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Registration Sweet Spot

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The Registration Sweet Spot

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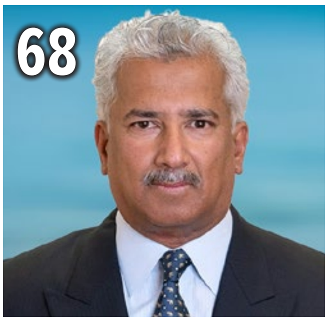

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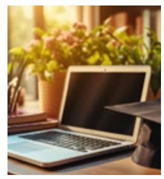
COLUMNS



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The Registration Sweet Spot

Nolan's Notes

by Nolan Johnson, I-CONNECT007

Registration is underrated and underappreciated. You can try to argue with me about this, but after diving into the current state of registration, I'm convinced. For example:

- 30 years ago, the state-of-the-art for integrated circuit geometries was in the low-double and high-single digits of microns, single-sided, on a consistently planar and highly polished crystalline substrate. Almost without exception, the entire integrated circuit was built *on top of* the substrate.
- Today, the bleeding edge of traditional PCB fabrication can reach into the 20-micron range, possibly multilayer, often still on epoxy-and-fiber substrate into which holes are drilled and metal plated; and it's expected that features across multiple layers will match up across the entire stackup.

That's asking a lot.

I am reminded of a scene in "From the Earth to the Moon" (Kinda want to get the boxed set, but is that still a thing?), an HBO series about the NASA space program of the 1960s. One particular episode opens with an aerospace engineer giving a presentation, standing next to an overhead projector. It went something like this:

"How hard is it to get a spaceship to the moon? Pretty hard. The ballistics are very complex; everything is moving. It's like trying to throw a rock over a house, and hitting another rock you can't see while it's flying through the air. Oh, one more thing: You're riding a bicycle."

This engineer's example certainly was evocative of that challenge. Every little detail needs to be right down the middle of its own "sweet spot" to accomplish the task; there is very little tolerance. Every single piece of that very complex process—launch, orbit, escaping orbit to go translunar, course corrections along the way, and braking exactly right to enter lunar orbit—needs very precise actions with an individual sweet spot. An error in the middle will only compound its way through the rest of the process.

In IC fabrication, in crystalline silicon, the IC engineers have the luxury of a remarkably stable foundation upon which to build in a highly regulated environment. Study the challenges in obtaining consistent, high-quality printed circuit registrations at today's geometries, and it does start to feel like a moonshot. When the coefficient of thermal expansion in your substrate can be larger than the features you are fabricating, getting all of them to line up across multiple layers is an exercise in multiple moving targets. In the flex world, there may be fewer layers, but that doesn't make it easier; some of the flex substrates are like plating on a sandwich bag. I digress (but only a little).

What's key here is ensuring proper registration from layer to layer across the entire printed circuit board. It's a holistic process requiring anticipation, prediction, precise attention at each step, and detailed data tracking and monitoring, because a slight error up front will only snowball as the process continues.

In this issue, we talk with some industry experts on getting it right with registration, with an overarching theme on how to keep all your steps in their respective sweet spots. Alex Stepinski shares his from-the-field lessons on how to design fabrication processes for improved registration, and some of his signature "hacks." Happy Holden returns to the value of coupons, and XACT's Andrew Kelley discusses the use of planning software tools to anticipate misregistration and compensate. We also visit with Aidan Salvi at Amitron, a PCB fabricator committed to improving registration—to the tune of 60+ pieces of new equipment and development of a Factory 5.0 model.

Also in this issue, we bring you columns from Preeya Kuray, who interviews U.S. Rep. Blake Moore; Paige Fiet discussing technical terminology for newcomers; Henry Crandall continuing his look at wearable medical devices; Mike Konrad showcasing the innovative engineering programs at Dartmouth; and a PCBAA member profile on Hari Pillai.

By the time you finish this issue, you will likely notice that registration and process data are interrelated. Registration can only be as precise as your processes and the data you use to monitor those processes. Sensors, data warehousing, data analysis, and data-driven process control are central to improving registration. Just like the moonshot, precision is required at each step, even while all the components might be in motion.

I'd also like to welcome Marcy LaRont, who joins I-Connect007 as the Managing Editor for *PCB007 Magazine*. If you've worked with Marcy in the past, you'll be just as excited as we are to bring her expertise and professional experience to our editorial team. I know you'll make her feel welcome. **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.

Recent Practices in PCB Fab Registration System Architecture

Feature Article by Alex Stepinski
STEPINSKI GROUP

The registration of copper features, both to interconnects and to each other, is a topic about which documented cases in the public space are less than abundant, other than individual supplier marketing with minimal backup data. Traditionally, this area is known to individual fabs as it involves multiple processes with a lot of variation in equipment makes/models, and even base materials between different shops. This article endeavors to document the current Pareto frontier of registration system design architecture for use by PCB fab engineers.

In general, registration system design involves managing the interaction of the bill of materials and the bill of process relative to feature alignment. The bill of process involves the equipment, associated procedures, and sequence of operations. The bill of materials involves the materials and tooling files specified in the ERP documentation.

The bill of process steps can be broken into three categories:

1. Compensation and measurement steps (imaging, drilling, punching, mechanical alignment of masks, alignment of inner layers, AOI).
2. Inelastic process steps (plating, multilayer lamination, mechanical scrubbing, >Tg bakes).
3. Elastic and noise steps (panel handling, edge machining, dry film lamination, plasma, micro-etching, etc.)


