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Finding Ultra

New demands on PCB fabrication, namely advanced packaging, ultra high density interconnect (UHDI), and new specialty materials, are converging, changing the landscape of our business; so is the CHIPS Act. Is it time to start paying close attention to this convergence?

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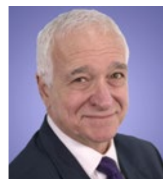

ARTICLE

DEPARTMENTS

Convergence

Nolan's Notes

by Nolan Johnson, I-CONNECT007

When I stop to consider the dynamics in our industry at this moment, I keep coming back to the idea of "convergence." Aspects of our industry historically thought of as distinct and separate are blurring the lines and overlapping.

As I look back on our coverage in the past five years, I see convergence taking place, moving like a glacier—slow and steady but with formidable force. In this issue of *PCB007 Magazine,* the three areas of convergence we consider are materials, advanced packaging, and UHDI.

First, a look at materials. At the outset, materials seem to be fracturing every which way. Virtually all manufacturers of materials have added to their lineup. There are special products optimizing high-speed, low-loss, temperature extremes, and the list goes on. Performance specification, pricing, and availability are all factors in selection, making the market seem fractured. But just as Newtonian physics works at the on-planet level of the universe (but not so well in the cosmic scope), all those specialized materials lead to the ability to make the right product for the right environment. Advanced packaging will change the landscape of assembly and soldering. In the end, the choices allow us to be better at what we do.

Now, what about advanced packaging? That's a semiconductor concern, isn't it? Yes, sort of. The convergence is with PCB-like substrates and interposers. Currently, almost all the advanced packaging fabrication capabilities are in Asia, so building out a globally resilient supply chain will require sufficient fab capability in Europe and the Americas.

Who will make the investment? Some folks think that whatever goes inside the package

is the semiconductor fab's responsibility. But there are some on the semiconductor side who see these intra-package connectors as more PCB than IC, with the commensurate opinion that PCB fabs are better suited to manufacture them. There's some truth to that opinion, but it overlooks a few uncomfortable facts, like the feature sizes that interposers and substrates require. After all, we're talking about fabricating PCBs at semiconductor IC pad size dimensions or thereabouts. Can your fab do that today? Over in IC land, they see the dimensions needed for substrates as 20 years behind what they're capable of in their fabs; retro-tooling new facilities will be necessary to support the advanced packaging capabilities.

All this leaves the interposers and substrates in a bit of a lurch. Everybody will need them, yet they're all hesitant to invest. Some companies are dipping their toe in the proverbial water. Skywater, for example, is building out the capability, as are a few boutique shops who see a market opportunity. This kind of manufacturing will require cleanrooms and reliable processes for fabricating at feature sizes moving toward the single-digits in microns for trace and space—with via sizes to match, of course.

By now, I'm sure you can start to see how ultra high density interconnect (UHDI) converges with the other two trends. To reach the dimensions we're heading toward, we reach a threshold of capability with the number of steps in fabrication: subtractive processes, copper smoothness, copper-to-substrate adhesion, management of CTE (coefficient of thermal expansion), and more. Of course, UHDI has found its early foothold in high-end, high-volume, cost-sensitive consumer products like cellphones, but it will be required for lower-volume, high-complexity work as we move forward. We can expect increased demand for this kind of ultra-small work from OEMs and designers—especially as the semiconductor companies force the issue with even smaller pad tolerances and larger package sizes to accommodate all the I/Os for these very complex chips.

Which brings me full circle to materials: The specialization and the larger inventory of products with specific characteristics is necessary to support this convergence. On the "innovation" side of the technology adoption bell curve, there is so much more convergence underway; this will only move steadily down the bell curve into mainstream adoption. This is why we're covering these three topics all at once.

In this issue, we talk about materials with Darren Hitchcock, and UHDI fundamentals with Happy Holden and Anaya Vardya. PCB Technologies' Oved Shapira launches the convergence conversation in his interview. Brent Fischthal of Koh Young discusses how inspection is tackling the additional challenges further down the chain in assembly. Finally, we bring you a video presentation by IPC's Matt Kelly to the U.S. Commerce Department, on behalf of the industry, regarding key parts of this convergence and how it should fit into the decision-making process for CHIPS Act funding. This presentation is not only educational but provides an eyewitness view of how industry organizations such as IPC, PCBAA, and USPAE are raising government awareness.

Another trend on the rise in the U.S. is captive facilities. This month, our special coverage of Schweitzer Engineering Laboratories (SEL) includes six equipment suppliers who participated in SEL's $100 million captive facility build-out. Whether you're upgrading a department or building out a new facility yourself, these conversations provide insight into the process of standing up your facility too. **PCB007**

Nolan Johnson is managing editor of *SMT007 Magazine* and co-managing editor of *PCB007 Magazine*. Nolan brings 30 years of career experience focused almost entirely on electronics design and manufacturing. To read other columns or to contact Johnson, click here.

The Drive Toward UHDI and Substrates

Feature Interview by the I-Connect007 Editorial Team

Panasonic's Darren Hitchcock spoke with the I-Connect007 Editorial Team on the complexities of moving toward ultra HDI manufacturing. As we learn in this conversation, the number of shifting constraints relative to traditional PCB fabrication is quite large and can sometimes conflict with each other.

Barry Matties: Darren, I recently watched your presentation[1] about the demands on material—resin, weave, surface, etc.—to meet the demands of higher density, finer features. What was your message to your audience regarding the state of the industry for materials in HDI and UHDI?

In that presentation, I covered some of the changes like glass style and the composition of the glass. For the longest time, we've had E-glass, which is, of course, the cost-effective option. But as electrical performance requirements have increased, we've seen more demand for low-Dk and ultra-low Dk glass. The increased trends toward these glass types mean improving availability and cost; as the electrical performance benefits are also decision factors.

I also drilled down on copper. The demand for smoother copper is increasing, which affects the industry standards. I'm involved in the IPC committee for copper and the committee for glass reinforcement. I chair the


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IPC committee responsible for IPC-4101 industry standard for PCB laminate and prepreg. I'm engaged in the industry consortia with OEMs, fabricators, and raw material suppliers.

Darren Hitchcock

Nolan Johnson: What's really happening in the industry around those groups?

In my SMTA presentation, I talked about the North American market, how the book-to-bill has been doing lately, and then I shifted quickly into talking about density.

At a high level, packaging density drives both PCB density and substrate density. As your packages get more stuff packed in—10 pounds of stuff in a five-pound bag, for example—everything gets smaller and more compact, and there's more I/O. That drives the packaging technology, which in turn, drives the PCB technology.

Johnson: Which then drives the materials?

Yes. From a materials perspective, they're getting thinner. The electrical drivers are making for a lower dielectric constant, but that's not the primary driver. The primary driver is the desire to get lower dissipation factor, or loss tangent. The next driver is to get the copper smoother.

The copper challenge is adhesion; as your resin systems become lower and lower loss, it's difficult to get them to stick to anything. At the same time, copper is getting smoother, which makes it harder to adhere to resin systems. Those are some of the emerging challenges for both copper and the resin system. As you continue to add filler, you have increasingly lower percentages of the resin in that system, which challenges adhesion. Glass transition temperatures in newer materials are getting higher, which makes them more brittle. The fillers make them brittle, too.

At the same time, the packaging is adding I/O, and the sizes of the packages are getting larger, especially in infrastructure, but also in the mobile space. The XY dimensions are growing to accommodate the I/O, plus the pad sizes are getting smaller. This means the surface area with the volume of your solder—the surface area to your BGA pads, both on the package side and on the PCB side—are getting smaller. Meanwhile the adhesion is getting more challenging and the materials more rigid. Suddenly, CTE mismatch becomes a much bigger challenge.

Johnson: And you might be talking about ball grid arrays for most of the packages that have thousands of potential solder failures per package.

Yes, the array packages and their increasing density is a challenge on materials. There are some creative things to be done on the material side to either absorb the strain between the package and the PCB, or to make them more robust to the stresses that they encounter.

Happy Holden: Electric vehicles are challenging. They're using the latest chip technology, but they want subassemblies which are low-cost but high reliability for a longer life. There are the mobile phone requirements for small form factors and power efficiency; that's a real dilemma.

That's where substrate-like or near-substrate technology comes into play. It's the space between a substrate or packaging side vs. the traditional PCB side. The line is blurring, and within that blurring is the desire for the density of a substrate but at the cost of a PCB.

Johnson: How big is that gap?

At one time, there was a gap, but now it's almost a continuum. Some traditional PCB fabricators have factories producing substrates. For those fabricators, there's a continuum; once you get to a certain density, it moves to

the substrate factory, and that line is ever changing. As substrate technology advances so does the PCB factory technology.

Johnson: Would you provide some background on fillers and the challenges those materials present on the PCB side?

The main filler in the market continues to be silica. There are also fillers related to the flame retardants, but we're moving away from brominated flame retardants. To have a fire you need a fuel source and oxygen. The brominated ones remove the oxygen, and they're quite effective at it. The halogen-free flame retardants are trying to cover up the fuel, creating a charred layer. That layer covers up the fuel so the fire will go out.

In addition to silica and halogen-free flame retardants, other fillers balance electrical, mechanical, and thermal performance. But we still need to drill it without burning through drill bits because of the fillers. A lot of things that go into these material systems are more filler.

> "There is a blurring between the materials traditionally used on substrates, and those used on PCBs."

Johnson: That affects the manufacturability?

Yes, definitely. It's the ability of the resin to fill in-between the voids, for example. As BGA packages get larger, that is a void in your plane. If you have a package that is, say, 100 millimeters square, you have less than 50% copper in that large area, which affects the planes.

Let's narrow down the focus to an infrastructure board; I call them the big, thick, and ugly boards. These are the 20-, 30-, 40-, 50-layer boards, a lot of plated through-hole vias with increasingly more HDI in the stack-up. These boards are using the very low-loss resins that are heavily filled, making it harder to fill up the space left by anti-pads, gaps in your planes, and areas of the power layer which should be free of copper. It becomes harder to fill and remain thin.

All these "planets" are lining up and they're pulling at each other. It's easy to fill, just make it thicker. But if your board is already 5 millimeters thick, how much thicker can you get and still plate your vias reliably?

Johnson: What's your take on the blurring line between boards and substrates?

There is a blurring between the materials traditionally used on substrates, and those used on PCBs. In some design cases, we may be looking at a substrate material even being used in a PCB factory, or as a PCB material. In general, those designs don't get pushed to the substrate factories because of the differences in requirements.

On the substrate side, they require the highest quality, meaning low defect rate, and very thin materials. Whereas the PCB side generally has cost pressures that are higher than the substrate side. That creates an opportunity for a big trade-off. Usually, the trade-off means different choices during development of a substrate material than for a PCB material.

Holden: Does this come down to the type of OEM, a general one like aerospace or military wanting traditional boards, or is this a semiconductor OEM? They each adhere to different standards.

If one PCB factory can figure out how to use the material, another one can. But the bigger difference comes in the substrate sites. The capital costs are very different, for one thing. With some of these technologies, like modified semi-additive plating (mSAP) or some of these high-end cleanrooms, extremely thin prepregs and laminates in the computerized systems are required to handle those materials; the cost to enter that technology is prohibitive for some, but not for others.

Let's look at glass fabric. In the 1990s, we had generally four glass styles: 7628, 2116, 1080 and 106. Everything you produced could use one of those four glass styles. Now, there are many more glass styles in regular use, plus thinner mobile boards. You have 1037, 1027, 1017, and the next wave may end up being 1010 or something even finer than that.

"The challenge is to be able to direct metallize a dielectric without the copper falling off."

Consider that the weavers now must handle a finer filament. You can't weave as fast, and those finer glass styles also have more weave per inch. You're tying up that equipment for a longer amount of time to get the same square meters of material. Therefore, it will cost more from a capital utilization. There are many things that will challenge the cost. The material suppliers have to balance those challenges.

Johnson: Is the demand for UHDI-type manufacturing load increased?

Demand is definitely increasing.

Holden: What is Panasonic working on with respect to a non-clad, additive build-up film (ABF)?

The challenge is to be able to direct metallize a dielectric without the copper falling off. The other challenge that the whole industry runs into is there are many different resin systems out there. Naturally, each supplier is trying to protect their intellectual property. There are tons of patents, so it becomes increasingly difficult to navigate through the patent landscape.

This is because in the PCB space, they're still modified with some additive plating or traditional buildup type, some manufacturing of circuitry. So, will it eventually go toward fully additive? As they get smaller, I'm not sure. It gets harder to find the ability to use a thin starter foil, because right now on mSAP it's usually somewhere between 1- and 3-micron foil.

If you think about PCB etching, typically it's a one-to-one aspect ratio. If you are going through 18-micron (half-ounce) copper, it's hard to get smaller than an 18-micron line. So, if you translate that into ultra HDI where you're looking at, let's say, a 5-micron line, 3 microns of copper foil begs the question: What's left over to plate your via? Even the ability to have a foil there is increasingly challenging.

Johnson: Must you be a greenfield facility to do this sort of work, or can you grow into it?

In Asia, the facilities that introduced mSAP technology were doing other technology at the time that it was introduced, so they showed that it doesn't have to be a greenfield facility. But if you look at the volume of handheld-type devices in the world today, that has spawned a significant number of mSAP lines. To enter that space takes a huge capital expenditure, not only in your cleanrooms and conveyorized equipment, but in plating technology. Greenfield might be the easiest way to do it, but that doesn't mean an existing facility can't do it.

Matties: Is the market space one that if you build it, they will come, or do you go out, develop customers, and then invest?

It might be good to have a customer in mind beforehand because it's a huge investment. Just because someone has that equipment doesn't mean a customer isn't willing to try. Now, if you have an OEM that needs that technology, are they willing to take a chance on somebody new, or do they just want to invest in somebody who already knows their products?

I would be cautious about the "build it and they will come" idea, but that doesn't mean you can't enter that space. There's certainly plenty of volume needed there.

Johnson: Which market sectors are most driving this move toward UHDI?

I would say mobile, and Internet of Things—anything that's handheld, such as watches, phones, and tablets. All those are tending to drive harder on the ultra HDI space. There are newer markets that have been developing. It's anything that is small, even your earbuds for sound. Medical keeps getting smaller probes, wearables—those are all driving the ultra HDI.

"Medical keeps getting smaller probes, wearables—those are all driving the ultra HDI."

Johnson: With ultra HDI, the concerns are becoming more complex, therefore, materials must become even more specialized, and even discussing the need for the glass, the materials are more expensive, yet they're going into products that are so very price sensitive.

Right, and even lower Dk- or Df-type resin systems are going into even more things that were traditionally considered consumer-type products; 5G, 6G, etc., are demanding a better performing material both from the copper and from the dielectric perspective, electrically. What we normally wouldn't have considered in that space is getting pressured to be in that space.

That goes back to some of the earlier comments on the properties of the material being driven and that becomes a bigger problem, because if you had a 0.25-millimeter pitch package vs. a 1-millimeter package, your CTE mismatch or your adhesion challenges are different. So, on an infrastructure basis, you don't expect someone to push your service stack over on the floor and have it dropped, but on a phone, watch, or any number of these headsets, people will drop them, so you need to be robust against the user.

Matties: Darren, what final advice can you share with the industry around this topic or otherwise?

Work with your suppliers. Consider the materials and the properties. It's a difficult balance. Don't be afraid to ask questions. Regardless of the supplier's name, in general, they have resources to help and give you insights. You don't always need to learn every lesson on your own the first time. If you rely on your suppliers for information, it can help you avoid some of the pitfalls that come with new technologies.

Johnson: Sounds to me like talking to your suppliers means not just talking to your fabricator but going further upstream to the other key materials as well.

Correct. Some OEMs are working all the way up into the copper and glass suppliers. Generally, your raw material suppliers have a pretty good grasp on that.

You need to understand the assembly perspective, have a raw material understanding, and know your fabricators and substrate suppliers. They are capable of certain things and have a capability that will give you good yields. They have advanced capabilities for people who are willing to give up a little bit on yield to try and advance those technologies.

Matties: Darren, thank you so much for your insights.

Always great talking with you. **PCB007**

Reference

1. 'Advanced Technologies for Printed Circuit Board Fabrication and Raw Materials', SMTA Oregon Expo 2023 Keynote presentation.

What is Ultra HDI?

Feature Article by Happy Holden
I-CONNECT007

Ever since high density interconnect (HDI) was created in 1982 by Hewlett-Packard to package its first 32-bit computer powered by a single chip, it has continued to evolve and provide the solutions for miniaturized products. The leading edge of HDI technology became the process used for organic flip-chip packaging for the semiconductor industry. The two distinct markets—IC substrates and product-system integration—are now colliding and utilizing the same ultra-HDI manufacturing processes (Figure 1).

Introduction

These two markets have different characteristics as well as specifications. The middle ground is currently occupied by the very high-density PCBs called substrate-like PCBs (SLPs).

The differences lie in that IC packaging is for components of unspecified final application while an HDI PCB is the result of a system-integrated product. But time and evolution have introduced a semiconductor component system integration strategy which the IEEE now calls heterogeneous integration (Figure 2). To meet this construction, a new player called the interposer was created in the substrate arena.

SLP vs. Interposer

This collision of two different products is where UHDI characteristics and specifications

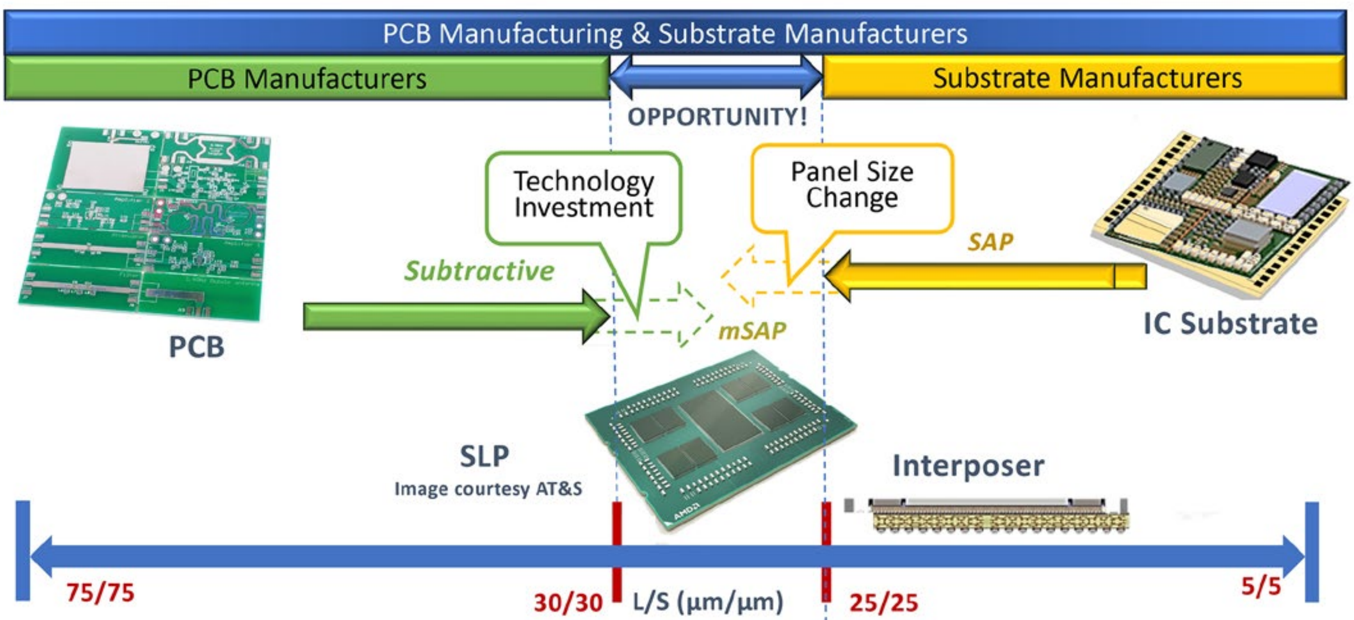

Figure 1: Conventional PCB manufacturing is now entering the domain of advanced IC substrate manufacturing characterized by geometries of equal to or greater than 30 µm. (Source: Inspired by IEEE HI-Roadmap[1])

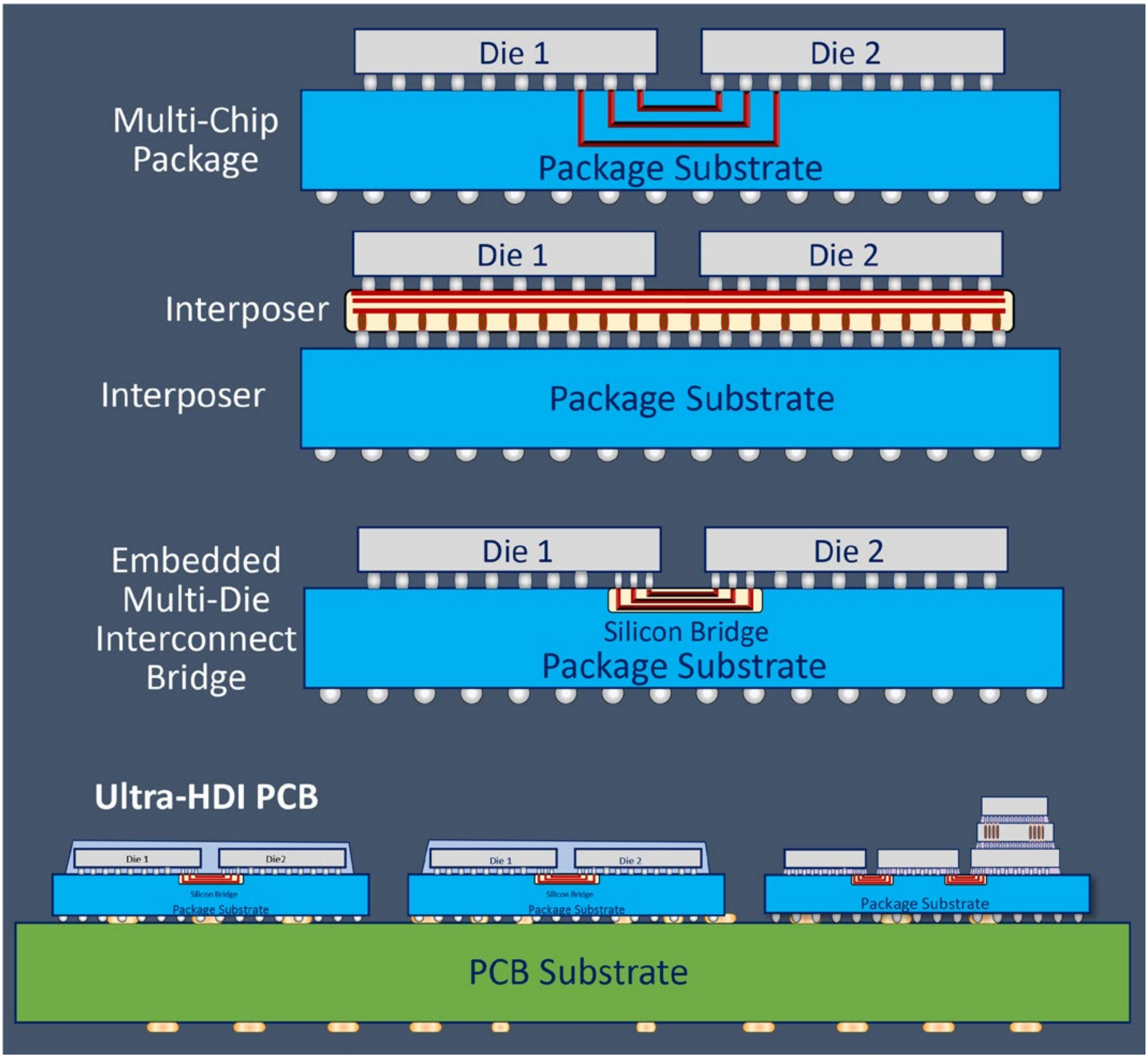

Figure 2: Multichip and heterogeneous integration have created a number of different packaging substrates as well as the interposer. Advanced PCBs seeking to use fine-pitch components and advanced packaging need to utilize ultra-HDI geometries[2].

will occur. IPC's 33-AP Ultra HDI Subcommittee is currently working on UHDI standards from a system integration PCB product point of view, while SEMI and the IEEE are focused on the interposer as a high-volume element of heterogeneous integration packaging components, using substrate materials such as silicon, glass, and liquid dielectrics. The SLP and organic interposer will continue to use high-speed, low-loss PCB laminates, prepregs, or films.

