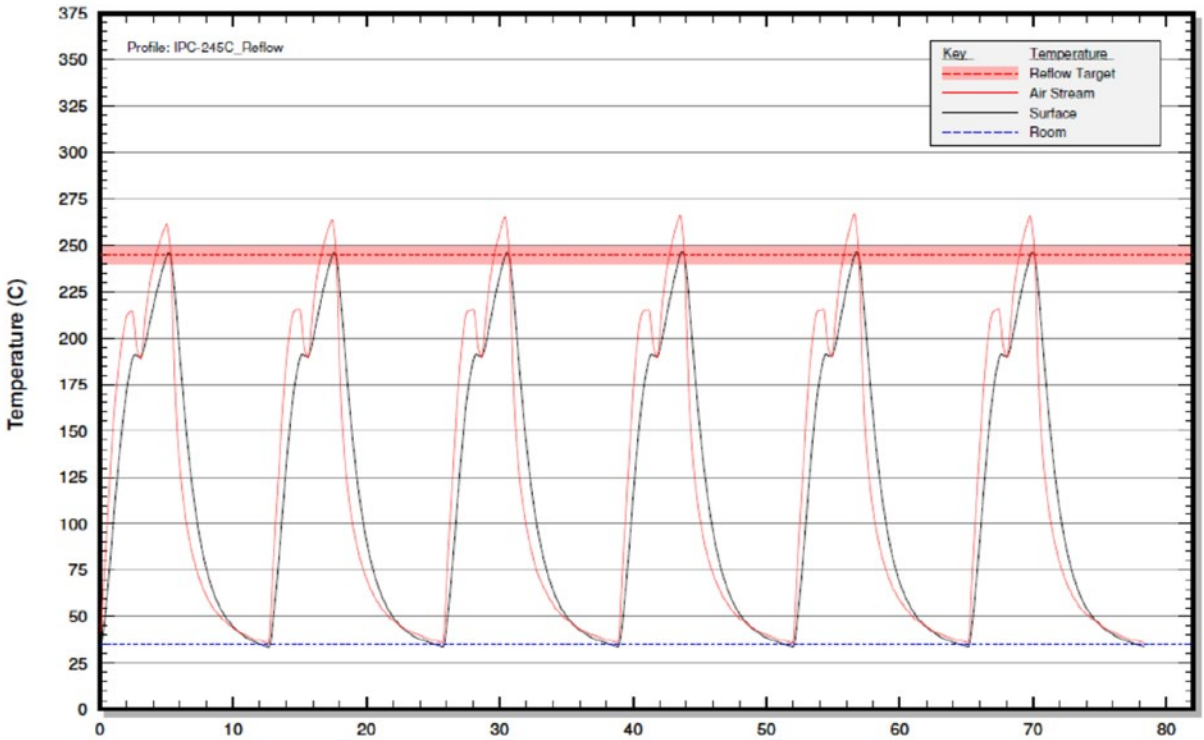


Figure 17: OM thermal cycling on the actual D-Coupons.