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Here are the general design considerations which process engineers should consider for each category. While this is not an exhaustive list, it does cover the primary variables of concern. Also included is a list of the eight most common best-practice hacks which the vast majority of fabs have not adopted, yet which have been proven to offer high ROI in the improvement of registration system performance. Note: They typically will cut registration error by >50% if all are incorporated.

1. Compensation and Measurement Steps

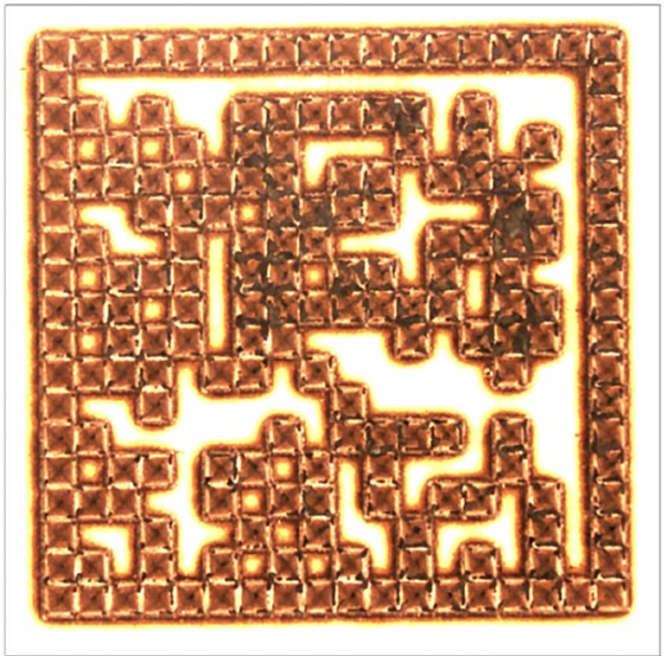
Compensation and measurement process steps consist of three general sub-process steps.

Environmental stabilization of product

Stabilizing the product prior to compensation and measurement is an often-neglected topic. Failure examples here typically include processing through drilling or imaging when the panels are still warm from either prepreg lamination, dry film lamination, or in-process baking/drying. In the newest factories, we typically include timed buffers in the process kit after each heat excursion to facilitate stabilization. After plating, it is important to do a copper-anneal bake since there is a risk that, if it is not done and the job is moving quickly through the facility, that the annealing/de-stressing of the deposit will occur in the lamination press under pressure, leading to unpredictable scale factors.

Hack: CCL serialization/pre-tooling of imaging targets

One popular hack for addressing stabilization controls for CCL, as well as providing for individual traceability of each core, involves the drilling (by mechanical or laser) of through-hole 2D codes and de-scaled imaging fiducials in each CCL. By so doing, the fiducials act as go/no-go gages to confirm whether the material is at nominal position prior to imaging. Some sites also measure the fiducials after placement on the same machine and save them to the 2D code in the facility data lake. In this way, at imaging we can use the offsets assigned to each code from the error between the CCD camera and the mechanical or laser process to gain a few more microns as well when placing the image.



Measurement of Fiducials

Fiducial quality, design, and placement are critical to ensuring that the measurements are representative of the PCB. As a general rule, each fiducial position should have a minimum of four targets which can be analyzed, as well as a back-up set of four in complementary offset positions in case of fiducial damage detected by a low quality score. Many shops still use one hole or one fiducial and this is like designing a process with a single point of failure.

Of critical importance is the camera/sensor used for target acquisition. White light, dual-wavelength, and X-ray measurements are all currently used in both dynamic-scan and fixed camera modes. Each sensor/camera has a known error, and the sensor type/quality must be matched to the product tolerance requirements. It is a common issue in the industry that the wrong sensors are used for the wrong applications because fab process engineers fail to convey the detailed product requirements to the suppliers to make sure the appropriate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camera/sensor is selected. The most common failure is the use of simple cameras in shops with high material mix, and then skipping out on the the detailed camera light settings calibration work required for each material. By contrast, the expensive X-ray is not susceptible to this issue at all, for example, and the dual wavelength systems reduce the potential error tremendously for a reasonable price. The decision is one of "pay me now/pay me later" (i.e., CapEx vs. scrap costs).

Alignment and Placement

Alignment algorithms are typically orthogonal or trapezoidal in nature for most machines, though any-point compensation has been available since 2017 from multiple equipment suppliers. Still, the most common method of alignment remains four-corner. On multi-up panels with tight tolerance requirements, the registration is done in the four corners on the sub-panel level to provide improved optimization. This is often called local registration.

Hack: Drill position compensation for placement error

After placing laser or mechanical alignment targets in the panel, it is valuable to remeasure the holes and record their size/positions. By doing this, one can identify the error between where the holes were supposed to be placed and where the spindle or laser head actually placed them. Especially, with mechanical holes, this can often be off by up to one mil or more, especially on the exit side of the panel. By measuring and applying these measured offsets on the subsequent drilling or imaging operations, the placement error can be nulled out, and for a very low OpEx investment, the gain in capability is high. This system works best when 2D codes are used, as offsets can be saved to each 2D code row in the database.