IC packaging already has a number of different packaging technologies. The introduction of silicon bridges and chiplets further differentiates them from PCB SLPs. But the Semiconductor Industry Association (SIA) Roadmap predicts a continuing reduction of packaging component pitch down to 0.10 mm pitch by

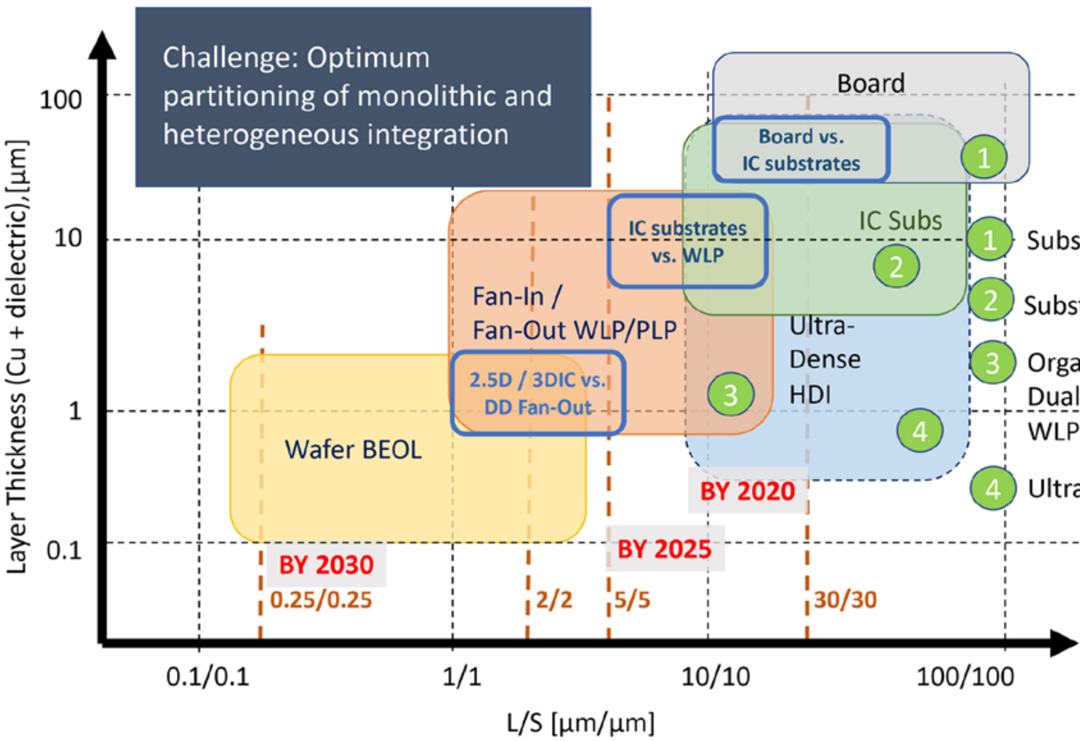

Figure 3: The tradeoffs between dielectric thicknesses and trace/space (t/s) geometries for heterogeneous integration are overlapping technologies of PCBs, IC substrates, UHDI, WLP/PLP, and wafer interposers-BEOL[3].

2030 using 0.25/0.25 µm t/s. Figure 3 demonstrates where the geometries of the two markets are superimposed as:

- Substrate vs. board
- Substrate vs. wafer level packaging (WLP)
- Organic WLP and dual Damascene WLP vs. 2.5D IC packaging
- Ultra-HDI vs. wafer-level back-end-of-line (BEOL) WLP

Conclusion

My prediction for UHDI is seen in Figure 3. Conventional HDI are originally focused on the introduction of small-blind vias of < 150 µm (6 mil), and geometries in the 75 µm/75 µm (3 mil/3 mil) trace/space. Ultra-HDI will have even smaller microvias and t/s from 50 µm/50 µm, (2/2 mil) down to ~5 µm/5 µm (0.2/0.2 mil)[4]. **PCB007**

References

1. Inspired by IEEE Heterogeneous Integration Roadmap, Chapter 2, pp 10.
2. Happy's Tech Talk #5: Advanced Boards for Heterogeneous Integration, *PCB007 Magazine,* February 2022.
3. Happy's Tech Talk #4: Semi-additive Processes and Heterogeneous Integration, *PCB007 Magazine,* January 2022.

For more perspective on how UHDI is different, read "A Primer on UDHI," by Anaya Vardya, *Design007 Magazine,* September 2023, as well as discussion on IC packaging and the CHIPS Act (*SMT007 Magazine,* September 2023, and *PCB007 Magazine,* January 2023).

Happy Holden has worked in printed circuit technology since 1970 with Hewlett-Packard, NanYa Westwood, Merix, Foxconn, and Gentex. He is currently a contributing technical editor with I-Connect007, and author of Automation and Advanced Procedures in PCB Fabrication, and 24 Essential Skills for Engineers. To contact Holden or read past columns, click here.

Advanced Packaging Capability Gap

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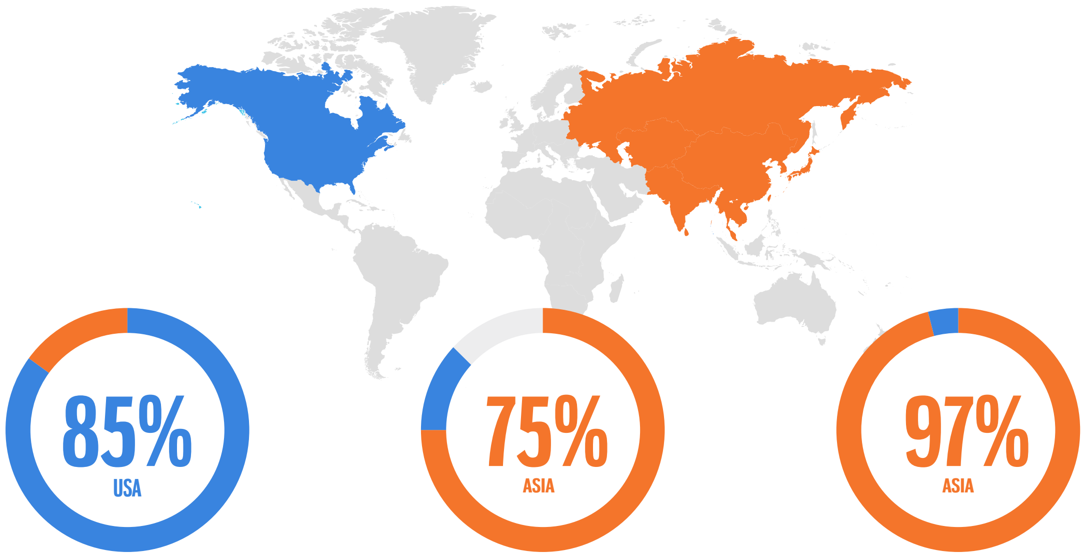

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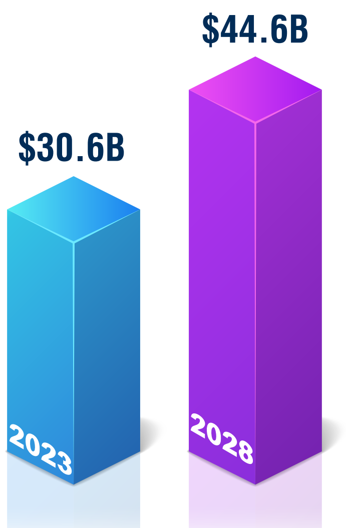
Source: DoD Presentation

ADVANCED PACKAGING MARKET SIZE



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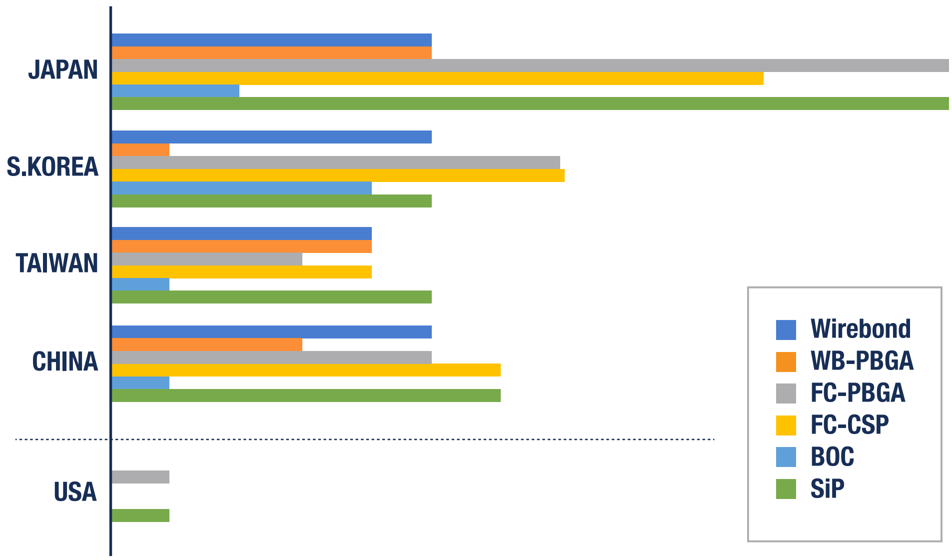


IC SUBSTRATE CAPABILITY COUNTS BY REGION

Source: IPC

Cutting-edge Inspection Challenges

A Feature Q&A With Brent Fischthal

KOH YOUNG

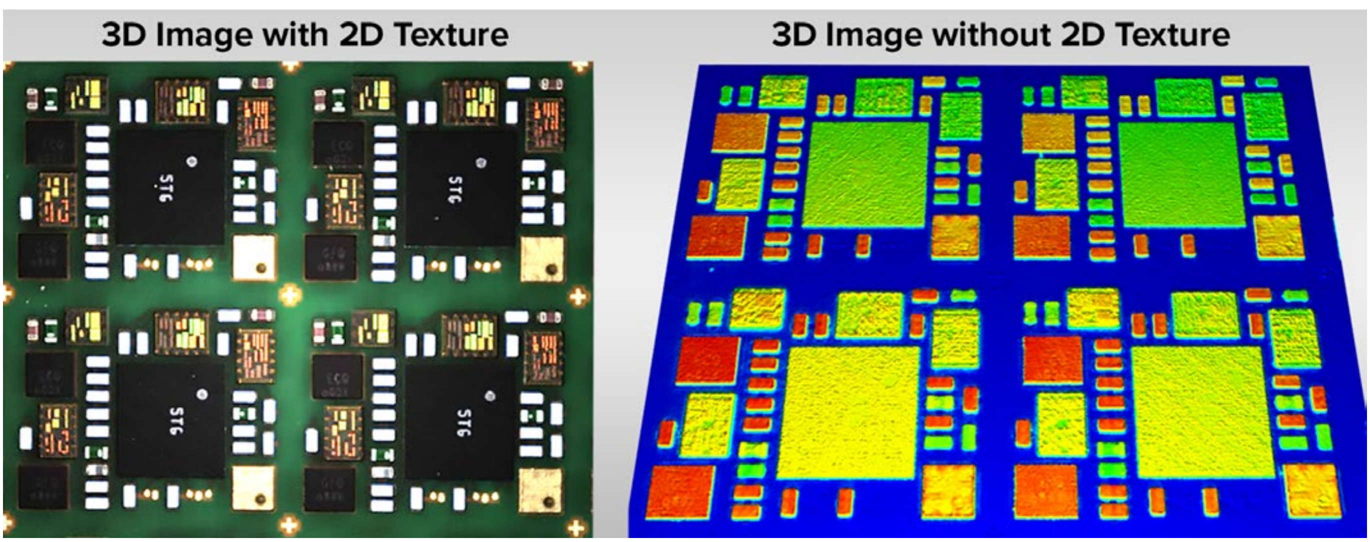
Koh Young's Brent Fischthal explains how UHDI and advanced packaging are challenging inspection systems.

Advanced packaging seems to be accelerating the trend toward larger component packages. What are the new demands/challenges these packages put on inspection?

The shift toward larger components and advanced packaging brings a host of challenges that impact the industry. These challenges include complexity, density, package diversity, and inspection methodologies, all of which necessitate a more innovative approach.

First, the increased complexity associated with advanced packaging techniques introduces more intricate board designs with multiple chip types and miniaturized components. Furthermore, the drive toward higher density and smaller pitch, facilitated by advanced packaging solutions such as 2.5D and 3D packaging, places significant demands on inspection machines. For instance, inspection systems must reliably address challenges like 10 mm thin solder deposits, 50 mm component spacing, and highly-reflective components within densely populated areas, even where access might be limited.

Moreover, the proliferation of diverse advanced packaging methods, including fan-out wafer-level packaging (FOWLP), system-in-package (SiP), and chiplets, requires inspection machines to accommodate a wider variety of package types and configurations. In addition, the variation in component heights, a common characteristic in advanced packaging due to designs like stacked die and heterogeneous packaging, requires the inspection system to overcome the shadowing created by these height differences in order to make consistent and reliable measurements.



4-way moire.

Besides larger component packages, OEMs and applications such as automotive, are demanding much larger volumes of finished boards, with much higher yields and increased reliability. How does this change the role of inspection equipment? Surely just making the machinery faster isn't the entire solution.

In the context of escalating production volumes, higher yields, and stringent reliability requirements, the inspection machine's role is indeed more than just speed enhancement; it becomes a multi-faceted, integral part of the manufacturing process. Larger and more complex packages, coupled with larger and more complex inspection data sets, make efficient data handling, storage, and analysis imperative. This enables the identification of trends, root causes of defects, and process improvements.

Within the context of Industry 4.0 and Smart manufacturing initiatives, inspection machines must seamlessly share data with other systems to enable real-time feedback and process optimization. This requires an increasingly higher degree of connectivity, interoperability, and compatibility with factory automation systems.

As production volumes surge, preserving product quality is even more important. Inspection machines assume the role of a gatekeeper, vetting components to ensure that only those meeting the quality criteria will progress down the production line. Inspection is increasingly contributing to statistical process control (SPC) techniques by capturing data for predictive analysis; SPC can preempt potential issues and enable proactive preventive measures.

Finally, inspection machines contribute to data-driven decision-making, generating a wealth of data which offers valuable insights into both trends and defects, which, in turn, generates process improvement efforts. Koh Young Process Optimizer (KPO) is a current example of applying AI for real-time process adjustments. This integration into Industry 4.0 initiatives fosters seamless data flow, facilitating improved productivity and enhanced connectivity with other systems.

In essence, the evolution of inspection means multi-faceted roles: process control, quality assurance, data-driven decision-making, and defect prevention. These roles ensure that manufacturing processes remain efficient, reliable, and agile in meeting the demands of the modern industry landscape.

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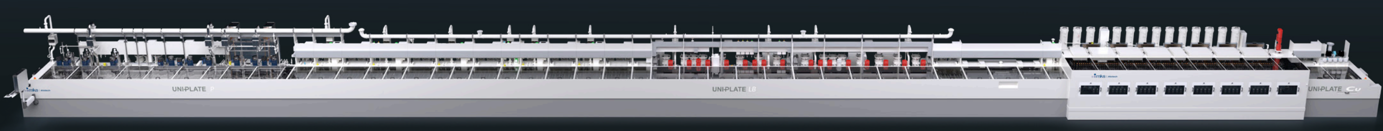

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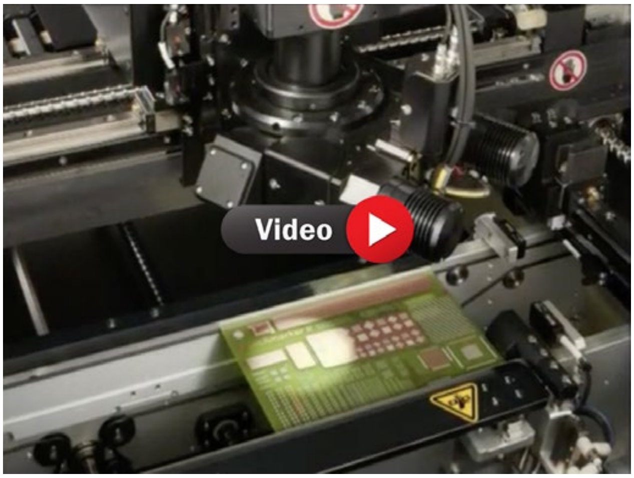


Koh Young Multi-Projection Moire Demo.

With that deep understanding of the materials, how much of that resides with the EMS engineers and operators, and how much of that is built into the inspection equipment itself?

These new specialized materials need tailored approaches to inspection. Substrates often feature intricate microstructures and fine surface details. Optical inspection systems need to precisely capture these features and identify defects, which demands high-resolution imaging capabilities. While the manufacturer needs to have some resident expertise, forward-thinking inspection equipment providers help by delivering "material agnostic" solutions to help alleviate the challenges.

For example, moiré phase-shift interferometry enhances the resolution of optical systems for defect detection, despite component reflectivity or substrate color, by providing detailed surface information, which then improves the sensitivity during inspection. Making use of moiré phase-shift interferometry to optimize lighting, imaging techniques, and contrast adjustments delivers trustworthy measurement-based inspection solutions.

Furthermore, advanced data interpretation and analysis tools help make sense of the complex optical data generated during inspection. To achieve these accurate, reliable inspection results, some customization and calibration of optical inspection systems is essential. **PCB007**

Brent Fischthal is head of global marketing for Koh Young.

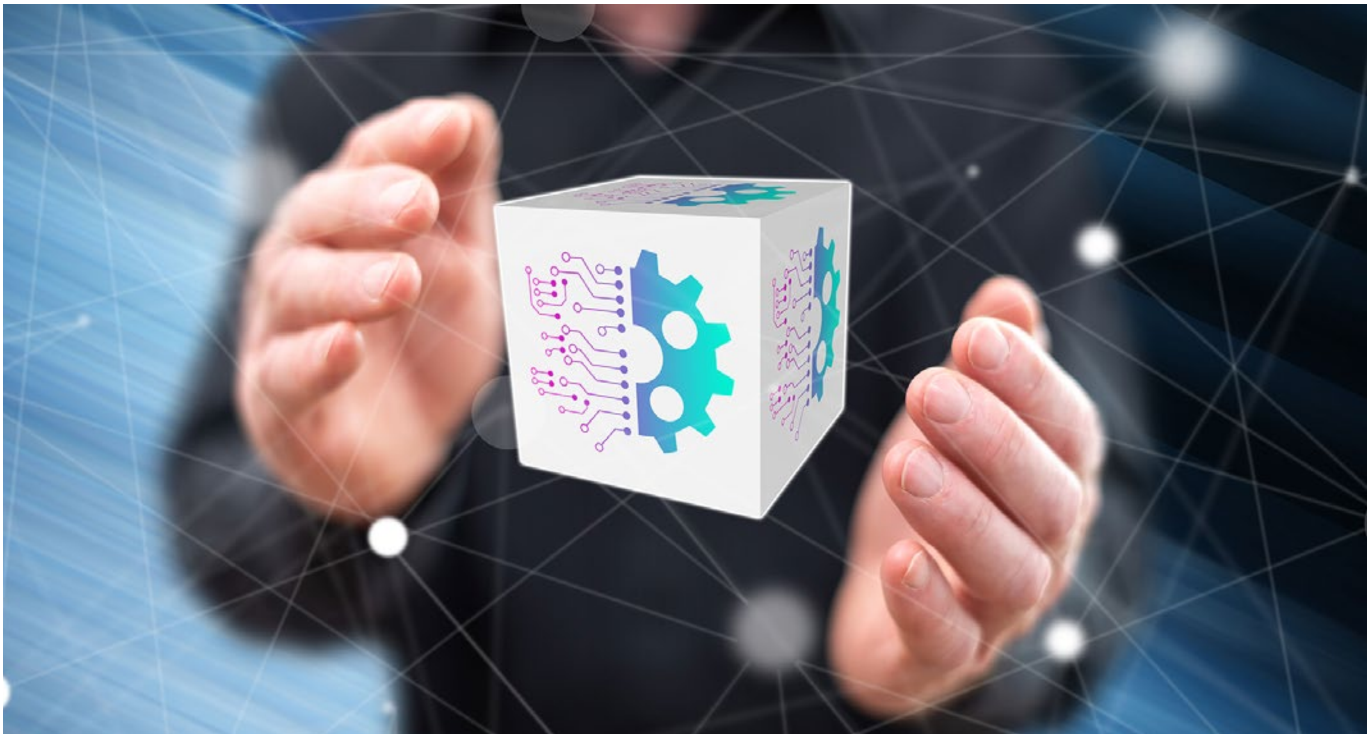
A Primer on UHDI

by Anaya Vardya
AMERICAN STANDARD CIRCUITS

There has always been pressure to reduce line and space as we have seen the bleeding edge technology go from 8 to 5 mils and then to 3 mils. The difference between then and now is that the prior advancements, for the most part, used the same processes, chemistry, and equipment going from 8 mils to 3 mils. But going from 3-mil to sub 1-mil trace and space is a quantum leap in printed circuit board (PCB) technology that requires a whole new set of processes and materials.