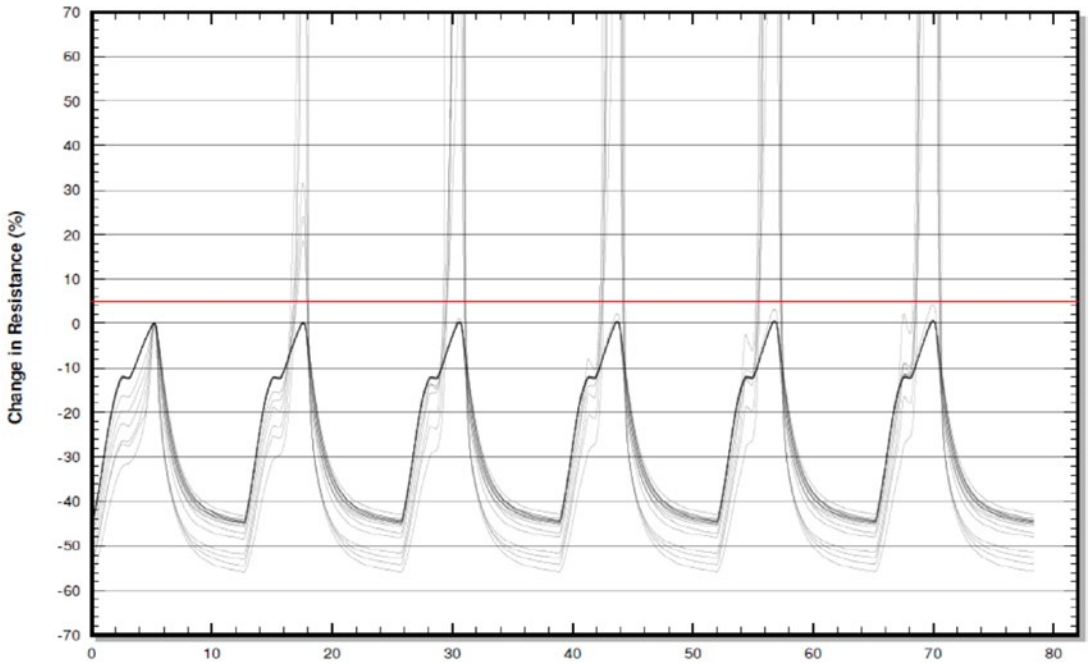


Figure 18: Resistance during the reflow of Net1 (notice that all coupons pass the first cycle).

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 245C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	0.435	0.514	0.995	0.913	2	>6	Open	0.3
2	0.477	0.551	0.868	Open	>6	1	0.5	Open
3	0.473	0.493	0.891	0.879	2	2	Open	Open
4	0.452	0.525	0.817	0.946	>6	4	0.9	11.6
5	0.486	0.584	Open	1.047	1	>6	Open	0.3
6	0.471	0.558	0.842	1.018	>6	2	0.6	53.2
7	0.478	0.488	0.922	0.855	2	>6	Open	0.4
8	0.465	0.526	0.818	0.932	>6	2	0.4	Open
9	0.503	0.540	1.071	0.962	2	5	Open	Open
10	0.577	0.602	1.045	1.095	>6	>6	0.3	3.9
11	0.466	0.531	0.826	0.936	>6	>6	4.4	0.5
12	0.452	0.520	0.810	0.943	>6	2	0.7	Open
13	0.480	0.530	0.860	Open	>6	1	0.8	Open
14	0.475	0.623	0.857	Open	>6	1	0.8	Open
15	0.433	0.472	0.937	0.837	2	>6	Open	0.4
16	0.437	0.492	0.783	0.893	>6	2	0.6	Open
17	0.479	0.535	Open	Open	1	1	Open	Open
18	0.419	0.460	0.749	0.820	>6	3	0.5	Open
19	0.470	0.594	0.964	1.062	2	>6	Open	0.8
20	0.510	0.560	0.920	Open	>6	1	0.6	Open

Figure 19: Failure by net.

Here is a coupon structure (Figure 19). The customer had two coupons per panel. He used a laser beam on only layer-one to layer-two on one coupon. Then, he had a buried two-to-seven by itself, and he wanted to do seven-to-eight microvias on the second coupon's second nets. Here are the results on the next page. These all failed because of microvia failure. We had to push the aspect ratio of the microvia. Therefore, I looked at it and found out we failed. We talked to the CAM department and told them to make the following changes.