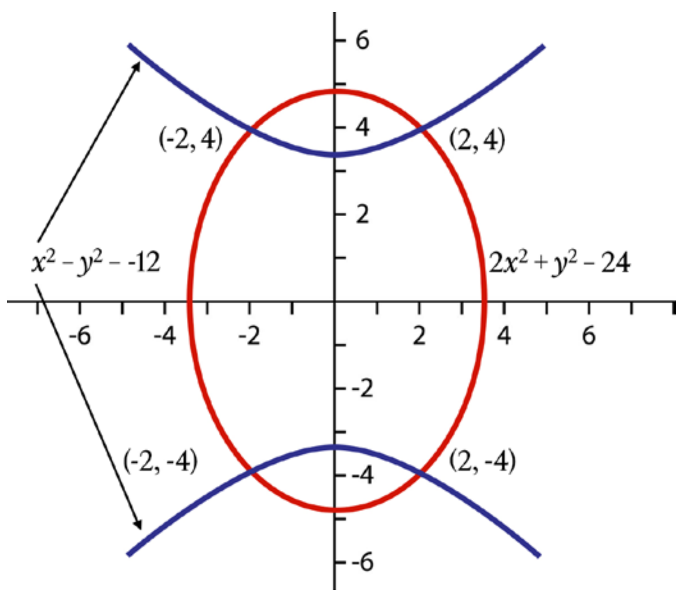
2. Inelastic Process Steps

Overall, this family of steps is a necessary evil which must be constantly modeled and controlled. It involves very strong process and product coupled interactions. Some of the potential processes are also incompatible with tight registration tolerances on thinner products and need to be completely avoided whenever possible. Inelastic process steps often lead to a non-linear error which is not measurable by four-point tooling systems, and often gets characterized as "random movement" and "swimming" by many shops.

Hack: Non-linear analysis for characterization of inelastic processes

Four-corner fiducial placement is not capable of detecting non-linear error, and compensation algorithms are generally only linear. This is simply because there are not enough points to determine the shape of the individual axis, since each axis only has two points to make the line (i.e., X1, X2, Y1, Y2). What is interesting is that if you add more fiducials (like at the midpoint of each axis, for instance), it is quite common that the non-linear error often exceeds the linear error on advanced designs (particularly with thinner dielectrics).

There are two ways to address this issue. One can move to eight-point or more tooling to characterize the error and do a non-linear best-fit globally (which adds cost), and/or one can analyze the eight points as part of a first arti-



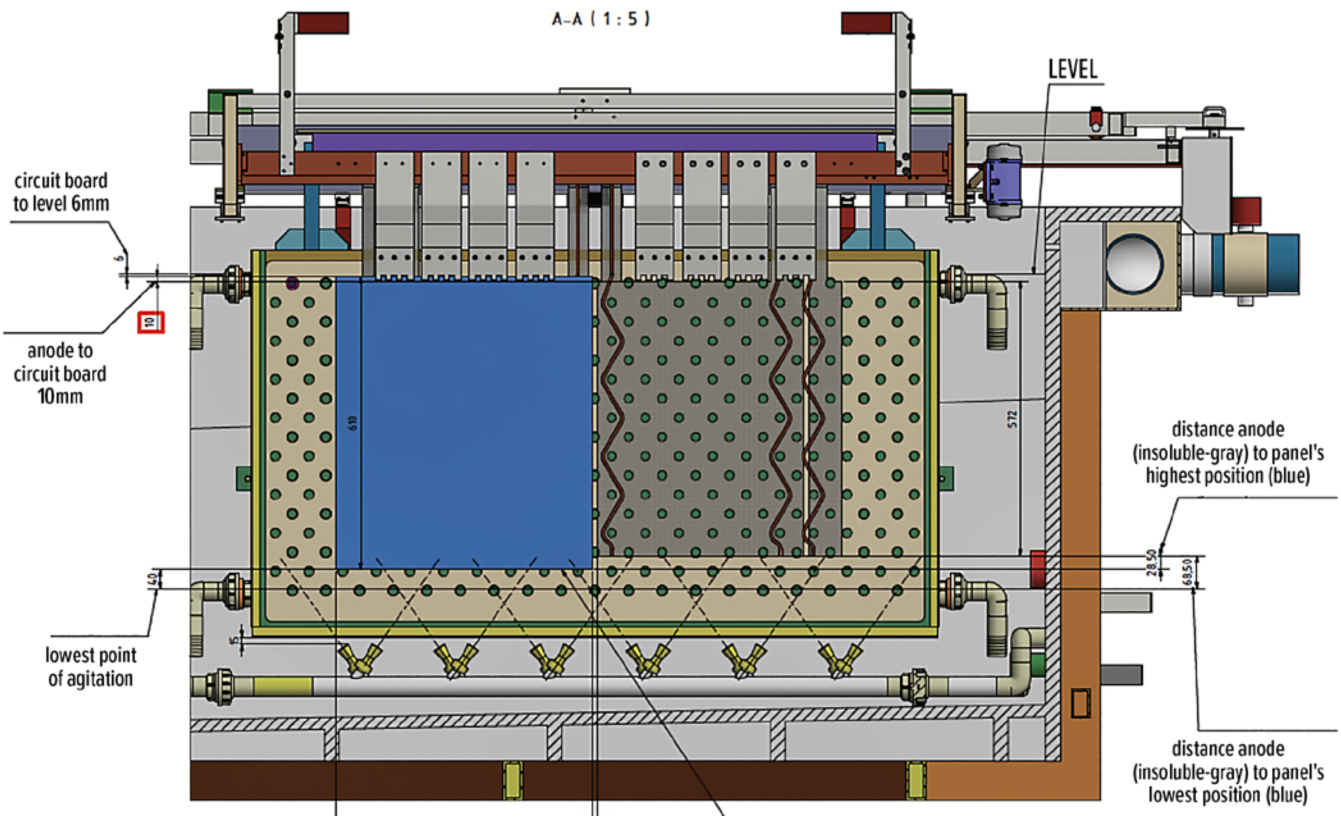
cle report process to determine whether it's necessary to employ. Aside from these quality control checks, I find that the most valuable use of a non-linear analysis is to optimize press cycles. When we measure eight-point systems before and after multilayer lamination, I find that about 20% of the non-linear error is already present in the core from post-etch movement, and an average of 80% originates in the press. Since press cycle optimization historically does not involve feedback from non-linear errors, it is often quite easy to tweak the cycle a little bit and reduce the non-linear error by 50% or more. The key variables to achieve this are lowering melt viscosity, extending gel time, and lowering pressure. Optimizing in this way also reduces Z-axis distortion, which improves back-drill capability and signal integrity as well. Non-linear analysis may even drive the user to select different materials with more reasonable press cycles.