High density interconnect (HDI, the predecessor of UHDI) deals with line width and space, but primarily employs via structures to increase density. In broad terms, HDI printed circuit boards are defined as PCBs with one or more of the following via structures: microvias, stacked and/or staggered microvias, buried and blind vias, and all with sequential lamination cycles. Printed circuit board technology has been evolving with changing technology that demands smaller and faster features. HDI boards allow smaller vias, pads, lines and spaces—in other words, higher density. This increased density also allows a reduction in the number of layers and a smaller footprint. For example, one HDI board can house the functionality of multiple standard technology PCBs. Conventional state-of-the-art technology has been stuck at the 3-mil line and space capability for the longest time, but that is just not good enough to meet the increasingly tighter real estate constraints of today's products. That is where Ultra HDI comes in.

Continue reading in the September 2023 issue of *Design007 Magazine*.



Pivoting on Substrates

Feature Interview by the I-Connect007 Editorial Team

Oved Shapira is CEO of PCB Technologies, the Israeli-based printed circuit provider. PCB Technologies has recently invested in facilities and expertise to design, fabricate, and assemble substrates, a key component for advanced packaging technologies. Oved spoke with Barry Matties and Nolan Johnson about how advanced packaging will influence the industry. He said it will shift everything, including design, fabrication, assembly techniques, and capital equipment development. Some of these shifts might be subtle, and others more seismic. Whatever the changes, Oved says it's coming.

Barry Matties: Since you joined the company, you have been instrumental in defining the direction for PCB Technologies. Could you give us an overview of the company's current strategic direction?

When I joined the company, I first asked where we were heading and where the market was going. For our major customers, what were their projected unmet needs? I asked our CTO to talk with the CTOs of our major customers as a way to develop a multi-industrial vision with advanced technology included.

Of course, when you ask CTOs about their unmet needs, you get much feedback from different angles. When you filter out all the feedback, we found three major issues that keep repeating.

Matties: What were those issues?

First was miniaturization. Second was heat dissipation management, which is very much connected to the miniaturization of more functionalities and the growing demand for high-power applications. The third was the registration of mixed materials.

Registration is one of the larger causes of failure on the PCB, Everything that involves multilayer and sub-lamination always has the risk of poor registration. That creates shorts or other quality issues. So, we came back to the drawing board with what we learned.


Oved Shapira

I joined after the largest private equity fund in Israel acquired the company. We had a favorable cash situation and decided to invest the capital in technologies that would serve miniaturization, heat dissipation, and registration. That's when we built a strategy of all-in-one. You can have a PCB shop, an assembly service, and advanced packaging of multi-chip modules or SIP (system in package).

So, we upgraded the PCB shop to PCB-like substrates. Today, we can go for a pitch of 50 microns, line/space of 25/25, or 20/30.

We create a unique design of organic substrates by integrating copper-moly-copper. We give them a solution for heat dissipation and heat management in combination with miniaturization. Then, we add to the substrate all our capabilities in PCBs.

We know how to combine rigid and rigid-flex, HDMI, sequential lamination, and thermal management solutions we use on PCBs are now incorporated into the substrate production line.

Launching our new packaging solutions company, iNPACK, back in January meant we could offer the customer an A-to-Z solution: the PCB substrate, packaging, and assembly of the model to box building or subsystem.

Today, if you want to develop a subsystem, it will take two to three years because you need to manage different stakeholders: the PCB fab, the substrate manufacturer, the OSAT manufacturer, and the assembly manufacturers. With every stakeholder in the value chain, you adjust to each design rule. The result is always the lowest common ground and compromising on your performance needs. We offer to the customer everything in one place, starting from engineering. They get the complete solution. We are going to the highest common ground, not the lowest. We give them maximum flexibility on design, and the development cost is much more efficient and faster.

In PCB fab, we give them the proof of concept and small- to mid-volume production solutions. But we can also take them to mass production, if not in Israel, then with our business partner in the Far East, depending upon the industry. We always maintain responsibility for the technology, quality, and supply chain, all the way to the customer.

It's been eight months since we opened iNPACK, and we have many projects. Some of them will convert into multimillion-dollar recurring businesses. The first orders have more Non-recurring Engineering (NRE); we design for the customers. But we do understand that down the road, recurrent production also means lower cost with optimal technique. This was the strategy we put together.

Nolan Johnson: PCB Technologies started a separate company to handle advanced packaging. Does that also imply a different facility?

We have a relatively big campus with a dedicated production area. It is a different production line setup compared to PCB or assembly.

Johnson: Tell me about the investment and the effort involved with setting up iNPACK. Thanks to the U.S. and European legislation and discussion, advanced packaging is critical to moving forward.

You must invest in a substrate-like PCB and packaging solution. Our current setup is for one million modules. Each module can typically replace five or six micro BGAs. If you are looking for form factor, you will see a 40% or more reduction than the current alternative.

In terms of volume for military and defense, they need quantities in the tens to hundreds to thousands, but they don't need many millions. This is also the case for medical or industrial; those are the projects getting our attention now. The electric vehicle sector and solar power companies are also coming to us for NPI and initial design. If they need mass production, then we have a solution for them.

The NRE will often be costly because most of the setup in the Far East is for high volume. If you want to develop a module in the Far East, it can be up to $1 million. Now, if you produce millions of these for white goods or mobile, that's acceptable. However, we offer the same project for up to hundreds of thousands and the flexibility to produce initial low-volume quantities of 10,000, 5,000, or even 100. This is the infrastructure and resources currently missing in the States and the EU.

Johnson: You mentioned that you have engineering staff for these new capabilities. Do you find that your customers have expertise in their team concerning advanced packaging?

No, and this is the big story here. When we used to do PCBs, most of our business was build-to-print. Today, most of the advanced packaging knowledge is in the Far East. For advanced packaging, you need more know-how in Israel, Europe, or the U.S. Most of the projects we do today are build-to-spec, not build-to-print because it comprises the packaging design.

This is something that the customer can outsource, not just the production or technology capability but also the engineering capability. That is a big difference and a missing link in the Western world regarding advanced packaging engineering.

Johnson: If a fabricator wants to move their printed circuit board manufacturing facility into advanced packaging, one of the significant strategic steps is to find engineers, because transitioning from build-to-print to build-to-spec is a philosophical change.

It does require different people. We changed R&D spending. When I joined the company, spending was zero. Today, we spend in the vicinity of $2 million every year on R&D, engineering, and design. Some of it is invested in developing the process and technology, but a lot of it is invested in design and technical support to the customer.

> "Today, we spend in the vicinity of $2 million every year on R&D, engineering, and design."

Johnson: What is your perspective on how large a company would need to be to successfully invest in adding advanced packaging?

The government should incentivize companies to get into this technology because of the shift to bring back chip manufacturing to the U.S. and Europe. PCB shops need to shift their mindset to be substrate manufacturers. The significant change that we made here was different from microelectronics. You can find facilities that will make flip-chip or wire bonding and microelectronic technology in general. However, you can make a big difference if you can do the substrates and advanced packaging, especially if you have the engineering support.

If I'm a PCB manufacturer, I need to ask myself what we have and whether we can make 1-mil line/space possible. Remember that the substrate design can also work in 2 or 3 mils. Going to 1 mil isn't always necessary.

You don't need to change everything if you are a PCB shop. It would be best if you adjusted some sections on the production line to 1 mil. The photo sections will likely need to be changed as some of the developing and the etching may need to be more precise. Good cleaning, and good capabilities for laser and mechanical drilling, can be managed, but on the layers development you'll need to invest. All in all, you need to put together anything between $10 million to $15 million just in the substrate, then you have the microelectronics and the packaging. It's all together anything between $20 million and $30 million.

> "You don't need to change everything if you are a PCB shop."

Matties: How did shifting to advanced packaging affect the assembly side of your portfolio?

You're doing miniature advanced packaging that reduces or replaces the number of BGAs altogether on one PCB board and puts them on one substrate as a chipset module. It's a threat to the PCB fabrication and assembly business because PCBs will be more of a commodity once advanced packaging takes assembly complexity.

When you understand that, you take all the design complexity from the PCB and put it into the substrate and the packaging design, including heat dissipation, signal integrity, or line/space density.

Matties: Then, if you're a standalone assembly business, what work should they be doing as a roadmap or what strategic thinking should they have?

A standalone assembly house must focus on efficiency and automation, and reduce labor cost, touch-up, and manual labor.

Johnson: As we move into advanced packaging, and more components go into a single package, the packages are getting a lot larger—we are hearing about packages 100 millimeters on the side. That is a big package with many potential solder failures underneath that. Does that change the technical abilities of assembly?

It creates more challenges, especially for signal integrity and heat dissipation. When using a large die, you can have a big challenge with CTE: the adjustment between the silicon and the substrate. Remember that organic substrates can replace ceramic substrates, creating more challenges with CTE and heat management.

Suppose the projection about the end of Moore's law is accurate. In that case, one of the best available solutions that you can have to improve your form factor and reduce your costs is advanced packaging utilizing 2D up to 3D designs. You need to go in the Z direction (not just the X and Y direction) to use your space better to put more transistors in a specific area.

Matties: At what rate will we see market demand increase?

We need to see the first facilities in the U.S. and EU able to produce a substrate; with substrates, we have advanced packaging. This is the first condition, and we need more capacity. You have it in the Far East, but it needs to grow in North America and Europe.

Second, we need more engineers qualified to design advanced packaging and develop production lines for packaging. The big story here is the substrates and developing the process using subtractive and mSAP technologies.

Matties: Thank you so much.

Thank you for the time and the opportunity to share with you. PCB007

The Pros and Cons of Tribal Knowledge

The New Chapter

by Paige Fiet, TTM-LOGAN

Tribal knowledge is important and quite common in the electronics manufacturing industry—for good reason. Many engineers, technicians, and operators have formed their careers around building PCBs. Some even worked alongside the founding fathers of electronics. Newer, young minds stand on the shoulders of this knowledge base. As a process engineer, I work with operators who have been coating panels with solder mask longer than I've been alive. Some know the exact coating parameters required for the toughest of designs. To watch them hand-screen panels is like learning the nuances of a family recipe handed down through generations.

What happens when those operators retire? It's so risky to leave this vital knowledge only in their minds as they leave the industry. Will we be left with 30+ years of knowledge just briefly passed to a new employee who is hoping to avoid similar mistakes that might have been made in those 30 years? Can that information be quantified and written down for the next generation, so young engineers continue to push the envelope further?

Losing this database of experience can be detrimental if not properly passed on during the training process. It may not be intentional and may just be the result of unquantified information required for success. For example, while working recently with a team of engineers on processing guidelines for our front-end engineering (FEE) team, the team asked the lamination engineer about signs that could exist

in an unbalanced design to cause severe warpage. The plan was to use these details to create a knowledge database that any engineer could access to create an adequate process flow for a new job. Unfortunately, we were met with the all-too-common response, "I can just tell by looking at the design and stackup." It took some time and a lot of conversation to begin the process of quantifying information he hadn't even thought to quantify before.

Once initial information had been collected, it was properly documented in a living document. Inevitably, the FEE team came back with more problems not initially included in the document. This allowed the document to grow with details that were previously forgotten. The most important part of this story is that the information was captured for years to come. Five to 10 years after our lamination engineer is long retired, the new lamination engineer can reference documents that include this pertinent information instead of taking a considerable amount of time to learn it for himself.

Beyond the risk of losing the knowledge curated by experience, tribal knowledge can be dangerous to the productivity of a facility. For example, if plating operators need to ask the engineering team about the current, processing time, or waveforms that should be used on every new job booked, the plating engineer could not get much done outside of setting up new jobs. What would happen if the plating engineer took a two-week vacation with no cell service? Would all the new jobs have to wait until that person returned? A less extreme example might be operators who are able to perform the set-up of most product on a plating line but have not learned the subtleties of waveforms for more complex work. Even for the most experienced operators, the details may be lost in translation. Why take the time to wait for one person to respond to an email if that same information can be readily available to anyone requiring it?

The biggest trouble with tribal knowledge is the effect it can have on company culture. Sometimes, tribal knowledge can lead to an "us vs. them" mentality within a working team. Rather than working together to solve a problem, more knowledgeable individuals may intentionally gatekeep information to maintain their status as "valuable" to the company. This mentality can prevent the team from making headway on problems, especially if newer employees feel they don't have as much to add. New employees can also feel overwhelmed by the amount of information required to perform their job. Without documentation they can refer to, they may feel embarrassed to ask what an acronym stands for or how to perform an undocumented process step. These feelings are damaging to any company looking to create a team-based culture.

While tribal knowledge is crucial to the success of all companies, it can be equally troubling. To maintain a baseline of information needed to advance, this information should be documented and readily available to the necessary parties. It should also be shared freely as a way to develop a team-based culture. However, to be truly helpful, when tribal knowledge is recorded, it must be accurate and relevant. Information should be shared in a consistent manner and format. It needs to be controlled by a small group of individuals to prevent loss of pertinent information. What information at your facility can be put into a formalized archive for the future generation to learn from? **PCB007**

> "The biggest trouble with tribal knowledge is the effect it can have on company culture."

Paige Fiet is a process engineer at TTM-Logan and in the IPC Emerging Engineer Program. To read past columns, click here.

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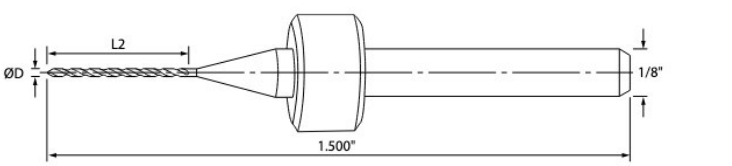

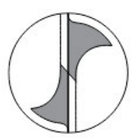

4 Facet Point Geometry

REPOINTING will be a new service offered by Insulectro through Kyocera. The company has recently invested in automated, state-of-the-art equipment and all repointing will be done in Southern California.

MilAero007 Highlights

BAE Systems Signs Agreement to Acquire Ball Aerospace ▶

BAE Systems announced a definitive agreement for the proposed acquisition of Ball Aerospace for approximately $5.55 billion.

Flexible Thinking: Growth of Flex and Flex-hybrid Electronics in Mil-Aero Applications ▶

Over the past several years, flexible electronics (FE) and flex-hybrid electronics (FHE) have enjoyed heightened attention in the electronics industry and have seen special interest and attention given by mil-aero companies. This is evidenced by June's NextFlex conference titled "Hybrid Electronics Commercialization Path for Aerospace Applications," an event at Boeing's Seattle facility. It is thus worth considering some specific examples of FHE applications in the mil-aero environment.

Lockheed Martin Australia Selected as Australian Defence Force's Strategic Partner for AIR6500 ▶

Lockheed Martin welcomed the announcement by the Department of Defence on being selected as the strategic partner to steward AIR6500 Phase 1 (AIR6500-1).

Jet Appeal ▶

In 2007, Stratos Aircraft set out to design and manufacture an exciting, high-flying new product, which they estimate is still at least five years away from going to market. With a hefty capital investment, they are now working on their second prototype: a six-passenger, single jet engine plane that cruises at 41,000 feet, with a range of around 1,500 nautical miles, and a comfortable cabin pressured to an altitude of 7,600 feet.

IPC Welcomes U.S. House Veteran Rich Cappetto as Senior Director of North American Government Relations ▶

IPC welcomes Richard Cappetto, a 14-year veteran of the U.S. House of Representatives, as its new senior director for North American government relations.

Northrop Grumman's B-2 Capabilities Enhance its Digital Communications ▶

Northrop Grumman Corporation, in partnership with the U.S. Air Force, successfully completed an integrated airborne mission transfer (IAMT) demonstration with the B-2 Spirit at Whiteman Air Force Base as part of the ongoing modernization efforts incorporating digital engineering.

NASA Selects Small Businesses for Orbital Debris, Surface Dust Tech ▶

NASA has selected six U.S. small businesses to receive nearly $20 million in total to advance technologies to address two challenges in space exploration: orbital debris and surface dust.

Boeing Partners With the World Energy Council to Advance Aerospace Energy Transitions ▶

Boeing has become a Patron of the World Energy Council, marking the first aerospace company to partner with the organization to drive sustainable energy transitions.


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Why TDR?

Testing Todd

by Todd Kolmodin, GARDIEN SERVICES USA

Time-domain reflectometry (TDR) is a measurement of impedance in a transmission line. This becomes very important in high speed or RF printed circuits. As a long-time amateur radio operator, I have had a lot of experience with characteristic impedance regarding power transmission.

For example, this is very important with transmission lines leading to an antenna. In the circuit board world, this could be cellphones or Wi-Fi devices. These devices transmit and receive RF signals at high frequencies, and mismatches from the transmission line to the antenna can have adverse effects on performance. So, in amateur radio, standard transmission cables are used with known impedance values. One example is coaxial cables, such as RG-8 or RG-58. These cables have a characteristic impedance of 50 ohms. This is considered a "constant" so that changes to only the antenna affect the resonance of the output.

In RF applications, a mismatch of the antenna length at the desired frequency can have significant effects on the effective radiated power (ERP) or reception functionality. When this happens there is a change in the standing wave ratio (SWR). On a matched transmission line to load (antenna), the SWR will be extremely low, and a perfect match will be a ratio of 1:1. This means full transmitted power is being radiated or passed to the load. As SWR increases, a portion of the power of the circuit is reflected toward the source or transmitting circuit. The higher the SWR, the more power is reflected. This is dangerous to the source as heat is produced and the high reflected signal can damage the output circuit causing failure.

Let's look at a Wi-Fi router. It is typically transmitting in the 2.4 GHz–5 GHz bands. These routers usually only transmit milliwatts, so it is very important that the best ERP can be achieved (yes, there are antennas in these devices). Depending on the design of the router, the length of the antenna may vary. Since we are in such a high frequency, the antenna will be small. For exam-

ple, it's not a coincidence that router antennas are only about 4-5" long. That is a full wave at 2.4 GHz (936/f = length of full wave in feet, where f is frequency). At 2.4 GHz, it's actually 4.68". As the frequency increases, the actual antenna length requirement shortens. As the 2.4 GHz band is 2.401–2.484 GHz, the manufacturers will target a mean resonance at the middle of the band, 2.445 GHz. That is roughly 4.58". You can double check by measuring the length of your router antenna(s).

In our router example, these typically transmit between 10-25 milliwatts. Matching the transmission line to the antenna is critical so as to radiate as much of the signal as possible. As SWR increases due to mismatch, the ERP of that 10–25 milliwatts is degraded. We start having loss on the circuit. When we talk about signal gain and loss, we use decibels (dB). When we start reflecting power back, we are losing ERP. Just for reference, a 3 dB loss is half the transmitted power, so, if we have a 3 dB loss when transmitting 10 milliwatts, we are now only effectively radiating 5 milliwatts. That's not good when we are using such low power to begin with.

> "As the frequency increases, the actual antenna length requirement shortens."

But, you say, my router has 5 GHz capability, too, and your calculation was only for 2.4 GHz. Why use the same antenna? The beauty of radio waves is they can work harmonically, or more specifically, using multiples of themselves. The Wi-Fi 5 GHz band is not just by accident. The 5 GHz band is a close harmonic of the 2.4 GHz band. So, using the same antenna at 1 full wave for 2.4 GHz, they can obtain matches on the 5 GHz band. A second antenna is not needed. The matching will be a little fuzzy regarding SWR but anything less than 1.5:1 is considered optimal while 2:1 is considered acceptable.

I'm sure you have noticed those huge towers on the hills rising hundreds of feet in the air. The actual transmission antennas are very small by comparison. Using our antenna calculator, I know of an FM station transmitting here in Oregon on 92.3 MHz on a tower over 1,000 feet in elevation. However, the driven element for a full wave is only 10 feet, 3 inches. When you look at these giant towers, remember the giant footprint is just to elevate the antennas as high above the ground as possible to propagate the transmitted wave as far as possible.

Okay, we now understand the significance of matching transmission lines to loads (antennae). In the finished circuit board, we have many other variables: ICs, capacitors, inductors, and resistors. Again, the transmission lines (traces) running around on the board need to be constant regarding calculating responses to signals. Mismatching can cause changes in waveforms that may not be desirable. Here, inductive and capacitive reactance can manipulate frequency waveforms, which may be desirable if designed. However, a mismatched transmission line can skew those waveforms, resulting in undesirable results. If the circuit becomes more inductive, the voltage waveform will lead the current waveform by 90 degrees. Conversely, when the circuit becomes more capacitive, the current waveform will lead the voltage by 90 degrees. Using these electrical properties, circuits can provide either gain or attenuation. However, this is only successfully achieved by stable transmission lines as a constant.