We made the dielectric one mil thicker and corrected the laser via back to six mils, as seen

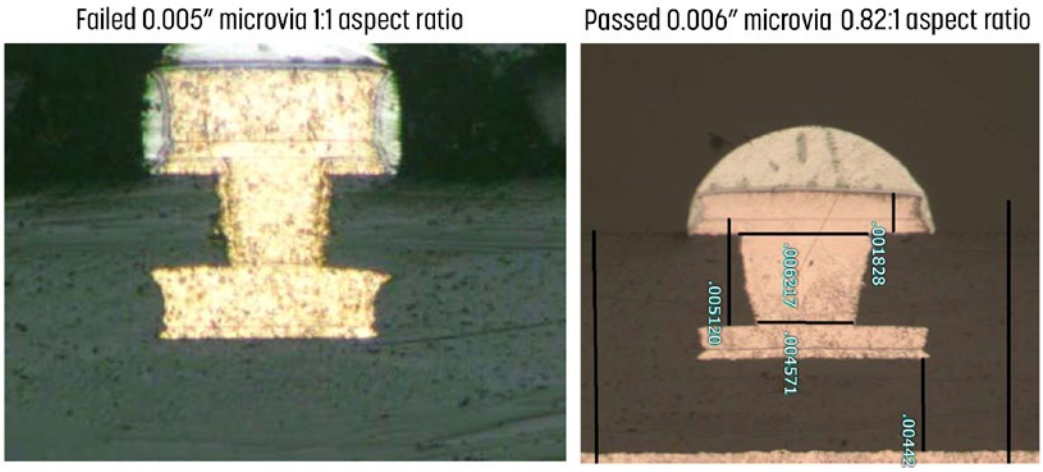


Figure 20: Remake with correct via and dielectric.

Coupon Number	Nominal Resistance at Room Temperature (ohms)		Reference Resistance at 245C (ohms)		Cycles to 5% Change		Change after 6 Cycles (%)	
	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2	Net 1	Net 2
1	0.572	0.500	1.040	0.903	>6	>6	-0.1	-0.0
2	0.591	0.629	1.115	1.173	>6	>6	0.8	0.5
3	0.489	0.541	0.905	0.999	>6	>6	0.1	0.2
4	0.478	0.551	0.910	1.032	>6	>6	0.8	0.3
5	0.467	0.487	0.868	0.901	>6	>6	0.1	0.1
6	0.475	0.521	0.907	0.981	>6	>6	0.7	0.4
7	0.503	0.477	0.938	0.886	>6	>6	0.1	0.1
8	0.480	0.575	0.921	1.088	>6	>6	0.6	0.3
9	0.487	0.444	0.914	0.826	>6	>6	-0.1	0.0
10	0.485	0.556	0.931	1.052	>6	>6	0.7	0.3
11	0.531	0.522	0.993	0.974	>6	>6	-0.0	-0.0
12	0.557	0.600	1.063	1.129	>6	>6	0.7	0.5
13	0.530	0.516	0.977	0.948	>6	>6	0.1	0.1
14	0.515	0.570	0.973	1.062	>6	>6	0.8	0.5
15	0.552	0.526	1.022	0.974	>6	>6	0.0	0.1
16	0.544	0.606	1.031	1.139	>6	>6	0.9	0.6
17	0.494	0.554	0.921	1.030	>6	>6	0.0	0.2
18	0.553	0.604	1.061	1.146	>6	>6	0.8	0.5

Figure 21: 100% pass with the correct via and aspect ratio.

in Figure 20. Nothing goes over the 5% threshold, and Figure 21 shows a 100% pass. The difference is in dielectric, and laser via diameter was half of one of my hair's thickness, and that is even the manufacturing process window shop.

It is extremely critical that the geometries are conducive for the reliable passing of OM testing, and your boards will pass through assembly, just as well.

Summary

In summary, the OM test validation will prove that your design and material selections and structural constructions meet today's challenging PCB requirements. It is validated by actual reflow conditions to your design geometry and detects failures at reflow that heal at room temperature. These test records are the actual temperature on the coupon and resistance values. It validates propagated via structures that match the PCB design and are consistent with IPC-6000 requirements.