Hack: Use of chemical planarization to eliminate the need for mechanical scrubbing of epoxy via fill

Mechanical scrubbing is the archenemy of dimensional stability and the problem worsens as the panel thickness decreases. One new development has been the use of epoxy paint strippers from the general metal finishing industry to remove the epoxy from the surface, while not affecting the epoxy in the holes. This has proven to be a revolutionary solution for thin products with epoxy via-fill requirements.

Hack: Elimination of buttons (use of panel plate + Cu thinning)

Button plate surface planarization is another mechanical scrubbing application, particularly popular in North America, to compensate for low capability of legacy plating equipment. Alternative methods today take advantage of the latest panel plating cell designs coupled with Cu thinning by chemical etch-down.

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Copper plating surface distribution with the latest cell designs can achieve down to 2–5% surface thickness variation, with similar result for the etch-down. These surface tolerances are better than anything that is possible from mechanical planarization of buttons, thereby improving yield and SI performance.

3. Elastic and Noise Steps

Elastic and noise operations impart very little variation to the registration process but must still be considered when specifying equipment. Considerations such as gripper/suction cup placement to avoid fiducial damage, dry film coverage areas, and fixture-contact locations can make a registration system inoperable if not accounted for.

Hack: Edge alignment and machining

Edge alignment is a topic often given insufficient attention in most fabs. Measurement of the edge location on CCL by camera, followed by drilling of imaging fiducials/2D codes, will often save a few millimeters of panel area. More importantly, however, it decreases the flash rout compensation after lamination. This is particularly important on sequential lamination products, where cutting back too much each time can lead to the need for carrying extra inventory of different dry film sizes, or even damaging tooling fiducials. Failure to cut back enough carries the risk of particle generation due to glass fibers and resin debris, since the edge encounters multiple desmear operations leading to debris formation if not cut back sufficiently (typically causing a higher incidence of plating nodules and imaging defects on SBU product if not managed).

The bill of materials can also be broken down into three general categories:

1. Stackup.
2. Tooling frame and sub-frame layout plus thieving strategy.
3. Manufacturing compensation factors.

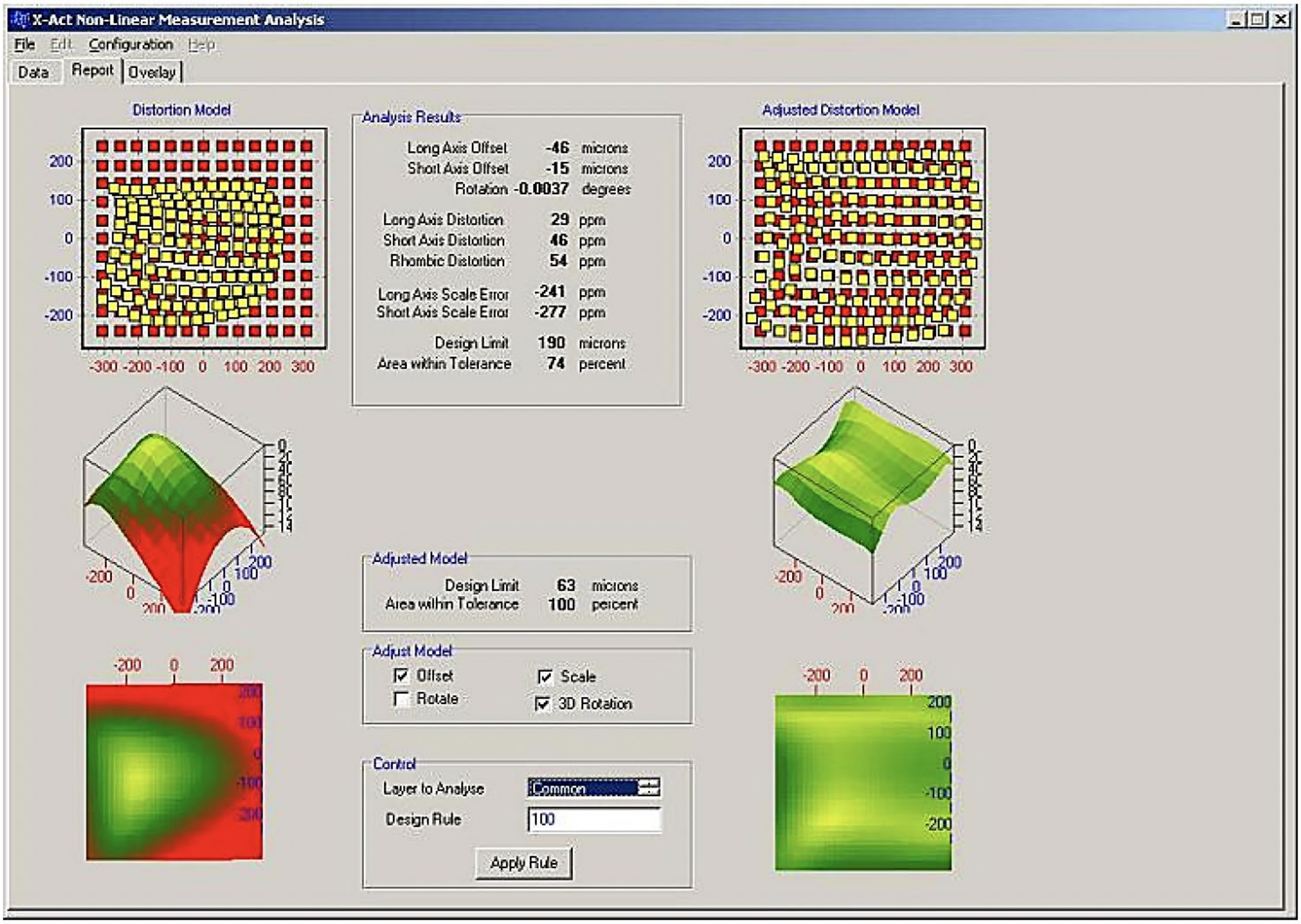
Stackup

The product stackup selection process is at the intersection of customer design requirements and the fab manufacturing experience. Choosing constructions based upon model confidence factors and quality history is becoming the norm worldwide. Often, compromises must be made to achieve the customer requirements. One of the biggest problems we see in stackup selection arises from excessive focus on core selection, instead of force vector analysis. Some cores work very well in some stackups, whereas they perform poorly in others. It all comes down to adjacent core/subinfluence as well as B-stage selection; this interpolation is a blind spot that is often missing in most industry models.

> “One of the biggest problems we see in stackup selection arises from excessive focus on core selection...”

Tooling Frame and Sub-frame Layout Plus Thieving Strategy

The design of the tooling frame is one of the most important elements to consider when developing a top-notch registration system. Historically, the tooling frame design was the result of an evolutionary process as equipment fiducial requirements changed only when equipment was replaced. Because of the cost of re-tooling legacy products, frame-tooling is often not updated even when there are much better coupons that could be used with the new, more capable equipment.



Some of the concepts which we often consider for new frame implementations or existing tooling upgrades include:

- Making the 2D codes on every layer offset, and thus readable in panel form by X-ray.
- Eight-point tooling for non-linear analysis.
- Use of clearances for fiducials instead of pads on X-ray coupons to avoid clearing out of Cu layers which can lead to lamination voids.
- Adding enough positions for sequential lamination tooling to avoid ever using the same tooling twice.
- Reducing legacy coupon sizes.

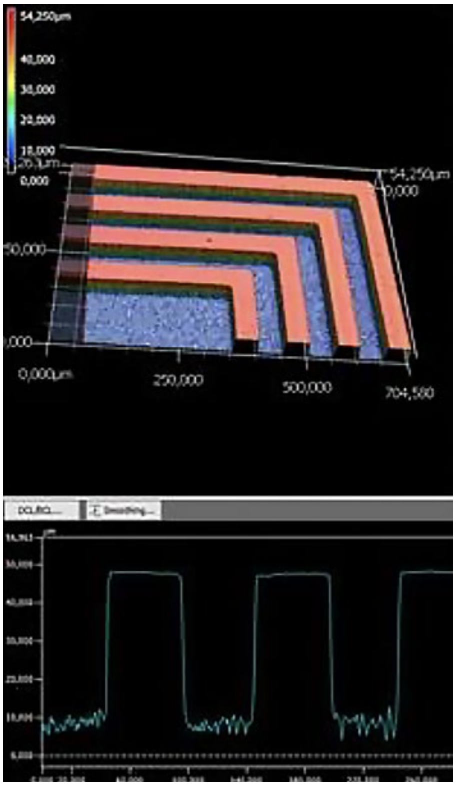
Hack: Normalization to zero of layup alignment fiducials

One popular hack for improving alignment accuracy is to compensate the targets for predictable process variation. This is commonly done on post-lam targets (global lamination scaling is applied), but not commonly done on post-etch/pre-lam targets (normally output without scale). It was discovered years ago that removing the scaling from post-etch targets made it easier for the post-etch tooling equipment to best fit since the deviations which needed to be compensated for were less. As an extension of this design practice, we also find that by taking the data from the post-etch tooling or layup operation, a model can be built which provides a post-etch scale-compensation factor to account for the movement which occurs from etching the pattern. This further reduces the need for compensation and makes the subsequent compensation errors less.