So, now we know why TDR can be very important in circuit design. Matched transmission lines provide optimal circuit performance, while mismatched lines can provide high reflected waves, signal loss, and even transmitting element failure. **PCB007**

Todd Kolmodin is VP of quality for Gardien Services USA and an expert in electrical test and reliability issues. To read past columns, click here.

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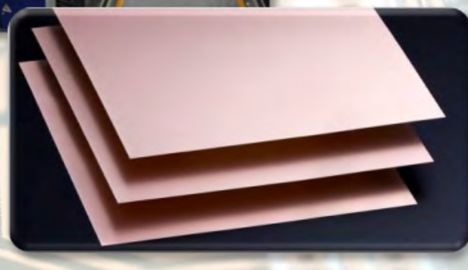

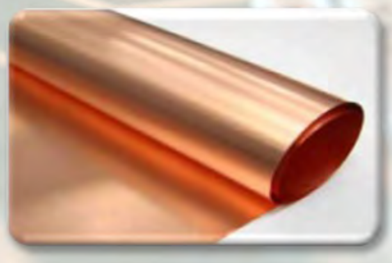

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Culture by Design: Building a Winning Team from the Start

Article by Brian Wallace
HR STRATEGIES NOW

"If you build it, they will come."

This line is from one of my favorite movies, "Field of Dreams." It's a fictional story about a character named Ray Kinsella, an Iowa farmer, who mysteriously receives instruction to build a baseball diamond in his cornfield. The result of his dedication and follow-through is a visit from timeless baseball legends, an experience that garners attention far and wide as people travel from across the country to watch them play.

One of the many reasons that I enjoy the movie is its underlying message about following your dreams and pursuing something great, even when the task seems daunting. This is how it can feel building a successful business: daunting. But the challenge can be rewarding, and the results can be incredible. Part of that building process involves making sure that you have the right people on your team.

If you want to attract top talent and achieve great results, your organizational culture is key. It's hands-down one of the most important elements in your business and it's quite possibly one of the best predictors of your long-term success. Studies have long shown the tie between strong cultures and higher productivity and revenue. So, it needs to be created and nurtured carefully. Your hiring practices need to support it.

Culture refers to the collective values, beliefs, norms, assumptions, behaviors, and practices that shape the environment within the organization—as Seth Godin defines it, "people like us that do things like this." It's the underlying current of how the work gets done and it can be a competitive differentiator. Build a great performance culture and you create a powerful movement of people who are engaged and motivated to achieve. Allow a toxic workplace culture and you are in for trouble.

Your hiring practices are a critical part of the culture building process. A candidate's culture "fit" should be a key consideration in any job interview. There are two reasons. First, a single employee can have a major impact on the chemistry and dynamics of the team. A strong match can add to the energy, capability, and focus of the team and they will often act as brand advocates. Second, their personal longevity and effectiveness in the job will be influenced. When people perceive that they belong (indicative of a good match), they tend to feel a stronger sense of purpose, show greater loyalty, and perform at a higher level.

When you create a great culture, your employees will do much of the recruiting for you. This gets back to the earlier movie line, "If you build it, they will come." Current employees are more likely to share positive experiences with their connections and because people tend to be drawn to organizations with great cultures, the time spent searching for high quality talent is reduced significantly. This is why the "Best Places to Work" designations are so valuable. It's one of the best ways to position your business to attract top talent.

On the other hand, comments left by disenfranchised employees on social media and sites like Glass Door can actively repel top talent. Negative work environments and toxic cultures can create a major challenge as you work to attract future candidates.

Now, a word of caution. Personal bias can lead you to hiring people just like you, which can become problematic if you're not careful. Culture fit is important but there is tremendous advantage in diversity. It allows the organization to bring new ideas to the table, which is an important ingredient for innovation.

If you want to increase the quality of your hiring and reinforce your culture simultaneously, here are a few recommendations:

- Describe the culture clearly in job ads. Even creatively. Let them know what it's really like to work there.
- During the interview, get beyond the technical skill questions. Take your time and ask the questions that will lead them to talk about their interests, perspectives, and experiences.
- Never oversell the position. Be honest about its responsibilities.
- Work to instill consistency between the culture you describe and the process that your applicants experience. If you espouse collaboration, communication, integrity, and/or innovation, make sure it's demonstrated in the process.
- Pay close attention to any red flags that appear, especially related to culture fit. You can often train for technical skill but adjusting behavioral patterns is a challenge.

Your culture has the potential to drive the success of your business if it is intentionally aligned with the organization's values and supported properly.

Great cultures don't happen accidentally; they are cultivated. Ensure that you are building the practices that create the environment you really desire. Look carefully for those individuals who align well and then practice transparency as you share that desire. Watch how they respond. If they are excited and energized by the vision, move them forward. If they hedge or hesitate, think twice regardless of their technical skill.

If you build it, they will come. Who knows what legendary performance might follow. **PCB007**

Brian Wallace is the founder and CEO of HR Strategies Now, a human resources consulting firm based in Cypress, Texas. He holds a master's degree in management and an SPHR certification from the Human Resources Credentialing Institute. He has led transformative HR initiatives across five industries for more than 20 years.

Don't Just Blame the Etcher

The Chemical Connection

by Don Ball, CHEMCUT

If your HDI or UHDI production process is quality challenged, don't assume your etcher is to blame. Many factors impact the quality of the final product, so assess broadly, and you may find that "the devil is in the details."

Generally, the first place most people can get good product specification measurement is at the end of the etching process. It's natural and easy to blame quality shortcomings on the etcher. By all means, look at your etcher and invest some time trying to improve its performance but don't stop there. Other factors may be affecting the etch uniformity.

Each process step prior to etching adds variation to the final product. In most cases, the added variation is small, but as the features on the etched panel get smaller and closer together, they become more important.

For example, back in the days when 0.004" (100 µm) lines and spaces were state-of-the-art (yes, I have been around that long), a circuit board manufacturer that had been mostly producing consumer boards requiring lines and spaces of around 0.008" or more took on a job requiring the then state-of-the-art 0.004" lines and spaces. Their yields went from more than 95% on their 0.008" line-and-space product to less than 50% for the 0.004" space product and they lost money on that job. A lot of time and effort was spent on etcher optimization, which improved yields significantly but not to the point of profitability.

In this instance, it was found that a change in procedures in the photoresist exposure step solved their problem. For most of their production panels, the exposure was made as soon

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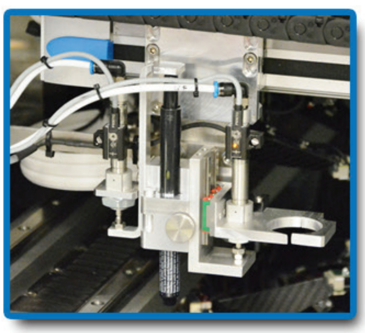

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as the vacuum gauges indicated full vacuum. For the 0.004" space panels, it was found that by delaying the panel exposure for 30 seconds after full vacuum was drawn, it brought their yields back to the 95% range. The extra time allowed the phototool to come into closer contact with the resist and prevented leakage from their non-collimated light source from causing shorts across the narrower spaces. Ultimately, they upgraded their exposure units to ones with collimated light sources and better and more consistent vacuum drawdowns to meet the specifications of the then high-tech products.

By today's standards, this is a relatively crude example, but it does show that some attention to other process steps as well as etching can solve some problems involved with high density circuit production.

"The research took two to three years to complete but, in the end, they were positioned to succeed in a highly competitive market."

A more recent example is provided by two companies I assisted with about two years ago. Both companies were making high-density flex circuits using a reel-to-reel process. Company B was consistently outcompeting Company A for business and Company A could not understand why. Both companies were long time customers and familiar with each other, so Company A was aware that Company B had a newer model etcher. They assumed that this was the problem, asked for an audit of their etcher, and for information on the latest advances in etcher technology.

Company A's etcher had been purchased in the mid-'90s but had been well maintained and optimized for their production. When I ran and analyzed my test panels, I saw that their etcher performance was on par with the etcher in my lab, which was the same model and vintage as Company B's (circa 2015 or so). I informed the management that I didn't think a new etcher would improve their competitive outlook. This advice was not well received. If not the etcher, what else could it be?

The difference was that when Company B decided to get into HDI production (UHDI was still in the future), they took the time to study each process step in the production line, from incoming materials to outgoing packaging, and looked at how to optimize each step. In the etching process, they looked in detail at surface prep, types of photoresists, resist application, phototools, resist exposure, developing, and etching.

By "in detail," I mean they analyzed such things as roller temperature for dry film lamination, exposure times and intensities, developer concentrations, etc., to find the most efficient and cost-effective ways to accomplish their goals for high density interconnects. The research took two to three years to complete but, in the end, they were positioned to succeed in a highly competitive market.

Some equipment upgrades were required but, for the most part, all that was needed was to tighten operating procedures and find the best operating parameters for each process. As far as I know, Company A is still looking for that silver bullet in terms of new etcher technology that will make them more competitive.

The moral of the story: As circuit features shrink and are squeezed into smaller and smaller spaces, one should focus on optimizing every step in the circuit formation process and not just one small area where you assume the problems exist. PCB007

Don Ball is a process engineer at Chemcut. To read past columns, click here.

The SEL Supply Line

Introduction by Barry Matties

During my recent tour of SEL's new $100 million PCB factory in Moscow, Idaho, I spoke with Engineering Director John Hendrickson specifically about the partnerships they formed with the many equipment suppliers it took to build a new factory. I wanted to know when he's choosing a supplier in a critical aspect, what is he looking for?

John Hendrickson: [As] close to home as possible. That's definitely one of the things we want to look for. Do their business philosophies align with ours, and do they have the right equipment sets to meet our needs? We find the right partner and maybe their equipment sets don't meet our needs today, but that's where we want to build those deep relationships and work together to develop technology that meets both of our goals.

John said that constant communication between all suppliers involved is key. Mike Brask, president of IPS and a key supplier to SEL, joined me on the SEL tour. I asked him to talk about the communication process from start to installation of the ENIG line.

Mike Brask: John had dedicated engineers for the ENIG line that would work on it with us throughout the entire process. SEL had also chosen their chemical supplier, so we met with them early in the process, aligned with them, and bound them to the project by integrating them into the decision loop of all the features that we'd want to build into the line. It was that trifecta approach—the customer, the chemical supplier, and us—with a clean sheet of paper working to identify potential problems and innovations.

As our conversation continued, I asked John about this collaborative approach.

Hendrickson: Mike and his expertise were instrumental for us—especially because, at the beginning of the project, our knowledge on the process was very limited. Mike and his team helped us understand some of the things we should and shouldn't do. He pointed us in some directions based on his experience. Relying on them—and our other key suppliers' expertise—to select the right equipment and help train our team gives us an advantage. We would meet at least once a week.

Mike Brask (left), and John Hendrickson (right).

Brask: Yes, the weekly meetings were key for us to keep the project on track. If an issue came up, it was flagged within a week. The high velocity of visits to our factory was very helpful. The amount of time SEL spent getting their employees integrated into the equipment before it even hit their floor was impressive. Their team would come to our factory; they were involved in the assembly of the hoists, the teardown, and the packaging for shipping. They were involved when that equipment got to their door, they helped set the machine in place, and—with the early training—they were 99% there. When it came to flip the power on, they were ready to go.

Hendrickson: Our goal was to go down to visit IPS at least once a month with our engineers/operators. I think one of the great things is, when we brought some of our equipment maintenance team, Mike put them to work teaching them how to plastic weld and everything else. By the time they left, they're like, "Hey, I know how to plastic weld." I think it was part of the key to our success bringing up the factory.

We hired the main core of our operators about a year ago and had them sitting next to our engineers; we had them paired up together on the processes. Not only did we take several of our operators to our equipment suppliers we also went to other board shops, so they could understand what these processes look like and what their day-to-day would potentially look like in the future.

I asked John if he had any final thoughts to share on this whole process.

Hendrickson: Make sure you don't start with what you think a supplier's catalogue is. Really dig down and understand what they're doing and where they want to go. With some of our other supplier partners, we ended up going with equipment that wasn't necessarily the thing they were trying to sell; it was their "go-forward" equipment. Instead of buying something that in a year or two they'd want to be moving away from, we jumped ahead. Building up that partnership and having that communication and those tight feedback loops is critical.

The following pages include interviews we conducted with some of SEL's other key suppliers. These companies talk about the equipment they sold and the partnerships they formed with SEL in the process. It's a process that can be duplicated, and that makes the content even more valuable. PCB007

GreenSource Engineering: An Eye on Design

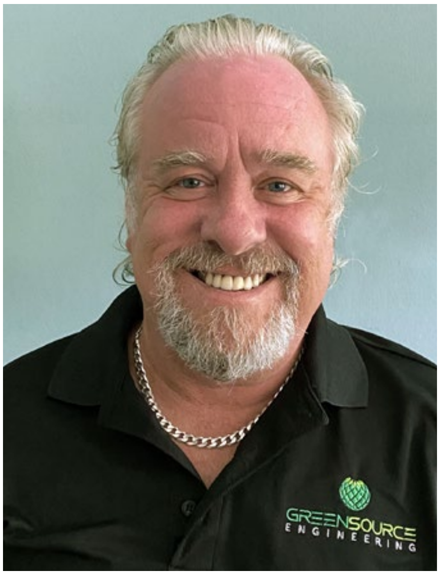
Schweitzer engaged the services of GreenSource Engineering to assist in the initial design of the facility, along with handling automation equipment. Nolan Johnson met with the GreenSource team— Michael Gleason, Marco Mirkovic, James Brown, and Rick Nichols—representing GreenSource Engineering and GreenSource Fabrication (GSF), to better understand their working relationship for the build-out of the new facility in Moscow, Idaho.

Your organization was involved with Schweitzer's greenfield facility in Moscow, Idaho. What was your role there?

Rick Nichols: Essentially, we placed a high degree of automation in their facility. Once the word went out that we had successfully built a plant in New Hampshire, primarily fielding our own equipment along with the zero liquid discharge (ZLD) unit—which is a key component to any greenfield site—we got involved

From left: GreenSource Engineering (GSE) double loader, photoresist strip line, GSE unloader.

with SEL fairly rapidly. SEL came to the fab in New Hampshire to receive base level training on all aspects; they were given full access to the shop, and our engineers helped them out.



Rick Nichols

SEL collaborated with GreenSource on the factory design and equipment selection to ensure that the GSF automation equipment and ZLD system worked well. Once SEL saw the setup in New Hampshire, they wanted a similar structure for their master plan. We designed horizontal equipment for them although we did not install this equipment. We installed the ZLD unit, a prime piece of technological advancement that greenfield sites will be interested in.

Rick, did SEL install custom-built equipment?

Nichols: Everything we build is custom, to some extent. I can give you an example. A typical stripping line in most board shops utilizes an alkaline solution of one kind or other, especially now. Often, shops use just sodium hydroxide, and this will tend to oxidize the panel's copper surface. Our stripper, for example, has a built-in post-clean to ensure that the panels that come out are directly readable by AOI.

How important is the zero-waste discharge to the overall facility?

Nichols: It's important because permits are required to release any kind of contaminant into the environment. Everybody is—correctly so—environmentally concerned right now. With traditional liquid discharge systems, they discharge clean water, but you're still basically bringing water in—at great cost, especially nowadays—and once it's done, you're pumping it back out. In the meantime, you're treating it using expensive hardware.

The benefit to our system is that, while you still have the treating step, you reuse the water back in your system. You may top it up from time to time due to evaporation, scrubber loss, etc. But let's say a facility was using X amount of water with a traditional process. Now, they will be using a fraction of this with our system. Most of the water they use and treat will go back into the fab.

Michael Gleason: Environmental sustainability is the number one attractor for the ZLD systems. The added benefit is recycling the water. Depending on the geography of a particular circuit board shop, either the treated water just exits their facility into a holding pond or it's trucked off and processed further, for which there is an added cost. With the ZLD system, there is both a major cost savings and a conservation element.

I'm curious about GreenSource's involvement in the design and specification of that. Will you be the design consultants for new greenfield facilities that are both zero waste and cutting edge?

Gleason: We certainly are. We've gained a lot of experience from our New Hampshire facility, SEL, and a third site here in New England. Based on this experience, we've received quite a bit of interest from the electronics community.

I want to say there's more interest on the potential semiconductor side than on the traditional PCB side of the industry. Obviously, there is a lot more money in semiconductor. That dynamic is changing, however, as various funding channels open for PCB fabrication in the U.S. We feel this is a marketable service.


Michael Gleason

I presume you mean advanced packaging and substrates.

Gleason: That's correct. That's where the interest is coming from.

With this equipment, can this take your customers down into the space of ultra HDI?

Gleason: Absolutely. We're producing ultra HDI right now and we are looking into the IC substrate, which we feel is a step below ultra HDI. There are mixed opinions about which feature sizes are ultra HDI. The 25-micron up to 50-micron range seems to be the ultra HDI sweet spot. We're doing that every day with the GreenSource Engineering equipment.

With the momentum ramping up behind the U.S. CHIPS Act and HR 3249, do you see this as a market opportunity? Is the government involvement helping the market?

Gleason: We certainly think it does. A full-blown greenfield site, obviously, is not a small ticket. It's a significant amount of capital for a company to pull forward, even if they receive funding. But there are elements which can be retrofitted to existing facilities.

Now, automation can be very difficult to incorporate into an existing footprint with existing equipment, and that might be antiquated. This is where the greenfield site, or an expansion to an existing facility, will help with setting up new lines.

As Rick mentioned earlier, we've now gone through multiple generations of processing equipment for developers, etchers, pre-clean, and strippers, supporting primary imaging as well solder mask imaging. It's this feedback loop which we consistently utilize that allows us to continually improve on all these designs as we're listening to the various needs of our customers.

Are greenfield sites on the grow?

Gleason: You know, everyone is waiting to see where the funds start dropping. If PCB shops are backed by venture capital or private equity, that will stimulate additional private funding. In our opinion, the best way to go is starting from the ground up to fully achieve the objective vs. trying to retrofit. Brownfield sites can be retrofitted to a certain point; ultimately, you're unlikely to get what you really want.

Tell me about the equipment that you put on the floor. How have you automated the handling for that facility?

Nichols: We didn't do all of it, but we're at least 90%. We're down to the last five pieces of equipment to be built and shipped to SEL.

Closing thoughts?

Nichols: I want to emphasize that one of the synergies was a rotation of SEL employees coming to GreenSource Fabrication for training and working on the equipment that represented closely what they would ultimately use. We trained their employees on the equipment that would be installed so they could hit the ground running. SEL have very capable employees that can be very proud of what they have achieved. Congratulations must go out to SEL.

Gentlemen, thank you for having this conversation with me. PCB007

Notion Systems: The Arrival of the 'Jet Age'

Notion Systems is a German-based company and one of the leading suppliers of industrial inkjet systems for functional materials. Antonio Schmidt, senior vice president of sales and marketing, explains that by applying the solder resist fully-digitally, Notion gave Schweitzer Engineering Laboratories (SEL) the opportunity to save time, investment, space, and labor in their new printed circuit board manufacturing facility.

Antonio, let's start with a quick introduction to Notion Systems.

Notion Systems is based in Schwetzingen, Germany, close to Heidelberg. We focus fully on developing and building industrial inkjet systems for functional material. Our parent company is the German-based Lab14 Group; we are part of about nine different companies which are active in the field of electronics and semiconductor fabrication equipment. Notion started 12 years ago, and just opened a subsidiary in the Boston area to support our customers in North America. We focus on high-end inkjet printing of functional materials, such as conductives, insulators, resists, and adhesives. We are in many different markets, from display to electronics to semiconductors. Our biggest market is applying solder mask digitally using UV ink instead of a solvent-based ink. With our technology, we are trying to minimize the carbon footprint in PCB production.

Antonio Schmidt

With that area of specialty, it makes sense that you were selected for SEL's new facility. Can you share details on the equipment you installed there?

We sold SEL several fully integrated and automated n.jet solder mask systems. They will run the whole backend solder mask process very economically and ecologically compared to other PCB factories. If you look at existing, older factories, there is a lot of manual work, carrying boards around and so on. Our n.jet solder mask system at SEL is fully automated and integrated using fab automation companies selected by SEL.

We print the solder mask and the legend inside one machine. I think our customers choose us because we have the biggest installed base in the world. We have, by far, the fastest machine. We can put up to nine printheads for solder mask printing and several printheads for legend printing; nobody else has this configuration. Our competitors have two or four heads, so they aren't as fast.

Why was the Notion system the right choice for SEL? Was it your automation, high speed, or other criteria?

In your interview with John Hendrickson at SEL, he shared several reasons why they bought our machines. One of the most important reasons is that it saves three to four process steps. You don't need a spray coater or a second dryer. You don't need an LDI or a developer. You are saving space and materials. For example, with the standard solder mask process, you can print maybe 20 boards per kilo. With our process, you can print approximately 75 boards per kilo, so that's three times as many. Likewise, you have energy and labor savings because it's all fully automated. One operator is able to run the entire solder mask backend.

Where have most of the Notion Systems equipment been installed?

It depends on the year. This year, we've sold a lot of equipment to North America, and by December, we should have between 10 and 12 machines installed. We have about eight machines installed in Europe and a couple in Asia. Our focus was to first catch all the interested customers in Europe, and then we saw a strong demand in North America, especially for new companies. There are several PCB makers moving production from Asia back to North America, and that gives us the chance to sell our equipment and our process into these new factories.

Are you seeing an uptick in North America for new factories?

Yes, there definitely will be a couple new factories in North America. We will also see new factories in Europe and Southeast Asia, especially in Thailand and Vietnam.

With this move toward more greenfield facilities, what are those customers asking for? How are those requests driving your innovation?

We save cost and material, so we decrease the carbon footprint. These are the main economic

Notion Systems' n.jet technology saves multiple process steps, large investments in valuable space, energy, and labor. This completely digital process also uses UV-curable inks instead of solvent-based inks.

and ecological advantages. There are also advantages within the application where you can generate new features which cannot be done with a traditional process.