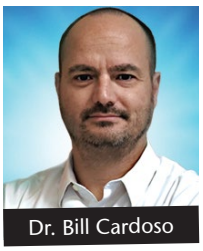
This data collection allows for better design practices. As you find designs that are not conducive for passing, you may want to change your design and increase the diameter of the microvia to eliminate certain structures and make your designs more reliable and profitable. **SMT007**

1 Knocking Down the Bone Pile: Removing Conformal Coatings for PCB Rework ▶

Bob Wettermann

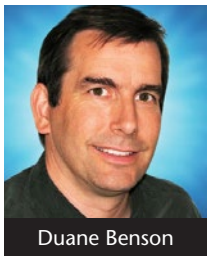
When the removal and replacement of components due to field failures or manufacturing defects needs to occur, the overlaying conformal coating layer first must be removed before being able to remove and replace a component. Bob Wettermann explains.

2 X-Rayted Files: Marching Toward 2021, 20 Miles at a Time ▶


Dr. Bill Cardoso

We're only at the halfway mark, and 2020 has been a real challenge. Our best-laid plans have been cast in doubt by the COVID-19 pandemic. During this transformational time, Dr. Bill Cardoso looks back a century for a bit of inspiration from Norwegian explorer Roald Amundsen.

3 Powerful Prototypes: A Trip Back to the Basics ▶


Duane Benson

Duane Benson recently designed a motion-sensitive lapel pin for the 2020 Open Source Hardware Summit, which was canceled due to the COVID-19 outbreak. Here, he shares lessons to learn and reviews more fundamentals from this project.

4 SMT Prospects & Perspectives: Rethinking Manufacturing—Bracing for and Embracing a Post-Pandemic Decade ▶

Dr. Jennie Hwang

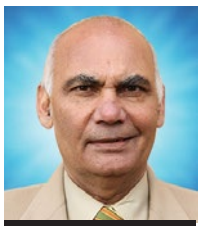
Against the potent backdrop of current events, how should our industry respond? How should we manage and rethink manufacturing? And what are the main issues at hand in near-term and long-term horizons? Dr. Jennie Hwang explores these questions, as well as three tangible areas of business and manufacturing.

5 Operational Excellence: Working Remotely—Redesign Your Information Systems ▶

Alfred Macha

Due to the COVID-19 pandemic, manufacturing organizations have been forced to quickly adapt to provide remote work options for manufacturing support employees. Alfred Macha shares a model to help your organization keep remote work employees fully engaged in supporting manufacturing operations.

6 SMT Solver: Industrial Revolution 4.0—Hype, Hope, or Reality? ▶


Ray Prasad

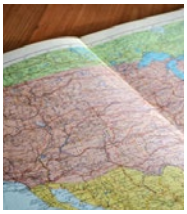
If you are in the electronics industry, you cannot help but notice the discussion about Factory 4.0. Ray Prasad discusses Factory 4.0 as he understands it and invites readers' comments on his interpretation.

7 Smart Factory Insights: Trust in Time ▶

Michael Ford

We've all heard of "just in time" as applied to the supply chain, but with ongoing disruption due to COVID-19, increasing risk motivates us to return to the bad habit of hoarding excess inventory. Michael Ford introduces the concept of "trust in time"—a concept that any operation, regardless of size or location, can utilize today.

8 Benchmark Delivering on $51M Order for Advanced Surveillance Technology to U.S. Border Patrol ▶



Benchmark Electronics Inc.—a global provider of engineering, design, and manufacturing services—announced the completion of phase two of five phases toward the delivery of mobile video surveillance systems (MVSS) to the Department of Homeland Security for use along the U.S. southern border.

9 RiverSide Incorporates Three Companies as RiverSide Integrated Solutions Inc. ▶

RiverSide Electronics Ltd., RiverStar Inc., and RiverBend Electronics Ltd. announced that the three companies are now operating under a single name and brand, RiverSide Integrated Solutions Inc.