Manufacturing Compensation Factors

Manufacturing compensation factors include modeled etch comp, modeled plat-

ing thicknesses, impedance/loss, modeled copper roughness, scale factors, thickness, non-linear modeling, etc. Overall, as an industry most of the models in use are too immature for self-learning Industry 4.0 facilities, and we are just developing the tools now to achieve low-supervision and unsupervised machine-learning loops for these attributes.



It is also very interesting that PCB fab companies spend millions of dollars on registration equipment to gain a few microns, yet often have pads and clearances (i.e., the actual targets being aimed at) that are tens of microns off because they set the AOI scanners at ±20% and do not have an effective feedback loop. They typically are focusing on line width only, instead of pad and clearance diameter with their AOI settings. This is compounded by the fact that circular clearances and pads typically finish smaller (i.e.,. harder to register) than planned. This is because pads etch faster and clearances etch slower vs straight lines (i.e., due to diffusion layer thickness differences from the fluid dynamics of positive and negative circles).

Hack: 3D Scanning to Gerber

One recent development in the market (in October) has been the application of the latest 3D scanning technology. By scanning post-etch product in full 3D, we can now rip the file to Gerber and pull it back into the CAM system to do a comparison with the master pattern, thereby optimizing our compensation factors in an automated way. Multiple machines are being released to the market for this function both this quarter, and early next year.

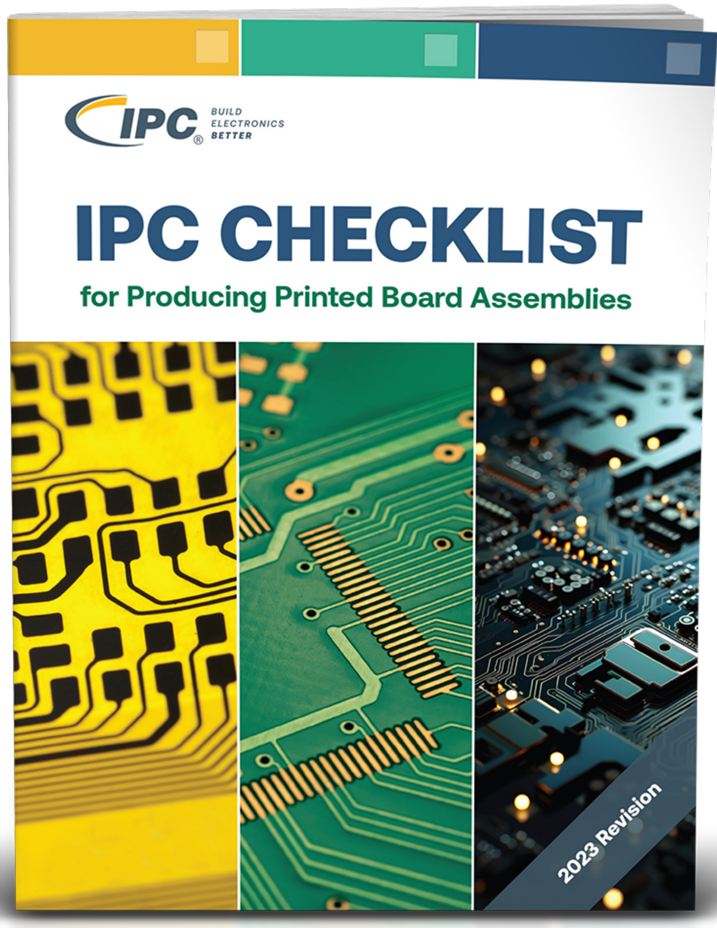
I hope this short article has been useful in demonstrating some of the latest design approaches to registration system architecture. Even if you only picked up one hack, based on our experience, we expect that the article will be a good return on investment. **PCB007**

Alex Stepinski is principal and president of Stepinski Inc., and principal of Smart Process Design.

Anatomy of IPC Checklist

Typical PCB production cycle, from design through end product

Complete list of current IPC reference standards



Cross-sectional view of plated through-hole issues

Step-by-step operations for design, fabrication, and assembly

Registration: From Raw Data to Intelligent Manufacturing

Feature Article by Andrew Kelley
XACTPCB LTD.

While previous industrial revolutions have introduced factories, mass production, and computer-controlled systems, the advent of Industry 4.0 and the concept of the Smart factory have ushered in a new era in PCB manufacturing. For the PCB industry it is a very ambitious and aspirational objective to evolve from disconnected processes to an integrated system with automated data capture, real-time data analysis, process visualization, autonomous control, and self-correcting processes.

Industry experts claim that those who fail to engage will rapidly fall behind, however, the paradigm shift that this revolution brings to manufacturing has left many plant managers wondering where and how to start the process of implementation. The reality is that implementation of a Smart factory is not a one-size-fits-all approach, and companies need to adapt their existing systems, process, and infrastructures to embrace this transformation gradually.