First, we can print the solder mask and legend in just one production step—solder mask followed by the legend. We can also print the 3D structures on a PCB. For example, if you don't want to use the white legend, you could use the solder mask as legend. That means we can print the solder mask with the same ink, just a little bit higher. Using the solder mask as legend saves an additional step. You can also print 2D codes on it. You can print watermarks and print dams right on it.

These are some lesser-known features which not all our customers are using, but they add value to the PCB. Everything adds value and revenue to our customers.

Historically, inkjet has been considered a slow process, especially for production quantities. What effect does your machinery have on the manufacturing floor?

When you look at the total cost of ownership and the total process time, it's a digital, layer-by-layer process that is very fast and precise. We have printing speeds up to 500 mm/sec; I don't call this slow.

Depending on the board design, we can produce up to 50 PCB sides per hour, depending on the copper layer. SEL was smart; they connected two machines with each other, so they are printing the front side on one machine and the rear side on the other machine. That doubles their throughput.

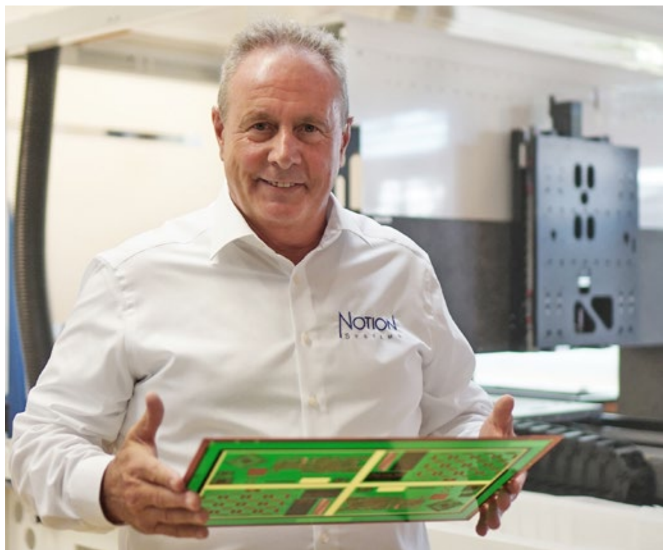
There are some processes which might be faster, but when the installation is fully automated, the entire process is much faster and running at a much higher yield because everything is connected to each other. In a manual process, you have a lot of yield losses; you need at least three or four times more operators to run the whole line—people are carrying the boards around, or you have these boards and trolleys.

Do you think these points are factors in your customers' decision?

We have eight years of experience in inkjet printing, a leading installed base worldwide, and the fastest machine. This is really the key to our customers' decisions. I also want to state that it is very nice working with SEL. They managed to build such a huge greenfield PCB factory in just one year. The whole team is very capable.

Tell me about the new office in Boston.

Yes, we have opened that office with the Lab14 Group. Currently we have two people in the office: Kurt Weber, director of business development North America, and one service engineer. We are looking forward to growing the team next year, as we are expecting more business from the electronics and semiconductor industries. We see great potential, not only in PCBs, but also in semiconductors and renewable energy. That is why we took the next step to open our own subsidiary in the Boston area.



Kurt Weber

Thank you. It was great talking with you.

It was great meeting you as well. **PCB007**

Mecer's acidic etchant copper recycling system—capacity 180,000 lbs. copper per year—helps make SEL's Moscow factory a zero liquid discharge facility.

Sigma Mecer: Turning Copper 'Green'

Andreas Littorin is CEO at Sigma Engineering AB. The company has been manufacturing equipment for the PCB industry for 45 years, mainly a mature product for copper recycling of alkaline and acidic etchants in the PCB manufacturing process.

You were recently selected by Schweitzer Engineering Laboratories (SEL) for its brand-new facility in Idaho. Tell me about your equipment that was selected for its facility.

SEL chose an acidic copper recycling system, a quite large one. It's capable of recycling 15 kgs (about 33 pounds) of copper per hour, all day, all year long. There's also a subsystem for oxidation and regeneration of the etchant. So, they have an oxidation reactor system connected to the etching line, and one more for the second etching line that is still coming.

When a facility is looking to reduce waste, or even to be zero waste, how important is this sort of equipment?

In terms of etching operations, it is very important. In terms of PCBs, in general, it's just one of the processes customers have in their plant.

But without the copper recycling system, you need to "feed-and-bleed" the chemistry, always sending in new and sending out spent chemistry. It's paramount to do recycling to achieve zero waste for the etching operation.

Am I right to conclude that this removes process steps?

Yes, because you don't have to treat the spent chemistry that you otherwise would end up with. Our system is the treatment, and you can reuse it indefinitely.

From your perspective, why was Sigma Mecer a good fit for this project?

The primary goal they approached us about was removing as much waste as possible. Of course, SEL did some benchmarking at a few other customer sites that use our equipment to get a proof of concept.

It's also important, of course, to believe in what we're doing. To some extent, I think it sounds too good to be true that you can reclaim the copper you're removing from the panel, but it is exactly like that.

I presume that the copper you're reclaiming could be turned around and run back through a manufacturing process?

We're working on that right now. The copper we are recycling is 99.995% pure. The plating lines which require phosphorus copper would not be compatible, obviously. But the lines that use this pure copper? Yes, absolutely.

What's the progress on the process for reclaiming the copper?

We have done several laboratory tests and validated the possibility to plate out 99.9% pure copper rods that can be cut into the same shape as is used in the pure copper dissolvers on the market. Right now, we are planning a test at one of our customer plants to dissolve the copper cuts from the laboratory tests. We are also validating to plate out the copper rods

Andreas Littorin

in their existing full scale electrowinning units, which were supplied by Sigma a few years ago. The intent is to offer an upgrade to existing customers once we have full scale tests verified in an actual PCB operation environment. We want to have this offer available to both new and existing customers by the end of this year.

How many worldwide installations of this equipment do you have?

About 20–25, something like that. We have had over 120 installs since the start. But of course, many of the plants from the 1980s and 1990s have closed down. There are still some old installations—20-plus years—still in operation. We're still supplying spares and consumables for those machines.

Is there new technology in your equipment compared to that older equipment?
Well, yes and no. As I said, the process is quite mature. Nowadays, we are fine tuning, optimizing, and automating as much as we can, trying to reduce the time required at the machine, which is already very low. Of course, the 20-year-old system was somewhat different. We've learned a lot over 45 years of operation, which we have integrated into the newer systems.

Where are you finding traction regarding bringing your system into a facility? Are they greenfield facilities? Is there a definite trend that you can identify?
Most of the discussions we're having with customers are still existing plants. It's a matter of timing and external factors. But the active projects are almost 50/50 these past two years—there are quite a few greenfield projects at the moment. It's a definite trend the last two to four years.

"From our perspective, it's a very interesting time and a good time to be in the business."

Greenfield projects, especially, seem to be paying attention to zero waste, closed loop systems; it seems to be a priority for them. There are a lot more brownfield sites that could be improving their zero-waste response, whereas there are fewer greenfield sites. If you're 50/50 with greenfield sites, that implies that the greenfield priority is for zero waste.
Absolutely, the big ones are greenfields. From our perspective, it's a very interesting time and a good time to be in the business.

What's your business presence in North America with respect to sales and support?
Sigma is based in Sweden, but we're working in the U.S. several times a year. We partner with IEC (International Electronic Components) to be our extended arm into the U.S. We have a lot of traction in Europe, but for the U.S. customers, to be in the correct time zone is very important, of course. I think we have a very good relationship with IEC, and that is a key advantage.

What could a brownfield customer expect to see for an ROI with this equipment?
It very much depends on the size of the plant. Historically, we've always been able to reach ROI around the two-year mark. Obviously, if you're a very small prototype shop, it could be harder. If you're a very big plant, your results could be quite less than two years. As I said, we have equipment still in operation after 20 years, so even if ROI takes three years, you still have 15+ years of gain because you're selling pure copper and getting both savings and revenue.

Final thoughts, Andreas?
There are exciting times ahead. Even though the greenfield sites are on the rise, there are a lot of brownfield projects that could be realized and, I think, subsidized. There are benefits to be gained quality- and cost-wise by investing. Fabricators can reach out and have us look at their numbers to see whether it makes sense for them to invest as well. We're always interested to help with an evaluation.

Thank you.
Thank you, I'm always happy to talk. **PCB007**

Stephan Kunz

Schmoll: Pushing Drilling Forward

Automation is everywhere, and nowhere is that more evident than the machines from Schmoll used in the new captive facility for Schweitzer Engineering Laboratories. Schmoll Maschinen GmbH Executive Director Stephan Kunz, and Evan Howard, service manager for Schmoll products, Burkle North America, discuss how their machines are perfectly suited for SEL's production lines.

Evan and Stephan, what Schmoll equipment did Schweitzer install in its new facility?

Stephan Kunz: Schweitzer decided on fully automated direct imaging for inner layer. We have the inner layer punch, and an X-ray target driller, including traceability functions by wave. After that, we have drilling machines, routing machines, and outer layer imaging. We also installed professional measuring equipment.

Evan Howard: The two MDI machines are our TTG model. This is a tandem table machine with automation arms. With the design of the open tables, automation arms are easily installed, whether they're provided by us or another company. The machine uses tandem tables to allow registration on one table, while exposing on the other. This creates a very streamlined process in an automated environment like Schweitzer. We achieve cycle times of less than 10 seconds, which is quite impressive.


Evan Howard

What are the advantages that Schmoll brings to a new production line project?

Kunz: Schmoll has a lot of experience in automated processes which are common in Europe, and more of those will be seen in America. When you look at all the processes, including X-ray, it's fully automated. Obviously, you need a certain quality, which we have.

With direct imaging, routing, and drilling, automation is adapted perfectly to these machines. The same applies to punch and X-ray, as well as drilling machines to routing machines, and outer layer imaging. On each individual piece, we do everything to deliver a high productivity machine. We have more than 500 machines with automation that have been installed in Europe.

Does automation seem to be a trend in the U.S. when companies are looking at new equipment?

Kunz: Oh, absolutely. I must be honest, there are certain products which are more complex to automate, such as extra-large panel formats, or very thick panels. For drilling or direct laser imaging, we get inquiries, and that leads to sales. If we look forward another three or four years, automation in the U.S. will be quite standard. In Europe, for example, we have a lot of unstaffed night shifts where the work is loaded up during the last day shift and run unattended through the night. This is something which, for sure, will come to America.

Schmoll has made a good name for drilling, punching, and laser machines. But the data collection gives us some advantage over communication as well. The customer requires fewer people to work on the machines.

It seems Schmoll has a well-established service organization in the U.S.

Kunz: That is one of our key strengths, and something we developed over the past three to four years to fulfill the customer's needs. We tripled our installation bases in America during that same period.

Positioned side-by-side, two fully-automated Schmoll XRA X-ray reference hole drilling machines.

Howard: When it comes to SEL, specifically, we moved a technician to Moscow, Idaho, to support this whole project. That technician was busy at SEL for a whole year getting all this started. That was a key factor in the service that supported this project.

When you talk about installation, the requirement was about 30 machines in just over a year. That turns into more of a project management task. We still have a weekly call with SEL to talk about machine arrivals, open points, things like that. It's truly been a partnership with SEL.

Do you see an increasing trend in the U.S. market toward standing up new facilities?

Kunz: There have been 20 to 30 years of investments in Asia with greenfield factories; we have not seen that sort of investment in the West for 25 years or so. It's impressive that in the last two to three years, we have seen a couple really big greenfield factories in the U.S. I don't think it's a trend yet, but it shows that some customers want to be independent from Asia. The output from these new facilities is not as much as compared to Asia, but the shift is significant.

Modul-XL drilling machine.

How do you see the market shifting? Is there momentum?

Kunz: What we find interesting is the importance of new equipment in America. Maybe five years ago, the equipment for America from our customers was 3–4% of our turn-over. In the past two years and next year, I'm expecting 20% of our turnover coming from America.

Gentlemen, thank you. PCB007

The highly accurate Schmoll Optiflex II post-etch punching machine.

Atotech: More Horizontal Panel Plating in the U.S.

Article by Christopher R. Daczkowski
ATOTECH USA

Recently, Schweitzer Engineering Laboratories (SEL) opened its new $100 million captive printed circuit board manufacturing facility in Moscow, Idaho. The new facility features state-of-the-art PCB equipment from MKS' Atotech, one of the leading providers of advanced PCB and IC substrate horizontal manufacturing equipment for the electronics industry. This type of equipment is normally delivered to Asian markets and is not usually seen in North America.

Equipment selection is a crucial decision for any company and directly impacts the quality and efficiency of production processes.

For our customers, several key factors usually drive the decision to install MKS' Atotech equipment lines. These include our long history as a reputable global solutions provider and proven record of successful installations worldwide. Today, we have delivered and installed more than 2,150 horizontal PCB systems for surface treatment, desmear and metallization, copper electroplating, and final finishing of printed circuit boards and IC substrates, of which more than 1,000 are horizontal copper platers. They are well known for their outstanding repeatability of copper deposition uniformity and pure copper plating results.

With the shift toward increased investment in local manufacturing in the U.S., our system solutions are appreciated as high-quality products to support manufacturing demand now and in the future. With our long history in the Americas, we are happy to see this development and are excited to provide the best possible technical support to our customer base, which is growing, especially with the trend of opening new, innovative PCB plants.

MKS' Atotech Uniplate® PLBCu6 and Uniplate® Cu18

Uniplate PLBCu6 is an inline wet-to-wet horizontal equipment for desmear, electroless copper, and flash copper plating. Uniplate Cu18 is a conformal plating and copper filling line for vias or through-holes. Both lines can be configured and connected with each other for a high level of flexible production set-ups. Customers can choose to run the lines separately or connect them with inlet and outlet stations in-between to create an inline process flow for enhanced plating performance. This allows customers a high level of flexibility and automatic line adjustment, depending on various PCB batches and their processing needs. For example, panels can be run twice through the desmear process, if required, or taken out after the flash copper plating for dry film pretreatment if the pattern plating process needs to be run subsequently. Alternatively, the processes can be run completely inline from PLBCu6 to Cu18 if conformal plating or copper filling of vias or through-holes in panel plating mode is required.

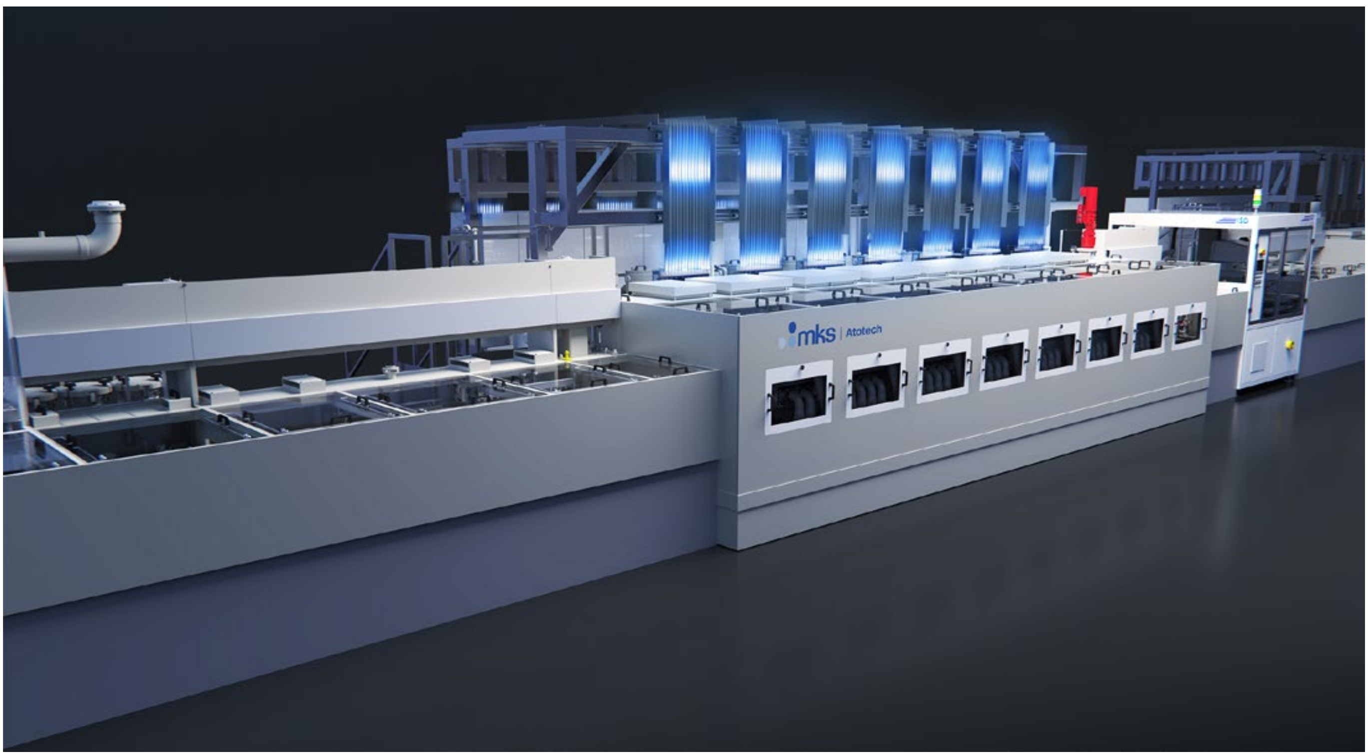


Figure 1: Uniplate® Cu18 for advanced conformal plating and copper filling of vias and through-holes.

Figure 2: Fully automatic cleaning equipment.

The new generation of MKS' Atotech horizontal lines are usually equipped with advanced copper plating units, which offer a higher fluid performance via increased pump power and fluid control capability compared to the standard Uniplate Cu lines. This additionally enhances the filling performance, especially for high aspect ratio boards, and enables more plating capabilities.

Uniplate stands for uniform plating results, which incorporates key technology features to enable:

- A uniform solution exchange based on patented flood bar technology
- Fully automatic control loops for critical bath solution parameters
- Auxiliary equipment for automatic replenishment of the chemistry. This includes the Oxamat for the desmear portion or the copper dissolving tank for automatic control of the iron copper concentration in the electrolytic copper plater.

Another feature for more uniform copper deposition is the turn gap adjustment (TGA), which picks up the panel utilizing a robotic arm and turns it 180 degrees to change the clamping position from one Cu plater unit to the next. Both lines are configured with optional features for process control, such as pH-control, conductivity measurement, and analyzer units to measure and control the critical process parameters, maintain them, and track them for quality control functions. Customers benefit from an automatic and tighter process control window, which results in high-yield production with less scrap and waste as well as reduced water, chemistry, and energy consumption. These production lines are equipped with several particle control features, such as fine-line filtration units and automatic cleaning equipment to minimize the impact of particles on yield rates.

Meeting Our Customer's Specific Needs

Traditionally, the MKS' Atotech lines are tailored to the specific needs of its customers.

Customers today have very specific production know-how and have developed their own way of manufacturing. We understand that each customer requires specific features for their equipment set-up to enhance the overall performance and efficiency of their manufacturing process. One of our strengths is to consult our customers and partners at an early stage to make it easier to install the equipment that fulfills their production needs now and in the future.

MKS' Atotech focuses on providing the most advanced technical solution with systems that also comply with the latest sustainable manufacturing standards. This is seen in the consumption monitoring feature for energy and fluids that allows customers to track and analyze resource usage to optimize processes and identify areas for improvement utilizing software that meets customer system requirements and enables seamless integration into MES systems.

All newly installed lines provide uniform and reliable copper plating capabilities like repeatability of copper deposition uniformity and greater automation. The smart communication of process and production data to customer MES systems via SECS GEM and XML interfaces enables automation procedures, such as automatic setups for different PCB batches via barcode scanning. This allows real-time production control.

Why Customers Choose to Partner With MKS' Atotech

Today, MKS' Atotech enjoys an excellent reputation for successful global installations of horizontal plating lines, most recently more in North America. Our solutions enable best-in-class pretreatment, desmear and electroless metallization, void-free copper plating, and pure copper deposition, as well as final finishing of PCBs. The quality of the plated copper plays an important role, especially in industries and applications where power transmission is crucial. Our equipment ensures that the copper plating process is highly optimized for efficient power transmission, resulting in high-quality products with highly reliable copper structures.

As one of the leading PCB equipment companies, MKS' Atotech is a leader in providing process chemistries, services, and recently, software to help customers in their journey

Figure 3: TGA system for 180° PCB turn/adjustment.

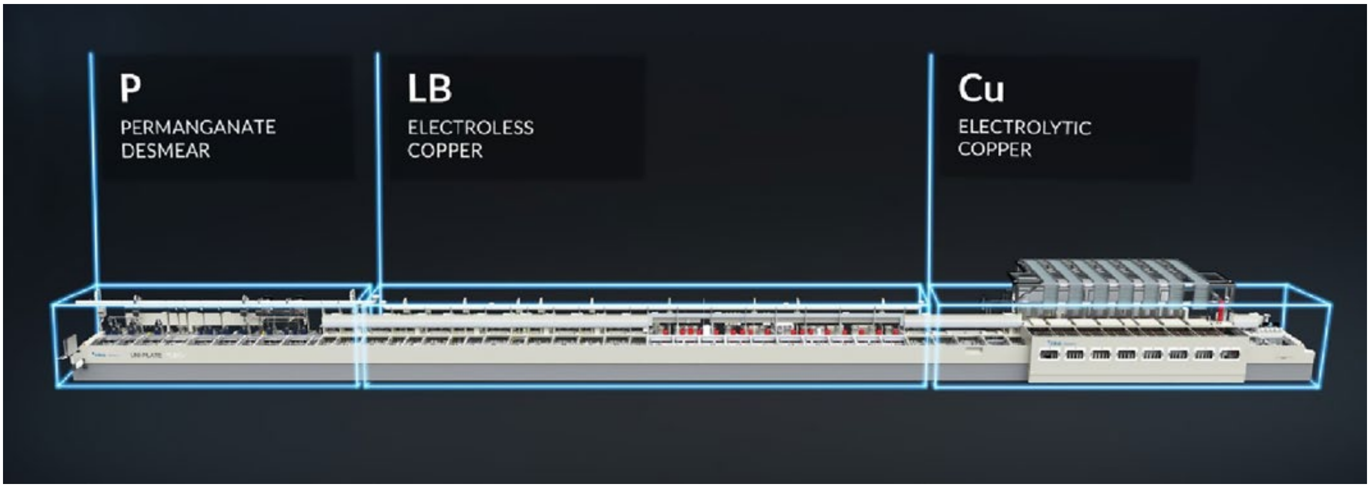


Figure 4: Uniplate® PLBCu6 for flash copper plating.

to transform to digital manufacturing. MKS' Atotech's Digital Factory Suite platform connects to the onsite production equipment and continuously collects process and equipment data during manufacturing. Using advanced analytics and platform applications, such as condition monitoring and traceability, the collected data generates high-value insights into equipment and process conditions. This enables factory engineers to perform supervision, maintenance, quality inspections, or general traceability activities directly from their workplace. In addition, real-time condition monitoring and mobile alerts prevent defects and alarms from being overlooked, thus reducing the risk of unplanned downtime. The Digital Factory Suite also provides applications to monitor and manage consumption, such as energy, that enable our customers to run a more sustainable production.