10 The Government Circuit: Environmental, Health, and Safety Issues Are Hot in U.S., EU, and Asia ▶

Chris Mitchell

Although coronavirus, trade wars, and supply chain concerns have dominated the discussion in our industry in recent months, many important environmental, health, and safety (EHS) issues are on the agenda as well. Chris Mitchell provides an overview of the EHS policy landscape and what IPC is doing to advocate for the electronics manufacturing industry.

For the latest news and information, visit SMT007.com. Subscribe to our newsletters or premium content at my I-Connect007.

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Waterbury, CT, USA

Research, develop, and formulate new surface treatment products for the printed circuit board, molded interconnect, IC substrate, and LED manufacturing industries. Identify, develop, and execute strategic research project activities as delegated to them by the senior research projects manager. Observe, analyze, and interpret the results from these activities and make recommendations for the direction and preferred route forward for research projects.

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West Haven, CT, USA

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MacDermid Alpha
ELECTRONICS SOLUTIONS

We're Hiring!
Illinois / New Jersey

Technical Service Rep:
Chicago, IL, USA

The technical service rep will be responsible for day-to-day engineering support for fabricators using our chemical products. The successful candidate will help our customer base take full advantage of the benefits that are available through the proper application of our chemistries.

Applications Engineer:
South Plainfield, NJ, USA

As a key member of the Flexible, Formable, and Printed Electronics (FFPE) Team, the applications engineer will be responsible for developing applications know-how for product evaluation, material testing and characterization, and prototyping. In addition, this applications engineer will provide applications and technical support to global customers for the FFPE Segment.

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Career Opportunities

Manncorp™

SMT Operator
Hatboro, PA

Manncorp, a leader in the electronics assembly industry, is looking for a **surface-mount technology (SMT) operator** to join their growing team in Hatboro, PA!

The **SMT operator** will be part of a collaborative team and operate the latest Manncorp equipment in our brand-new demonstration center.

Duties and Responsibilities:
- Set up and operate automated SMT assembly equipment
- Prepare component kits for manufacturing
- Perform visual inspection of SMT assembly
- Participate in directing the expansion and further development of our SMT capabilities
- Some mechanical assembly of lighting fixtures
- Assist Manncorp sales with customer demos

Requirements and Qualifications:
- Prior experience with SMT equipment or equivalent technical degree preferred; will consider recent graduates or those new to the industry
- Windows computer knowledge required
- Strong mechanical and electrical trouble-shooting skills
- Experience programming machinery or demonstrated willingness to learn
- Positive self-starter attitude with a good work ethic
- Ability to work with minimal supervision
- Ability to lift up to 50 lbs. repetitively

We Offer:
- Competitive pay
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- Retirement fund matching
- Continued training as the industry develops

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Near Chicago, USA

We have a great opportunity at Ventec's Elk Grove Village facility to join our customer services team as a customer service representative (CSR) to act as a customer liaison, manage incoming orders, order entry into ERP system, provide product/services information, and resolve any emerging problems that our customer accounts might face with accuracy and efficiency. As a CSR, you will provide a two-way channel of technical communication between Ventec's global manufacturing facilities and North American customers to ensure excellent service standards, efficient customer inquiry response, and consistent highest customer satisfaction.

Skills and abilities required for the role:
- Proven B2B customer support experience or experience as a client service representative
- Strong skill set in Excel, Word, and Outlook for effective communication
- Strong phone contact handling skills and active listening
- Customer orientation and ability to adapt/respond to different types of characters
- Excellent communication and presentation skills
- Ability to multi-task, prioritize, and manage time effectively
- High-school degree

What's on Offer:
- Excellent salary & benefits commensurate with experience

This is a fantastic opportunity to become part of a successful brand and leading team with excellent benefits.

Please forward your resume to jpattie@ventec-usa.com and mention **"Customer Service Representative—Chicago"** in the subject line.

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MivaTek Global

MivaTek Global: We Are Growing!

MivaTek Global is adding sales, technical support and application engineers.

Join a team that brings new imaging technologies to circuit fabrication and microelectronics. Applicants should have direct experience in direct imaging applications, complex machine repair and/or customer support for the printed circuit board or microelectronic markets.