In the PCB manufacturing plant, there is a profusion of design and production data that is held in many places and in many different formats. There is an opportunity to incorporate this information with data gathered in real time from manufacturing processes to provide intelligent analysis, derived actions, and con-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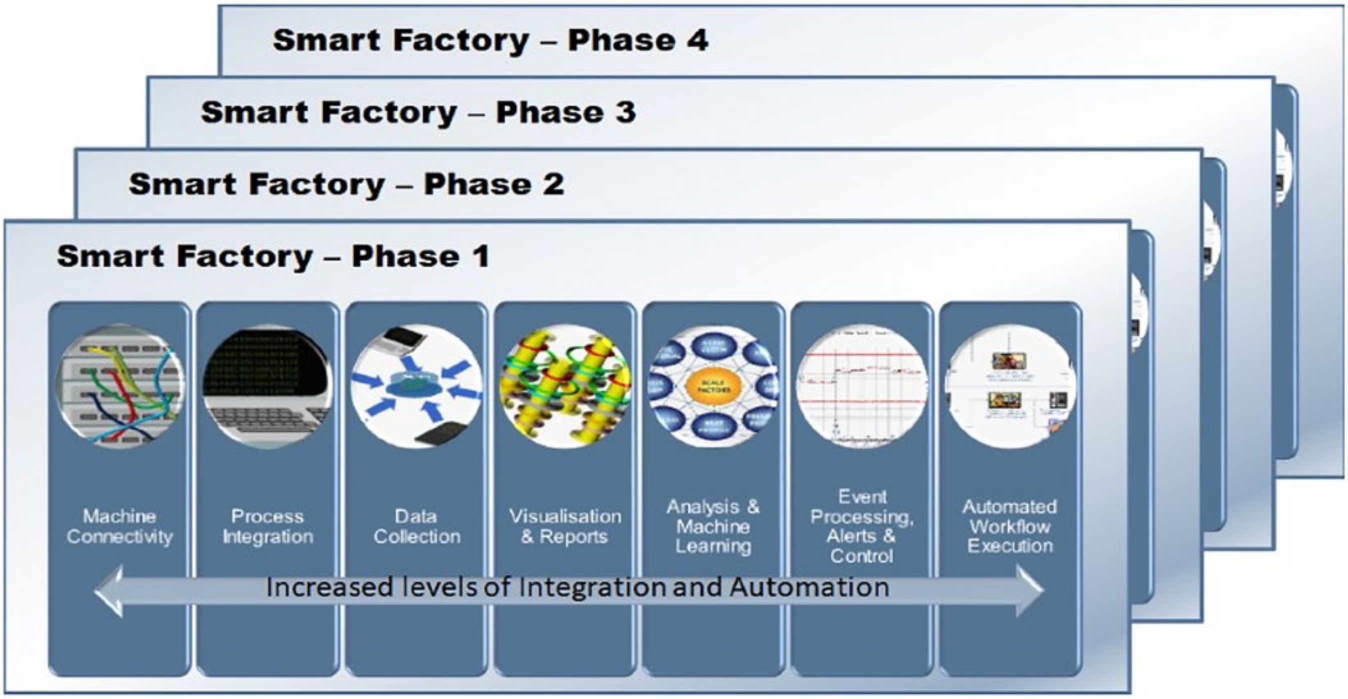


Figure 1: Smart factory implementations can be approached one step at a time.

trol immediately for use throughout the manufacturing process chain. Very few companies will start a Smart manufacturing implementation from nothing. The key will be understanding how to adapt existing systems, processes, and infrastructures to the requirements of the Smart factory. A step-by-step implementation focused on key aspects of manufacturing will allow the benefits to be realized. Therefore, the smart manufacturing solutions implemented should be modular, scalable, and flexible. This approach allows businesses to establish proof of concept, leverage existing equipment, and strengthen their infrastructure without the need for building entirely new factories. To embark on this journey successfully, it is crucial to harness the power of data and transform it into actionable information and knowledge.

The Importance of Data

The foundation of a Smart factory is built with data, and most equipment used in PCB manufacturing processes either generates or uses data. While this data is a strategic business asset, the value of data lies not in the data itself but in the information, insights, and actions derived from its analysis. Without capturing that data, it is not possible to derive the information required to make decisions that will improve products and processes.

Most fabricators are collating data from their processes, however, many fail to realize the true potential of the data they collect due to various barriers and limitations:

- Fragmented data
- Duplicated data
- Local variants of the same data
- Difficulty in obtaining timely and accurate information
- Data usage is mostly driven by management reports rather than manufacturing requirements

Additionally, a silo mentality within organizations, characterized by poor communication between different processes and a focus on vertical rather than horizontal communication, compounds these issues leading to limited collaboration and information sharing. This can result in an under-utilization of technology and engineering expertise.

Connected Data Integration

To create a Smart factory, it's essential to establish robust data integration, machine networking, and automated data capture systems. Data must be accessible from remote systems via factory networks, whether wired or wireless. Monitoring systems should capture data in real-time, eliminating the reliance on manual data transfer. This shift in data integration is not just an IT exercise but a fundamental shift in manufacturing operations.

There is a need to review the data available and the data required by designing an end-to-end operational data flow from the start. Participation of engineering and manufacturing experts is essential, as only those that understand the data can add value. Scrutinize the current manufacturing processes and procedures to identify gaps and opportunities where automation will remove risk by considering potential scenarios where mistakes will have a negative impact. Determine any required data that is not currently available and take the necessary steps to provide this.

"In the realm of smart manufacturing, the seamless availability of data across the factory is imperative."

The goal of the Smart factory is to capture, collate, integrate, and understand the process data—getting the right data in the right context in real time—to allow informed decisions and actions to be taken as quickly as possible. The integrated manufacturing systems will provide a connection between the people and processes generating data and those using it.