We are honored that SEL trusts us as a world-class solution provider for horizontal plating of PCBs in their innovative manufacturing facility in Moscow, Idaho. The collaboration demonstrated our innovative strength, flexibility, and ability to meet customer requirements by providing a high-quality, high-volume production line setup. We are excited to continue our partnership and assist SEL in the future.

New Trends in the U.S. Market Present an Opportunity for MKS' Atotech

The U.S. market is currently experiencing a significant shift toward increased investment in local manufacturing. This is due, in part, to factors such as the need for greater control over supply chains, the desire for reduced reliance on international shipping, which has been disrupted in the last years, and geopolitical hurdles such as tariffs and trade restrictions. Greater control over local manufacturing streamlines operations, reduces lead times and improves overall efficiency—a trend that affects a wide range of sectors, including the electronics and automotive industries and consumer goods. MKS' Atotech is ready and able to support this evolution with the necessary technology and equipment to build our customers' local manufacturing capabilities. **PCB007**

Christopher R. Daczkowski is a systems engineer II at Atotech USA, LLC, Materials Solutions Division, MKS Instruments, Inc.

Chemcut:
Blending Capabilities and Culture

Mike Soble, who works in technical sales for Chemcut, explains that despite the long-distance between Idaho and Pennsylvania, working with Schweitzer Engineering Laboratories on its new facilities was truly a perfect match.

Chemcut was selected by Schweitzer Engineering Laboratories (SEL) for its new facility in Moscow, Idaho. What equipment did you put into their facility?

We installed a DES (develop/etch/strips), a DES Pre-Clean, an oxide system, a HASL-Pre-clean, and a solder mask developer. Two of those systems were duplicates.

What are the advantages of Chemcut equipment for this project?

Philosophically, this was a good match between Chemcut and SEL. They want to partner with vendors that are geographically close. Certainly, we had an advantage over other competitors because we're based in the U.S.

We've been around for 65 years, so we have a great degree of stability. Even though cen-

Chemcut CC8000 inner layer develop-etch-strip (DES) system using cupric chloride etchant. The two large portions of the line shown are the etching chambers.

tral Pennsylvania is a bit far from Idaho, we can get there. SEL has a very large cross-functional team, and once they visited Chemcut and met our team, they decided very quickly on buying our equipment.

The SEL team certainly has taken on a huge project, going from outsourcing all its printed circuit boards to building its own fab. What was it like to work with them?

It ranks up there as one of the most enjoyable business ventures we've had in quite some time. As you know, they're very big on partnerships with vendors and suppliers. From my perspective, they handled the transition smoothly; it went without a hitch.

When they visited Chemcut, they brought in representatives from management, purchasing, project management, engineering, and maintenance. As the project progressed, they learned a lot about Chemcut. At one point, we were demonstrating some of the construction techniques to their engineering and maintenance staff, and their engineers jumped right in. The best way to describe their whole organization is they just go and do it.

Likewise, the communication channels were excellent. With any project, there are some bumps and bruises, particularly in the current supply chain environment. SEL offered their help when suppliers were having difficulties.

The SEL team is quite impressive for taking on such a large project. It starts with the people; not just senior people are involved; a core of younger people—who probably had never managed a project like that—were involved. It was just a positive attitude that really fostered teamwork with the suppliers. Their staff was technically competent, and they gained more competency as the project went along. They do a great job in terms of cross-functional teams and communication.

As we got to certain milestones in the project, we started video conferences. SEL came in at certain stages to prep for factory acceptance testing. We've found that when we start a turnkey installation, the customer's perspective is, "That's Chemcut's equipment." Because we have them assist with the installation, after we've finished and gone, their new perspective is, "That's our equipment." There is such a fundamental shift when the people can embrace the concept of the equipment during the construction and installation phase. Everybody at SEL was hands-on. They wanted to do it. They wanted to dig deep. That's a tribute to them, and it made our job so much easier.

Mike Soble

Were there any new product innovations put in place for SEL?

They went with our CC-8000 product for the DES equipment. This is Chemcut's premium product offering for fine line features and thin material transport. Chemcut's XLI was selected for all their processes. All this was driven simply by the needs of their product demands.

It sounds like the work was primarily in configuring the systems to get the manufacturing results that SEL was looking for: single-sided etch on the bottom side only, for example.

We had a number in our discussions with them to get them to move into a more standard double-sided etching. By demonstrating the capabilities of our equipment, they made that decision quite rapidly.

After years of essentially no build-out in the U.S., we're starting to see some greenfield facilities. They tend to be captive manufacturing, like SEL. From your position at Chemcut, do you see this as an emerging trend?

Professionally, I go back to the days of IBM and AT&T engaging in the captive house concept. I believe one of the drivers may very well be a leading-edge trend as OEMs increasingly want to protect their intellectual property. There's recognition that the supply chain is quite fragile, and the more vertically integrated they are, the more predictable their business model will be.

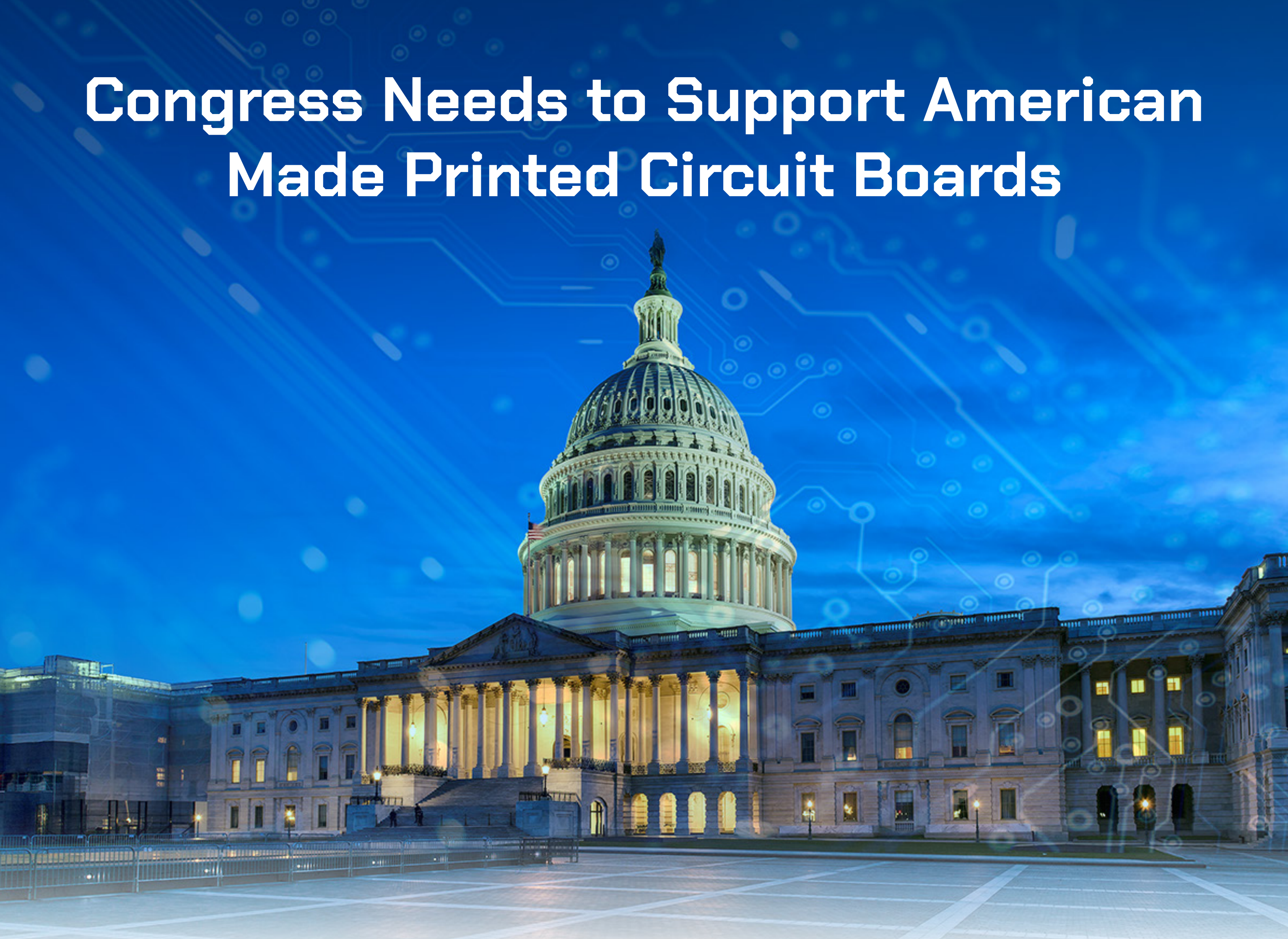
Do you see momentum from influences like the CHIPS Act, etc.?

Yes. Also, there have been some acquisitions that could likely lead to some new facility builds. There are various tax structures throughout the United States that can have a very positive impact on these business decisions.

Mike, it sounds like this has been a worthwhile partnership. Thank you for speaking with me.

Yes, I agree. Thank you. **PCB007**

Chemcut chemical cleaning system.


Congress Needs to Support American Made Printed Circuit Boards

Processes to Support IC Substrates and Advanced Packaging, Part 4

Trouble in Your Tank

by Michael Carano, IPC CONSULTANT

Introduction

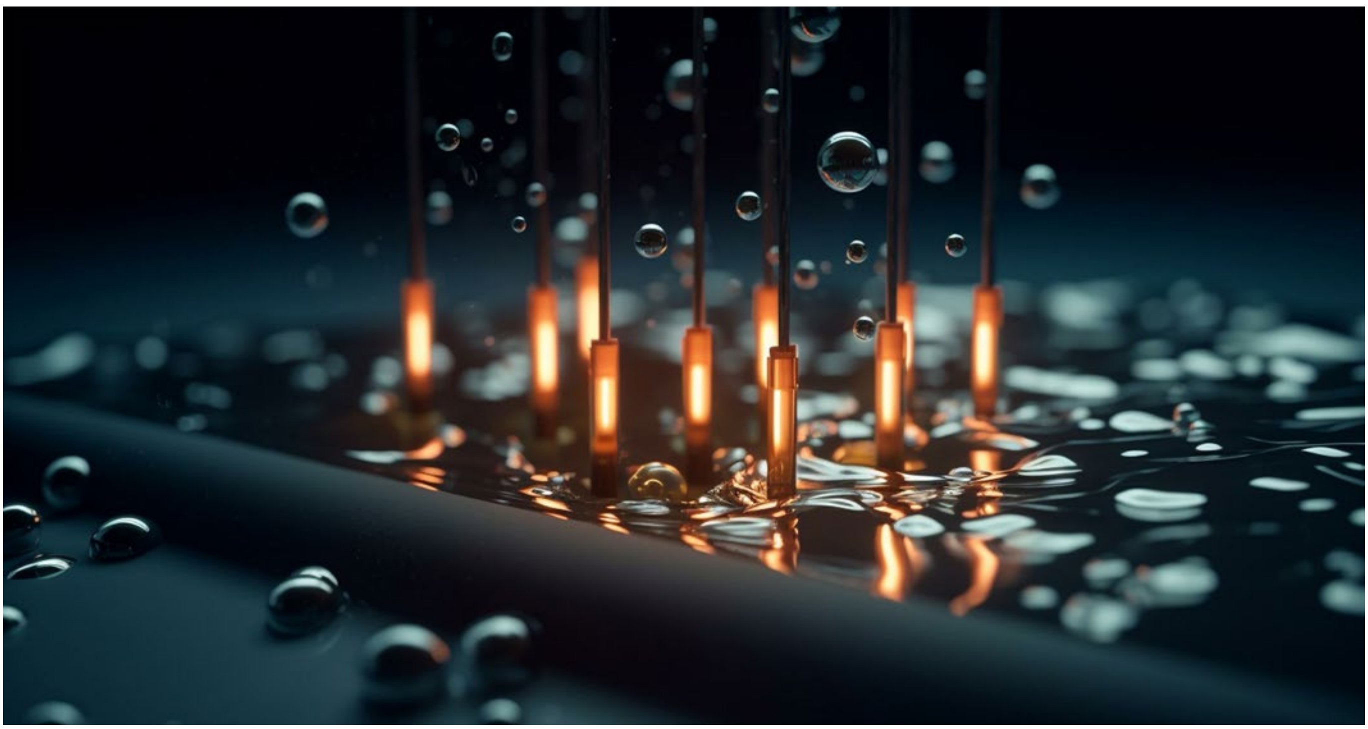
In a previous column, the critical process of desmear and its necessity to ensure a clean copper surface connection was presented. Now, my discussion will focus on obtaining a void-free and tightly adherent copper plating deposit on these surfaces.

Metallization

After the desmear process, the task is to insure a continuous, conductive, and void-free deposit on the via walls and capture pad. Today, there are several processes that can be utilized to render vias conductive, including:

- Conventional electroless copper
- Palladium-based direct metallization
- Graphite direct metallization
- Carbon black direct metallization
- Conductive polymer direct metallization

These metallization processes (also known collectively as "making holes conductive" or MHC) are well developed for both plated through-hole and blind via metallization.



Direct metallization (DM), in particular, is applicable to horizontal processing, although vertical systems are also used. These processes typically involve the deposition of a conductive coating (palladium, conductive polymer, graphite, carbon black). This step is followed by electrolytic copper; thus, the actual electroless copper step is eliminated.

These processes have been presented and thoroughly discussed elsewhere[1]. While direct metallization processes may reach certain limitations for use with very high aspect ratio rigid circuit boards, these processes are very efficient and effective for HDI. Direct metallization systems primarily function by coating the substrate, as opposed to a true chemical reaction that is inherent in conventional electroless copper plating processes, such as electroless copper. Contrarians of direct metallization point to sheet resistance measurements of the direct metallization coatings vs. electroless copper. Yet, while the DM films are somewhat less conductive, most of the direct metallization processes have resistances in the neighborhood of 5–25 ohms square. This is more than sufficient to promote electroplating propagation in blind vias and mid- to high-aspect ratio through-holes.

Another advantage that DM processes have over conventional electroless copper is the ability of these DM films to render higher performance materials conductive without overly aggressive desmear tactics. It is well known that electroless copper requires sufficient roughening of the resin to promote palladium adsorption and to insure adhesion of the subsequent copper deposit. However, most direct metallization processes require only minimal resin roughening to promote adhesion. This is because the more popular systems commercially available today rely on coating technology. And with the use of special polymers, these DM materials bond and adhere to a wide variety of resin materials with relative ease[2].

It is understood that higher performance resin materials—with the characteristics of higher Tg, lower CTE, and higher Td (temperature of decomposition)—are more chemically resistant, making desmear more difficult. With less resin removal and minimal restructuring of the resin surface after desmear, one can surmise that electroless copper would be less effective on these types of materials. The carbon- and graphite-based direct metallization systems do not require a palladium catalyst to first adsorb onto the glass and resin in order to catalyze the deposition of the copper. The electroless copper deposition process is shown below. The presence of palladium is required to effect the reaction as shown below. The process is essentially two half-cell reactions (see Figure 1).

A byproduct of electroless copper plating is hydrogen gas (H_2). The ability of these fine gas bubbles to lodge in blind vias and high aspect ratio through-holes is well understood. Even with the use of vibration and modified plating solution agitation systems, hydrogen gas remains an issue. However, the direct plating processes, as stated earlier, are coating processes, not chemical reactions. Thus, hydrogen gas evolution is not present.

Overall Reaction:

$$Cu(EDTA)_2^- + 2HCHO + 4OH^- \rightarrow Cu + H_2 + H_2O + 2CHOO^- + EDTA^{4+}$$

Sources of formate: secondary reducing agent

1. $Cu(EDTA)_2^- + 2HCHO + 4OH^- \rightarrow Cu + H_2 + H_2O + 2CHOO^- + EDTA^{4+}$
2. $2HCHO + OH^- \leftrightarrow CH_3OH + HCOO^-$

Figure 1.

There is a second byproduct of electroless copper—the Cannizzaro reaction. Here, the reducing agent in the electroless copper plating solution reacts with the caustic component of the solution to produce sodium formate. The sodium formate leads to an increase in specific gravity of the solution, which in turn can lead to solution instability and a slow deposition rate. Additional concerns with increases in specific gravity are plating defects such as hole wall pullaway (HWPA) and interconnect defects (ICD).

Another advantage of these DM systems is the relatively low cost to automate the plating line. As an example, a graphite-based or carbon black process with a horizontal plating tool is able to prepare and coat a board in five to six minutes. The panel is then ready for either panel plating in electrolytic copper or is sent to dry film imaging prior to pattern plating.

In next month's column of Trouble in Your Tank, I will present a more in-depth discussion of direct metallization. **PCB007**

References

1. *HDI Handbook,* by Happy Holden.

2. "Comparing the Reliability of a Graphite-based Direct Metallization Process to Conventional Electroless Copper for Rigid Through-Hole Printed Circuit Boards," by Michael Carano, Electronic Circuits World Convention 12, November 2011, Taipei, Taiwan.

Michael Carano brings over 40 years of electronics industry experience with special expertise in manufacturing, performance chemicals, metals, semiconductors, medical devices, and advanced packaging. To read past columns, click here.

PCB Industry Advocating with U.S. Government Officials

In a recent presentation to the CHIPS Act Industrial Advisory Committee R&D Gaps Workgroup (IAC), IPC's chief technology officer, Matt Kelly, shared industry dynamics in the wider electronics manufacturing ecosystem. We are publishing Kelly's presentation here, in its 22 minute entirety, for your edification and as an example of the work done by all the advocacy organizations representing our industry.

Computer-aided Bare Board Testing, Revisited

Happy's Tech Talk #22

by Happy Holden, I-CONNECT007

This is from a paper I gave at an IPC conference in Denver in 1983. Obviously, computers have come a long way since 1983, so the minicomputer I discuss using here can easily be replaced by a simple desktop or notebook computer. The statistics are from Dr. W. Edwards Demings' first book and the software used is from NIST'S *Engineering Statistics Handbook*. It's still very appropriate.

Even though I speak in the present tense in the paper, I am talking about 1983; much of what is discussed here is related to the industry from the early 1970s through 1983.

Introduction

Over the past decade, Hewlett-Packard (HP) increased the performance, capability, sophistication of its products, and the PCB multilayers it contains in their complexity. One of the results of this trend has been the increasing use of high density multilayer printed circuit boards, so the ability to find electrical opens and shorts through a visual inspection process has declined to the point that now it has become impossible. Today, many PC manufacturers view bare board electrical test as unavoidable,

Released November, 1983, the HP-150 (aka HP Touchscreen or HP 45611A) was a compact, powerful and innovative computer made by Hewlett-Packard. (Source: Thomas Shanz, Wikimedia Commons)

and few perform any type of defect analysis to see why boards fail this test. HP's Sunnyvale Printed Circuit Facility (SPCF) set out to exploit the information potential of the board test process.

Continuity testing occurs when a printed circuit is approximately 85% completed. Testing supplements PCB visual inspection, which was the only prior means for finding opens and shorts. The current average electrical defects at first test are reported in the HP PC Manufacturing Standards, Section 407 (Raw Board Electrical Test). This section has details on HP's Electrical Test Standards. This includes when to test, test extent, electrical characteristics, and fixture documentation specification. The development of this standard has gone a long way in eliminating the uncertainty and unknowns with our (HP's) customers. The criteria of when to test a bare board is now a simple equation.

When to Test

The debate on when, how much, and how often to electrical test bare PCBs ended when Dr. W. Edwards Deming provided insight into the test and inspection question. In chapter 8 of his manual, "On the Management of Statistical Techniques for Quality and Productivity," he outlined the equations below. The essential elements in the decision are the average electrical defect, the cost to test one unloaded PC board, and the cost to test and repair it if a defected board is loaded. Estimates on the average defects are shown in Figures 1 and 2.

The following (provided by Dr. Deming to HP) are developed to minimize the average total cost of a lot.

(1) The average cost of inspection of a lot of N parts is Y_1,
$Y_1 = N (P+Q x) k_1 / q$

(2) The loss from (N-n) Q p defective parts that get into the production line is Y_2,
$Y_2 = N (1-x) Q p (k_2 + k_1/q)$

(3) The average total cost per lot will be $Y = Y_1 + Y_2$.
$Y = (N k_1 / q) [1+Q q (kp-1) (1- x)]$ where K = (3).