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Contact **HR@MivaTek.Global** for additional information.

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BÜRKLE NORTH AMERICA, INC.

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Qualifications

Required: Bachelor's degree from a technical college/university in an associated field. Three years directly related experience, or equivalent combination of education and experience. Must possess a valid driver's license and have a clean driving record.

Preferred: Experience in control systems and electronic troubleshooting, as well as in general electrical and mechanical service tasks. Experience and knowledge in the PCB manufacturing process, with a focus on laser drilling and/or direct imaging.

Send resume to hr@burkleamerica.com.

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Career Opportunities

LENTHOR ENGINEERING
MAKING THINGS FLEXIBLE IN A RIGID WORLD®

Sales Account Manager

Sales Account Management at Lenthor Engineering is a direct sales position responsible for creating and growing a base of customers that purchase flexible and rigid flexible printed circuits. The account manager is in charge of finding customers, qualifying the customer to Lenthor Engineering and promoting Lenthor Engineering's capabilities to the customer. Leads are sometimes referred to the account manager from marketing resources including trade shows, advertising, industry referrals and website hits. Experience with military printed circuit boards (PCBs) is a definite plus.

Responsibilities

- Marketing research to identify target customers
- Identifying the person(s) responsible for purchasing flexible circuits
- Exploring the customer's needs that fit our capabilities in terms of:
  - Market and product
  - Circuit types used
  - Competitive influences
  - Philosophies and finance
  - Quoting and closing orders
  - Providing ongoing service to the customer
  - Develop long-term customer strategies to increase business

Qualifications

- 5-10 years of proven work experience
- Excellent technical skills

Salary negotiable and dependent on experience. Full range of benefits.

Lenthor Engineering, Inc. is a leader in flex and rigid-flex PWB design, fabrication and assembly with over 30 years of experience meeting and exceeding our customers' expectations.

Contact Oscar Akbar at: hr@lenthor.com

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LENTHOR ENGINEERING
MAKING THINGS FLEXIBLE IN A RIGID WORLD®

Senior Process Engineer

Job Description

Responsible for developing and optimizing Lenthor's manufacturing processes from start up to implementation, reducing cost, improving sustainability and continuous improvement.

Position Duties

- Senior process engineer's role is to monitor process performance through tracking and enhance through continuous improvement initiatives. Process engineer implements continuous improvement programs to drive up yields.
- Participate in the evaluation of processes, new equipment, facility improvements and procedures.
- Improve process capability, yields, costs and production volume while maintaining safety and improving quality standards.
- Work with customers in developing cost-effective production processes.
- Engage suppliers in quality improvements and process control issues as required.
- Generate process control plan for manufacturing processes, and identify opportunities for capability or process improvement.
- Participate in FMEA activities as required.
- Create detailed plans for IQ, OQ, PQ and maintain validated status as required.
- Participate in existing change control mechanisms such as ECOs and PCRs.
- Perform defect reduction analysis and activities.

Qualifications

- BS degree in engineering
- 5-10 years of proven work experience
- Excellent technical skills

Salary negotiable and dependent on experience. Full range of benefits.

Lenthor Engineering, Inc. is the leader in Flex and Rigid-Flex PWB design, fabrication and assembly with over 30 years of experience meeting and exceeding our customers' expectations.

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Qualifications and skills

- A love of teaching and enthusiasm to help others learn
- Background in electronics manufacturing
- Soldering and/or electronics/cable assembly experience
- IPC certification a plus, but will certify the right candidate

Benefits

- Ability to operate from home. No required in-office schedule
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APCT currently has opportunities in Santa Clara, CA; Orange County, CA; Anaheim, CA; Wallingford, CT; and Austin, TX. Positions available range from manufacturing to quality control, sales, and finance.

We invite you to read about APCT at APCT.com and encourage you to understand our core values of passion, commitment, and trust. If you can embrace these principles and what they entail, then you may be a great match to join our team! Peruse the opportunities by clicking the link below.

Thank you, and we look forward to hearing from you soon.

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Career Opportunities

Manncorp™

SMT Field Technician
Hatboro, PA

Manncorp, a leader in the electronics assembly industry, is looking for an additional SMT Field Technician to join our existing East Coast team and install and support our wide array of SMT equipment.

Duties and Responsibilities:
- Manage on-site equipment installation and customer training
- Provide post-installation service and support, including troubleshooting and diagnosing technical problems by phone, email, or on-site visit
- Assist with demonstrations of equipment to potential customers
- Build and maintain positive relationships with customers
- Participate in the ongoing development and improvement of both our machines and the customer experience we offer

Requirements and Qualifications:
- Prior experience with SMT equipment, or equivalent technical degree
- Proven strong mechanical and electrical troubleshooting skills
- Proficiency in reading and verifying electrical, pneumatic, and mechanical schematics/drawings
- Travel and overnight stays
- Ability to arrange and schedule service trips

We Offer:
- Competitive Pay
- Health and dental insurance
- Retirement fund matching
- Continuing training as the industry develops

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- Washington
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- Candidates must have previous PCB sales experience.

Compensation:
- 7% commission

Contact Mike Fariba for more information.

mfariba@uscircuit.com

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Field Application Engineer (FAE)
Has worked as a respected FAE in the U.S. for global companies. Specializes in working alongside sales teams. Large experience base within the interconnect industry. He is looking for a full-time position.

Business Development Manager
Understands all aspects of interconnect technical sales from PCB design and fabrication to assembly and all technologies from HDI microvias to flex and rigid-flex. Has also sold high-tech laminates and equipment. Proven record of sales success. He is looking for a full-time position.

CEO/President
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PCB General Manager
Forty years of experience serving in all capacities, from GM to engineering manager to quality manager. Worked with both domestic and global companies. Available for turn-around or special engineering projects. He is looking for long-term project work.

Process Engineering Specialist
Strong history of new product introduction (NPI) manufacturing engineering experience: PCB/PCBA. Held numerous senior engineering management positions. Leads the industry in DFM/DFA and DFX (test) disciplines. He is looking for either a full-time position or project work.

VP Sales Global Printed Circuits
Worked with a very large, global company for a number of years. Built and managed international sales teams. Created sales strategies and communicated them to the team. One of the best sales leaders in our industry. He is looking for a full-time position.

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This professional has years of experience running PCBA companies. Led his companies with creative and innovative leaderships skills. Is a collaborative, hands-on leader. He is looking for a full-time position.

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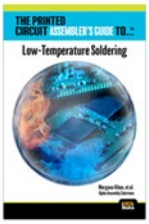
The Printed Circuit Assembler's Guide to...

Process Validation, by Graham K. Naisbitt, Chairman and CEO, Gen3
This book explores how establishing acceptable electrochemical reliability can be achieved by using both CAF and SIR testing. This is a must-read for those in the industry who are concerned about ECM and want to adopt a better and more rigorous approach to ensuring electrochemical reliability.

Advanced Manufacturing in the Digital Age, by Oren Manor, Director of Business Development, Valor Division for Mentor a Siemens Business
A must-read for anyone looking for a holistic, systematic approach to leverage new and emerging technologies. The benefits are clear: fewer machine failures, reduced scrap and downtime issues, and improved throughput and productivity.



Low-Temperature Soldering, by Morgana Ribas, Ph.D., et al., Alpha Assembly Solutions
Learn the benefits low-temperature alloys have to offer, such as reducing costs, creating more reliable solder joints, and overcoming design limitations with traditional alloys.

Conformal Coatings for Harsh Environments, by Phil Kinner, Electrolube
This handy eBook is a must-read for anyone in the electronics industry who wants a better understanding of conformal coatings. Kinner simplifies the many available material types and application methods and explains the advantages and disadvantages of each.

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