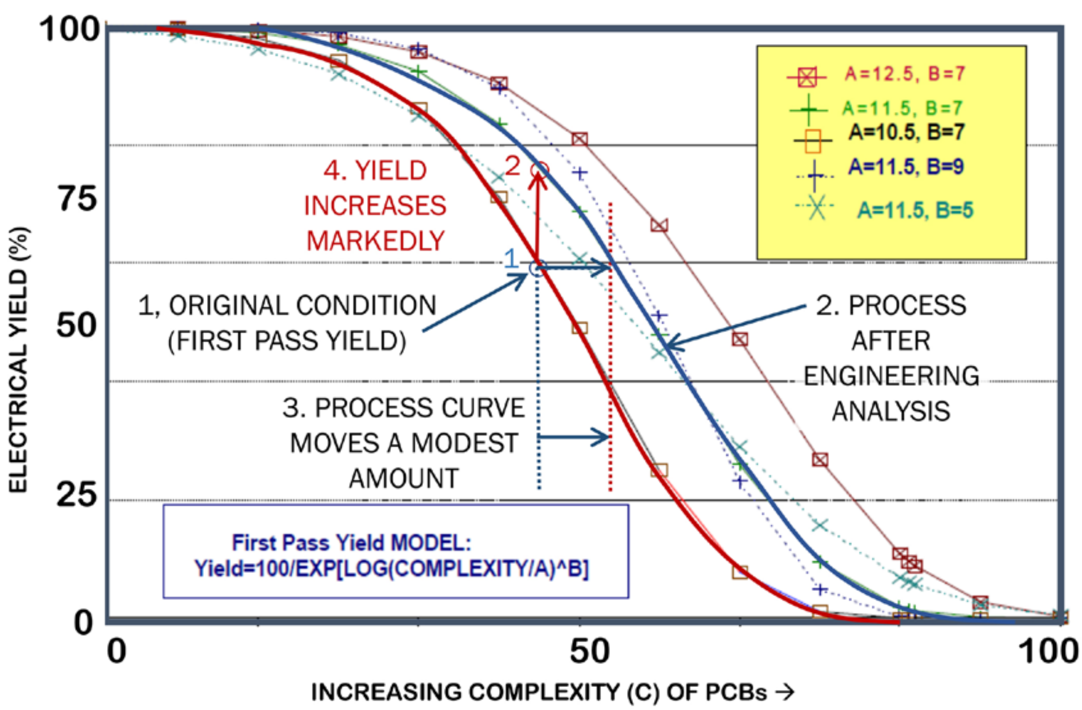


Figure 1: Electrical yield loss due to PCB complexity.

1. If $Kp < 1$, we have minimum Y if n=0: Therefore, no inspection or test. (This is the cost to inspect and correct the final product, $Np [k_2 + k_1/q]$.)
2. If $Kp > 1$, we have minimum Y if $n = N$: Therefore, 100% inspection or test. (This is the cost to test all bare boards, Nk_1/q.)

The two conditions of n=0 or no testing, and n=N or 100% testing can be plotted in Figure 3. This is the curve of Kp=1, the point of indifference. It is the values of p and the reciprocal of p, $1/p=k_2/k_1$. By calculating the ratio k_2/k_1 and estimating p, any point above the curve in Figure 3 represents the need to electrical test. Below the curve, no testing is required.

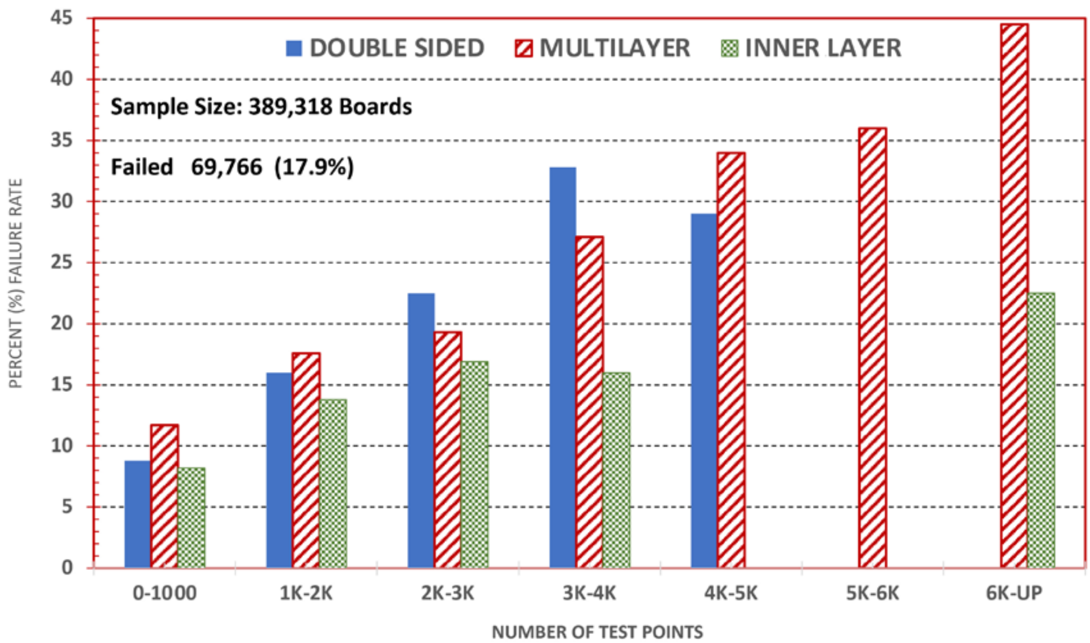


Figure 2: Electrical failure rate compared with number of test points. (Source: Testerion Inc., August 1983)

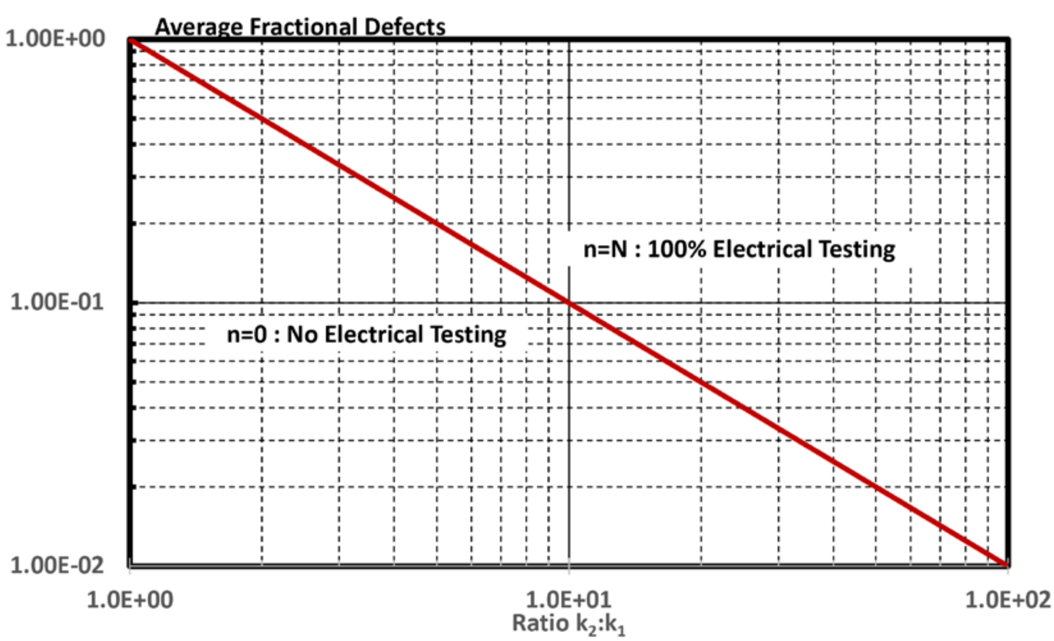


Figure 3: Optimum decision on inspection of PCBs. (Source: W.E. Deming to HP, 1981)

Notations:

N = Number of pieces in a lot
n = Number of pieces in a sample from lot
p = Average fraction defective
q = 1 - p
k_1 = The cost to test one unloaded PC board
k_2 = The cost of a defective piece that gets into the production line. Includes the cost to discover that this is the defective part, non-recoverable parts, and the cost to replace the PC assembly as well as to retest the replaced assembly.
P = Proportion of lot set off for screening (testing)
Q = 1 - P

How Much to Test

Test extent for dedicated fixturing: The most thorough test of a printed circuit board is to check for all possible shorts and to verify there are no open traces on the board. Checking for shorts requires a minimum of one probe on each circuit network. Checking traces for opens requires a minimum of two probes for each trace. An opens test will usually have more probes to verify every end of a network.

Since the cost of fixturing is directly proportional to the number of probes in a test fixture, the most thorough test also requires the most expensive fixturing. The following table defines general criteria for the types of tests to be performed for dedicated fixtures.

Test level 1 is a bare minimum test but for use only when opens are improbable. Test level 2 is the minimum recommended test level. Test level 3 is the most desirable as it evaluates all shorts and opens at lowest cost. Tests 4 and 5 pinpoint the trouble spot to a smaller area. Refer to Figure 4 for examples of test point locations for the different test extents.

No Testing

If there is no electrical test in a PC shop, the visual inspection area is burdened with trying to find electrical opens and shorts. As PCBs continue to become denser, with closer spacings, more layers, and smaller traces, opens and shorts become more common and finding them through visual inspection gets harder. The most obvious benefit of implementing electrical test is that it allows visual inspection people to concentrate on specification tolerances and cosmetic defects, which gives the PCB manufacturer a marked productivity increase in that area of his shop.

Test Level	Test Probe Configuration	Test Extent
1	One probe per network	Short only, if no opens
2	Two probes per network in critical or problem areas	Shorts and some opens
3	Probes at end of networks	Shorts & all opens
4	Probes at all component holes	Shorts & all opens
5	Probes at all component holes, plus critical vias and fingers	Shorts, all opens & improved diagnostics

Level Extents	Location	# Probes
1	A	6
2	A + B	8
3	A + B + C	16
4	A + B = C + D	32
5	A + B + C + D + E	34

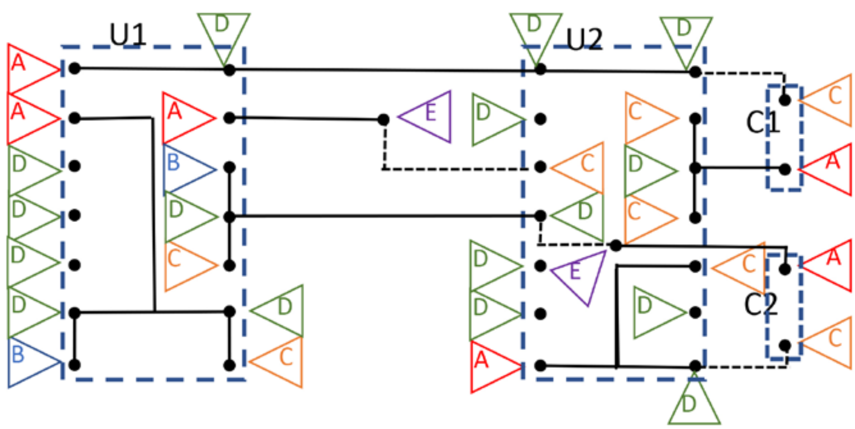


Figure 4: Example of test point location and test levels.

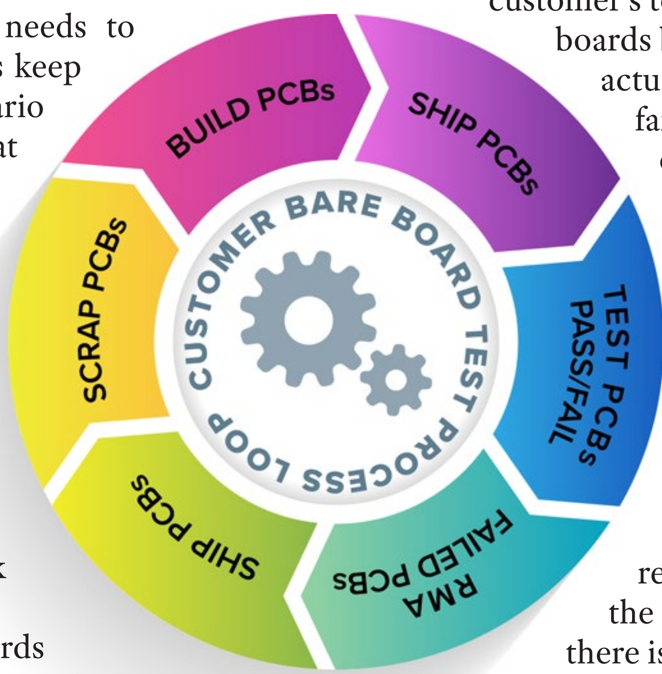
When a PCB customer buys boards untested and does not do a bare board test of his own, it is difficult at best for him to identify defects in the boards. This is usually attempted in a pretest area after the boards have been loaded with components, and it is complicated by his not being able to see the board under the components, the possibility of bad components, and the processes such as wave solder that the boards have been put through. Suffice it to say that all but a small minority of defective boards end up being scrapped (components included) with too much time having been invested in them while trying to get them to work. So, no one's the wiser? Probably not for long.

Customer Testing

Most PCB customers are well aware of the "Japanese Scenario" wherein all components of a product (including PCBs) are tested prior to assembly so there is very little troubleshooting, repair, or rework investment. This is what the customer wants. A second aspect of the scenario is that of process feedback, wherein, when a part fails a test, an engineer immediately researches the cause, and fixes it upstream so it does not happen again. This is what the PCB manufacturer needs to improve his yield. Let us keep both aspects of the scenario in mind and look at what happens when a customer buys a bare board test system (because the PC manufacturer doesn't have one).

This is a self-perpetuating circle. The circle is detrimental because:

- There is a good possibility that the artwork the manufacturer was given to build the boards with, or one of his upstream processes, is somewhat out of spec. This means that the defective features get included in the boards somewhat regularly.
- The manufacturer first learns that a percentage of a PCB run failed when his customer calls to order more, as soon as possible. Scheduling is disrupted by another hot order.
- Depending on distances involved, board volumes, and return for credit processing delays, the manufacturer may always be one or more runs behind in finding out what went wrong.
- Unless the test error printouts attached to returned boards show a blatant correlation, research into defect causes requires a time-consuming correlation of errors by hand. The manufacturer probably cannot spare the labor because hot orders are coming through.
- The customer test circle is bad for public relations. The customer sees all process problems before the manufacturer has a chance to rework and alleviate them.
- The manufacturer has no control over the customer's testing. Some of the boards being returned may actually be good but were failed because of sticking or bent pins in the test system and fixture.
- A testing operation needs troubleshooting feedback to insure valid test results. A troubleshooting (and repair) operation needs retest feedback to ensure that repairs are effective. In the customer test circle, there is so much time and red tape between these operations that neither function well.



From the above, we can see that customer testing implies that the PCB manufacturer can only implement process feedback in a fashion that is too late with dubious data in an inconvenient format (i.e., old error printout). Progress begins when a test system is brought in-house.

In-house Testing to Raise Yield and Productivity

It will be helpful to think of process feedback as a constant endeavor to tune up and fine tune upstream processes and tools by learning from your mistakes. Yield improves when you quit making the same mistakes. Productivity improves in relation to yield.

The key to effective feedback is information; the fact that an electrical test (ET) operation rejects more boards than any other process is simply an indication of this information potential. The development efforts at SPCF toward exploiting ET information began due to needs in the ET area itself.

Getting Started

Now the testing happens in-house. Visual inspection is no longer a bottleneck, customers are happy, and the test and troubleshooting areas are complementing each other. However, how do you use ET information to find why the bad boards failed, when you already seem to spend too much time finding a good board?

Bare board test systems operate by comparing the electrical connections of a board being tested, with a memory representation of the connections in a "good board." Finding this idealistic "good board" can be a problem, especially for complex PCBs that will eventually show a 30% or higher failure rate. The amount of time spent in the "find a good board" mode directly depends on how often new part numbers and revisions are tested, the complexity (and hence the yield) of these new boards, and the data reduction capabilities that are available.

To give an example, we will assume that the self-learn mode of the test system is used to program the connections in a board sitting on the top of the stack to be tested. Next, the system is placed in the test mode and, say, 10 boards are tested, only to find that each of them shows an appalling number of errors. A perceiving question at this point is, "Just how often are each of these errors occurring?"

Error Correlation

The concept of a communication link between a test system and an external or "host" computer has been a key to the developments at HP's SPCF. In response to the question of how often each of these errors are occurring, SPCF developed a computer program that ran in a microcomputer which was interfaced to their first test system. When the test system detected an error in a board being tested, it would tell the microcomputer about it. The microcomputer would log it into memory, and on request, correlate all the logged errors and produce a display with the number of times each error was seen, from the most frequent on down. The program would also count the number of boards tested and failed, and produce hard copy reports identifying the run, test results, and the most frequently correlating errors. A sample report is shown in Figure 5. This relatively simple tool has the following major effects:

1. It differentiates between "systematic" and "random" errors. Systematic refers to the same type of defect occurring repeatedly in the same location. Systematic defects are the foundation of process feedback.
2. It provides a constant diagnostic on the test system and fixture. By doing a correlation occasionally while testing, intermittent pins are soon highlighted, and a quick check of the failed boards confirms this.
3. It allows a drastic time savings when finding a good board. For example, highly correlating opens at the top of the display point to probable shorts in the board that was programmed too.

Test systems capable of logging and correlating detected errors are just now becoming available. Systematic errors most often point to artwork or design problems (i.e., close traces, narrowing line widths, scratches, dust, etc.). They also indicate tooling problems such as misregistration and drill skew. The nature of random errors indicates process problems such as whiskers and voids, but the assumption of random errors should be proven by statistical testing[1].

Phantom Errors

A phantom error is an electrical open/short which is reported by a test system but does not exist in the PCB being tested. Phantom errors are caused by the presence of solder mask, oxides, or etching residue in and around PCB holes, which act to insulate/short test probes from the holes.

At SPCF, software in the host computer allows ET operators to halt the test system when an open is detected, though electrical stimulus is still applied to the test points in question. By briefly reactivating the fixture in the test system, while observing status indicators, electrical contact to the PCB can usually be achieved. A key on the operator's terminal instructs the host computer to discard the error, and the test continues. Through detecting and discarding phantom errors during the test process, time is saved in troubleshooting and retesting. An estimated average of 15% of all errors reported in finished boards are phantom errors.

```
COMPLETE PASS 1   02620-80085
            820318   SPC

HP SUNNYVALE BARE PCB TEST REPORT:   SYSTEM -> 1

!---) TEST RUN (----------------------------------------!
!     PART #      ! VENDOR ! OPER !  DATE  !    WO #    !
!-----------------!--------!------!--------!------------!
  02620-80085        SPC     S.H.   820318   42664785

!---) FIXTURE INFO (---------------------------!
! FIX# ! NFXIM ! NCNIM ! FXEXT ! FXTYP ! FXST !
!------!-------!-------!-------!-------!------!
  370      2      23       C       A      H.

!---) PCB INFO (----------------------------------------------!
! REV ! AWDATE ! NLYRS ! SQICH ! NHOLS ! SIDE# ! TRNUM ! PANIM !
!-----!--------!-------!-------!-------!-------!-------!-------!
   B   810225     4      154     3954     0       2       0

!---) RESULTS (------------------------------------------------!
!NUMBER!NUMBER!  %   !%W/OPENS!%W/SHORTS!%W/BOTH!TOT RUN!AVG-TIME!
!TESTED!FAILED!FAILED!  ONLY  !  ONLY   ! OP&SH ! TIME  ! / BOARD!
!------!------!------!--------!---------!-------!-------!--------!
  1061    300   28.28   14.33     60.00    25.67   1020      .961  (--HISTORY

    78     17   21.79   11.76     35.29    52.94     47      .603  (--THIS RUN
                -----   -----     -----    -----             -----
                -6.48   -2.57     -24.7    27.27            -.359  (--VARIANCE
==================================================================
           HISTORIC TOP 5 ERRORS FROM LAST TWO RUNS:
 DATE   SYS#   FREQ              ERROR                 SEEN IN IMAGES
820318   1      1--) SHORT FROM CN-  1 PT-    2....TO CN-  1 PT-   35    ,1
820318   1      1--) SHORT FROM CN-  1 PT-    1....TO CN-  1 PT-   17    ,2
820318   1      1--) SHORT FROM CN-  1 PT-   43....TO CN-  6 PT-   18    ,2
820318   1      1--) SHORT FROM CN-  1 PT-   49....TO CN-  6 PT-   18    ,2
820318   1      1--) SHORT FROM CN- 10 PT-    7....TO CN- 11 PT-   23    ,1

820322   1      9--) SHORT FROM CN- 17 PT-   59....TO CN- 19 PT-   63    ,1,2
820322   1      8--) SHORT FROM CN-  2 PT-   23....TO CN-  2 PT-   45    ,2
820322   1      6--) SHORT FROM CN-  2 PT-   24....TO CN-  2 PT-   44    ,2
820322   1      6--) SHORT FROM CN-  2 PT-   25....TO CN-  2 PT-   43    ,2
820322   1      6--) SHORT FROM CN-  2 PT-   26....TO CN-  2 PT-   41    ,2

           TOP FIVE ERRORS IN THIS RUN:
820318   1      2--) SHORT FROM CN-  5 PT-   51....TO CN-  5 PT-   52    ,1,2
820318   1      2--) SHORT FROM CN-  5 PT-   52....TO CN- 13 PT-    2    ,1,2
820318   1      2--) OPEN  FROM CN-  8 PT-   54....TO CN-  9 PT-    5    ,1
820318   1      2--) OPEN  FROM CN-  9 PT-    5....TO CN- 11 PT-   44    ,1
820318   1      1--) OPEN  FROM CN-  7 PT-   48....TO CN-  8 PT-   24    ,2
```

Figure 5: Sample report including part information, lot information, current and historical defects, and specific defect analysis.

Testing in Panel Form

Testing in panel form refers to testing PCBs before they are routed out of the panel that contains them. A number of productivity advantages are realized in this way. Phantom errors are nearly alleviated because the boards have not yet been through a solder mask operation. Test throughput can be greatly increased by using multiple image fixtures oriented to the stepped and repeated PCB images in the panel. A number of boards are then tested at the same time as a single board. It is much easier to troubleshoot and repair boards before solder mask and graphics are applied. If a board cannot be repaired (i.e., due to inner layer shorts), it is scrapped before additional downstream costs are invested in it.

The geographical location of defects in a panel gives important clues to upstream causes.

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Contact: Brendan Hogan ● M (610) 620-3795 ● b.hogan@MivaTek.Global

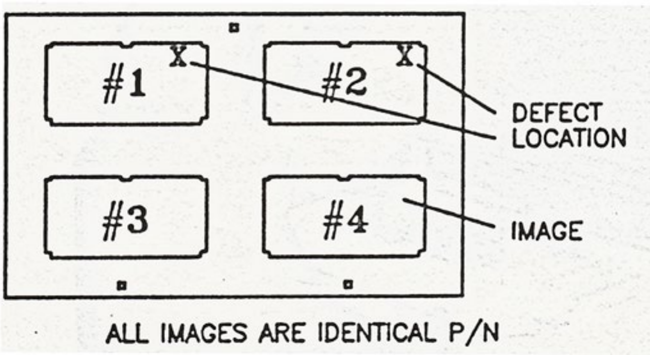


Figure 6: Geographically significant defects on a PCB panel.

This information is lost when testing finished boards. Figure 6 illustrates the significance of geographical defects.

Currently available test systems will report errors in a panel as though it were a single finished board. A few setup parameters used by the SPCF computer allow it to indicate which image is failing, and it translates all errors back to the first image. A single image overlay (or roadmap) can then be used for troubleshooting. Error correlation displays indicate what images each error was seen in. Note: Each image in a multiple image fixture must be wired in the same connector-pin sequence. This has always been the normal wiring method used by SPCF fixture vendors.

SPCF System Overview

An overview of the current SPCF system may be helpful to those engaged in bare board test development, as stand-alone test systems having a number of the following capabilities will not be available in the near future.

The PCB test systems are located at SPCF, Building 71, in Sunnyvale, California. Each of the five test systems has an adjacent HP2621P terminal as an operator console. The test systems and terminals are linked to the electrical test HP1000 computer (one of five in SPCF). A test operator uses these terminals to initiate the test procedure by entering a workorder number (and possibly a part number if the boards have not been tested before).

The integral printer will document any defects as they occur, and these printouts can be attached to each printed circuit panel to allow the review of possible repair of the defect. Figure 7 shows a system diagram of the electrical testing and AOI.

The SPCF system described above has a number of major functions:

1. Translate test errors into various formats (absolute, x-y, etc.).
2. Correlate and store errors-by-run and run-to-run.
3. Download and save test programs to and from the test systems.
4. Store fixture and PCB descriptions.
5. Store run results by part number, workorder number, vendor, revision, and inner layer side number for a period of one year.
6. Generate various reports by time limit, part number, workorder, and vendor, detailing production information, worst offenders, graphical trends, etc.

Benefits

The major benefit of this new approach is that it focuses on preventing errors in the first place. It identifies systematic defects so their sources can be tracked down, it nearly eliminates phantom errors, and it provides information on random errors that can be used for process control. SPCF believes that the new system eventually will help them to achieve a zero-defect rate in electrical continuity for all boards made at SPCF.

So far, the most significant improvement has been seen in newly designed, complex multilayered boards. Systematic defects in these boards have been cut by nearly 30% since the system was fully implemented. More subtle systematic defects will be found as historical data accumulates and the more frequent defects are eliminated.

Another major area of benefit is vendor feedback. Some of the panels tested by SPCF

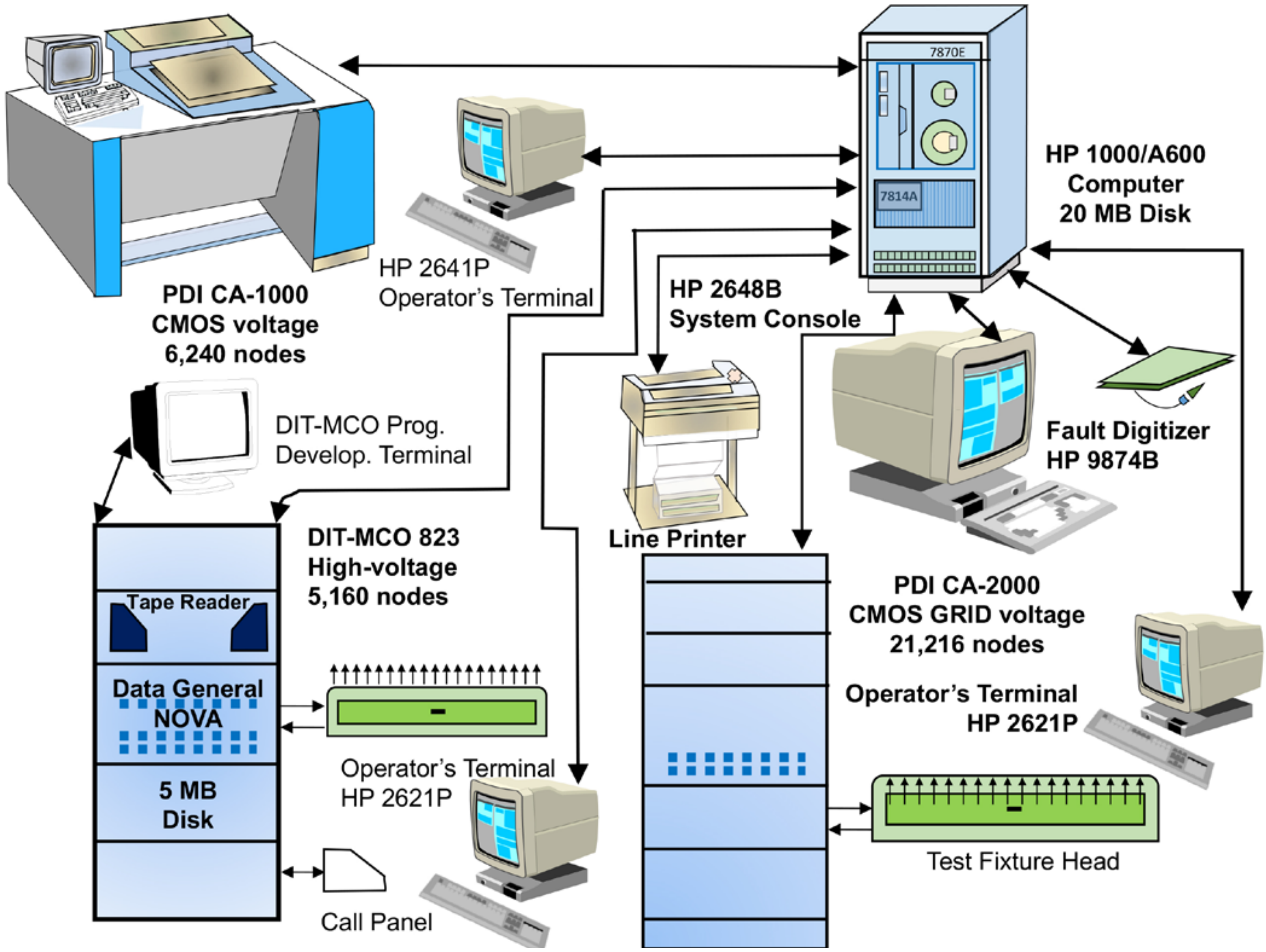


Figure 7: Electrical test, AOI and quality analysis control center.

are bought from outside vendors. SPCF can give these vendors precise data on the type, location, and extent of defects.

SPCF estimates that the new system has reduced repair labor costs by 30% because of reduced defects, fewer phantom errors, and prior knowledge of systematic defects. In addition, the system shortens test setup time by one hour per machine daily. Also, testing in panel form is several times faster than testing finished boards. Significant labor savings are seen in a number of other ways, because the system has practically eliminated paperwork that used to burden the operators, their supervisor, and process engineers. Figure 8 illustrates an operator in the process of testing a two-image panel.

Product cost analysis has been improved due to repair information and accurate test time information. Test costs can be predicted as well as machine throughput.

The test area and affiliated software was developed by test engineers from 1979 to 1981. The software was written and implemented in three phases to match test demands as well as available resources.

- Phase 1 was to develop error translation, error correlation, and a useful test results report. This was implemented on an IMSAI microcomputer in 8080 assembly language.
- Phase 2 was to interface all five machines to the HP1000 and generate in FORTRAN the control programs established as useful in Phase 1.

- Phase 3 was to define and generate an IMAGE-1000 database for the electrical test, troubleshooting, and repair areas. This phase included the control programs to supervise set up, download, and save of connection files, test, and test suspension, as well as routine QA, production reports and graphs.
- Phase 4 was to incorporate advanced statistical analysis (T-tests and F-tests) learned from the NIST Engineering Statistics Handbook and the free Dataplot software supplied by NIST[1].

Computer-aided Manufacturing[2–4]

The electrical test/quality analysis system is one of five automation centers at SPCF. The other four centers control:

1. Chemical processes
2. N.C. fabrication
3. Manufacturing engineering
4. Manufacturing planning and control (as diagrammed in Figure 8)

This is a computer-aided manufacturing (CAM) strategy that has been implemented in most of Hewlett Packard's 44 manufacturing divisions throughout the world. The strategy follows a hierarchy of computer systems, each focused on specific requirements and functions. This hierarchy is summarized in Figure 9. Other papers on automation at HP's PCB facilities are available in *Automation and Advanced Procedures for PCB Fabrication*[5]. **PCB007**

References

1. *Handbook of Statistical Methods,* and software, NIST/SEMATECH.

2. "A Distributed Approach to Computer-Aided Manufacturing," by Happy Holden, Electronics Manufacturing Technologies and Systems Conference, February 1983.

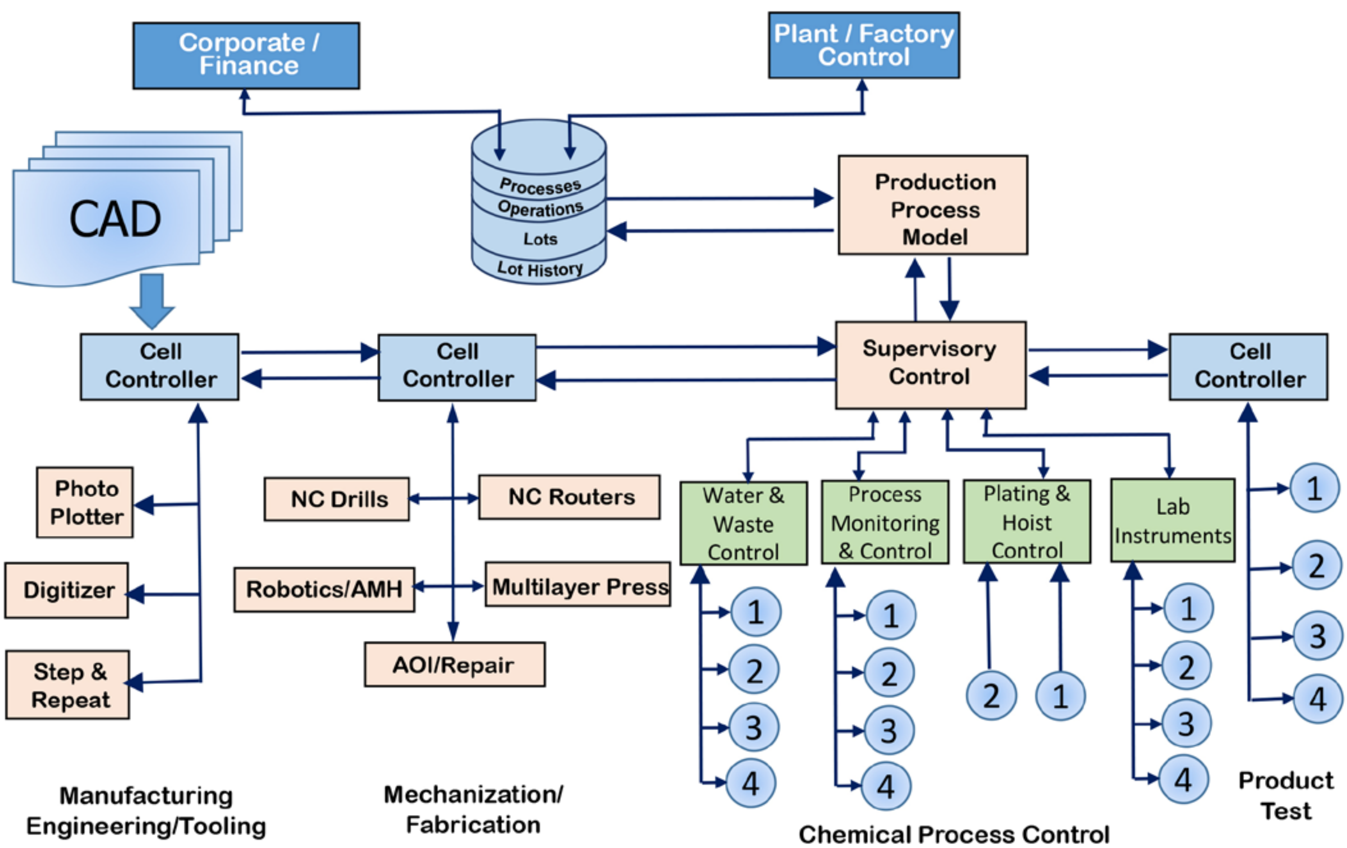


Figure 8: CAM, system hierarchy of an HP Printed Circuit Facility.[5]

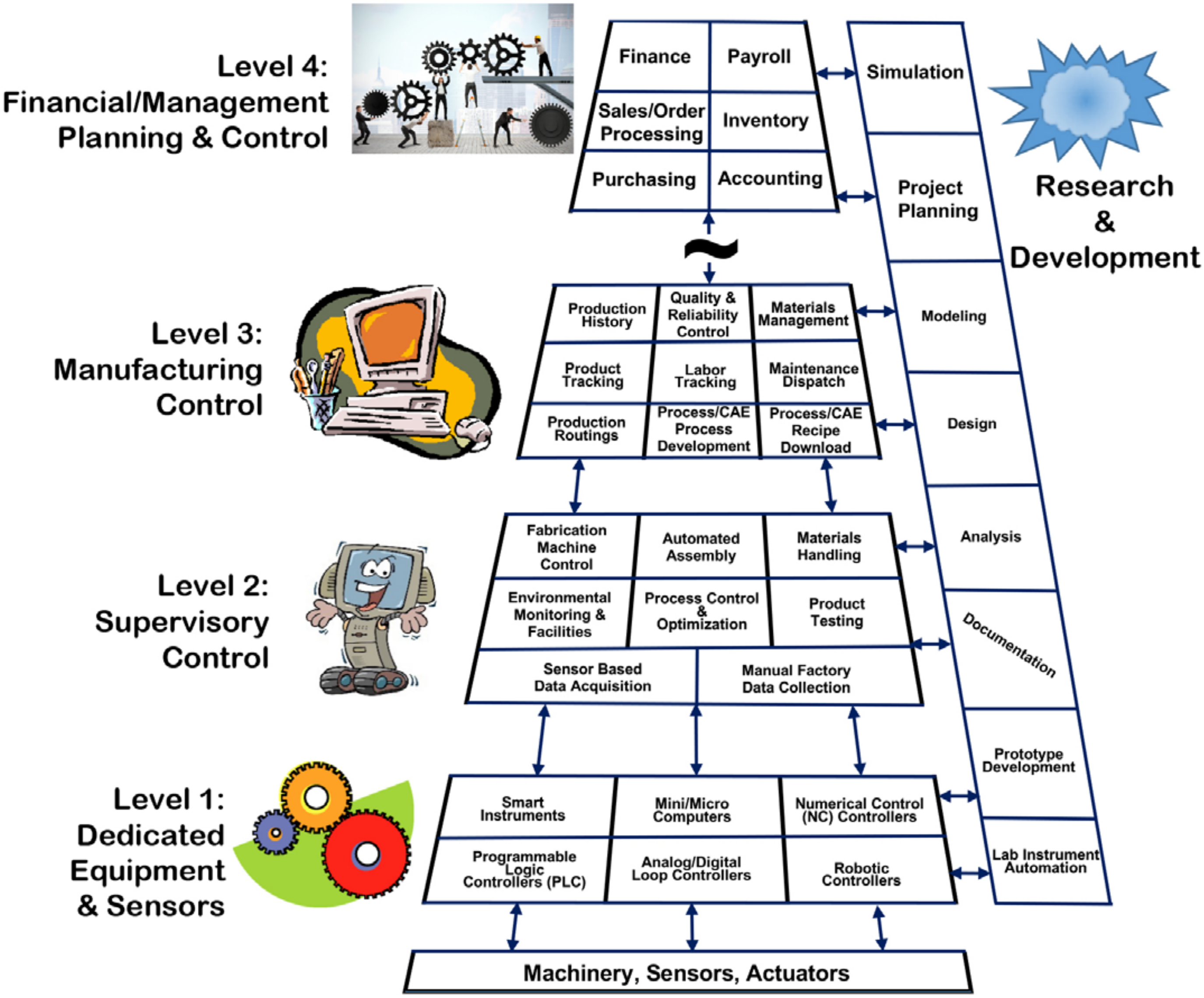


Figure 9: The hierarchy of systems and the functions they perform.[5]

3. “CAD/CAM in PCB Manufacturing,” by Happy Holden, Assembly Engineering, Page 40-43, July 1981.

4. “Computer Process Control in a PC Facility,” by Happy Holden, 8th Annual Advanced Control Conference, September 1982.

5. *Automation and Advanced Procedures in PCB Fabrication,* by Happy Holden.

Happy Holden has worked in printed circuit technology since 1970 with Hewlett-Packard, NanYa Westwood, Merix, Foxconn, and Gentex. He is currently a contributing technical editor with I-Connect007, and author of *Automation and Advanced Procedures in PCB Fabrication,* and *24 Essential Skills for Engineers.* To contact Holden or read past columns, click here.

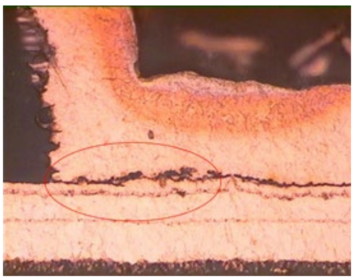
TOP TEN

EDITOR'S PICKS

The Shaughnessy Report: Developing a Strategy

How does a leader plan a strategy? In a field of competitors offering basically the same services, how can your company differentiate itself? Will you be a cost leader, or focus on serving a niche market such as medical or defense? As we learn in the August 2023 issue of *PCB007 Magazine,* one question that successful leaders need to ask themselves is, "What do I not want my company to be?"

Trouble in Your Tank: Processes to Support IC Substrates and Advanced Packaging, Part 3



In two previous columns, I explored several of the key competencies and processes required to successfully jump into IC substrates. In this edition, the key process of desmear will be explored. These processing steps require additional improvements over normal through-holes due to small diameter through-holes and blind vias. Getting process chemistries down into these small holes can be very difficult, especially if they have any trapped air bubbles.

Fein-Lines: The Road Less Traveled—Working From Home or the Office?

During the past few years, the ability to choose to work from home or the office has become a hot topic. When the pandemic was at its peak, working from home had obvious advantages. For many, it was a necessity, and then it became the norm. Now, employers are moving many positions back to the corporate office. Which is better for you?

A Look Inside SEL's New PCB Factory

After years of planning, Schweitzer Engineering Laboratories is now manufacturing printed circuit boards in its new $100 million captive facility in Moscow, Idaho. I recently toured the facility with Engineering Director John Hendrickson, who managed the design and setup of the greenfield site, along with Mike Brask, president of Integrated Process Systems (IPS), a key supplier for the new Moscow facility.

Linkage Technologies Ready for 'China Plus One'

Andy Shaughnessy recently spoke with Mehul Davé and Michael Schumacher of Linkage Technologies. In this interview, they discuss their acquisition of a PCB facility in Malaysia, their global expansion plans, and how Linkage stands to benefit as companies begin pursuing the China Plus One sourcing strategy.

IPC Welcomes U.S. House Veteran Rich Cappetto as Senior Director of North American Government Relations

IPC welcomes Richard Cappetto, a 14-year veteran of the U.S. House of Representatives, as its new senior director for North American government relations.


Richard Cappetto

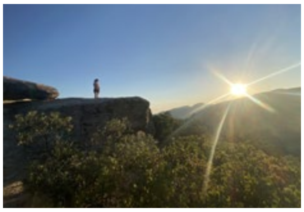
North American PCB Industry Sales Up 23% in July

IPC announced the July 2023 findings from its North American Printed Circuit Board (PCB) Statistical Program. The book-to-bill ratio stands at 1.01.

The Big Picture: Essential Engineering—The Intersection of Humans and Machines

While quality engineering is dependent on high-end technology, machines, and data sets, it is essential for companies to prioritize the expertise, innovation, and critical discernment of its people—the engineers themselves. It is the engineering team that designs and drives the vehicle of production, not the other way around. Because they are inextricably linked, humans must understand and leverage machines to engineer the best possible products and free themselves to do the essential work machines are not capable of doing.

The New Chapter: Smoothing the Rocky Road of Onboarding



Imagine you accept a job halfway across the country, move there with no family or friends nearby, and you're extremely overwhelmed by your living situation. It can be really tough. To be honest, when I first interviewed for my current position, I was excited to move away from my home state of Indiana. I was thrilled about a new adventure on my horizons.

TTM Technologies Aerospace & Defense Sector Awarded Contract from the U.S. Army for AN/UPR-4(V) PDRS

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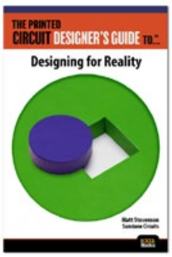
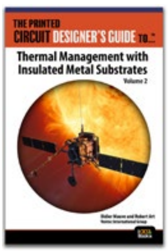


Designing for Reality

by Matt Stevenson, Sunstone Circuits

Based on the wisdom of 50 years of PCB manufacturing at Sunstone Circuits, this book is a must-have reference for designers seeking to understand the PCB manufacturing process as it relates to their design. Designing for manufacturability requires understanding the production process fundamentals and factors within the process. Read it now!



Thermal Management with Insulated Metal Substrates, Vol. 2

by Didier Mauve and Robert Art, Ventec International Group

This book covers the latest developments in the field of thermal management, particularly in insulated metal substrates, using state-of-the-art products as examples and focusing on specific solutions and enhanced properties of IMS. Add this essential book to your library.

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