In the realm of smart manufacturing, the seamless availability of data across the factory is imperative. This necessitates the creation of decentralized "data highways" where humans and machines can both access and contribute to the data, enabling it to flow to the locations where it is needed.

There are typically two such data highways in the PCB factory:

- Production data: Providing data consumed by the processes, including bill of materials, CAM data, and NC drill programs
- Process data: Providing data generated by the processes, including product measurements, process, and environmental monitoring

Front-end engineering drives data into the production data highway for use by the production processes, whereas the data collected in process is driven into the process data highway for use by process engineers and management reports. These data flows are usually one-way with little to no data transferred directly between the processes, and where that data is transferred between processes it is often using a paper-based traveler document. It is also difficult for processes to send meaningful data back to the production data highway because the raw data captured is not directly useable. This raw data needs to be transformed into intelligent manufacturing information.

Developing Data Into Actionable Manufacturing Information

Process data is sets of facts that are the results of observation or measurement, but information comes from arrangement or interpretation of the data to provide meaning. It is possible to have data without information, but it is not possible to derive information without data.

The problem of registration control demonstrates the need to develop raw data into an intelligent manufacturing solution. Typical methods of controlling registration include pilot lots, cross-section analysis, scale factor look-up tables, X-ray/vision drill optimizers, and coordinate measurement machines, all of which result in great quantities of disconnected data with limited analysis or understanding.

Considering one of these options, the X-ray drill process is a key source of data for registration control. If used effectively, it collects coordinate data relating to the position of measured target features on individual layers within a panel. However, this coordinate data cannot be used directly by a drill machine to correct for scale errors or misalignment of layers within the panel. The drill machine requires an NC program indicating the location of each hole to be drilled, not the location of inner layer targets. However, using analysis, the measurement information can be transformed into linear scaling, offset, rotation, or even non-linear transformation parameters that can be used to modify the NC program to best fit the measured panels and achieve the tolerances required by the end customer. The drill machine may use these parameters to transform the NC program online or a transformed NC program can be generated offline before the panels reach the drill machine.

It is possible for an X-ray drill machine to directly influence the drill machine by drilling location holes in a panel to allow optical alignment on the drill machine, but how is the location of these holes determined? The X-ray drill does not have access to the annular ring tolerance of each hole on each layer of the panel, then providing a compensated location weighted to the critical layers of the panel. The holes are drilled to fit each panel individually, which will lose efficiency in high volume production as each panel must then be optically aligned on the drill machine—removing the ability to use multi-spindle drill machines drilling several panels high.

To determine the optimum compensations to apply to a drill program requires additional data from the production data pipeline. This data can be used to identify the critical layers and features where annular ring restricts the compensations that can be applied, and if a single set of compensation parameters cannot fit all panels, a Smart manufacturing system will be able to identify groups of panels within lots that can be drilled together for maximum efficiency.

All this enhanced data can then be automatically pushed into the production data highway ready for the next process, but use of this data will be limited without the ability for processes

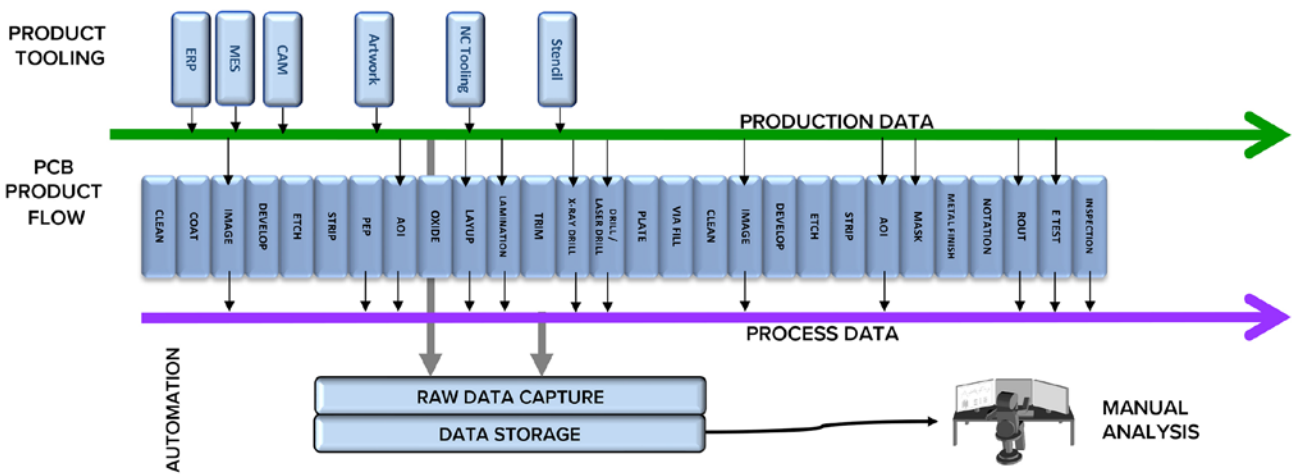


Figure 2: Relying on descriptive and diagnostic data alone is too late. The production problem has already happened.

to uniquely identify each panel. This can be achieved by the application of machine-readable 2D barcodes—allowing processes to automatically set up for the panels as they arrive.

Learning From the Data

Data represents raw facts resulting from observation or measurement. Information is data arranged or interpreted to provide meaning, while knowledge is information that has been understood and can be used to make decisions. By adding interpretation and context to data, it can be transformed into meaningful information and, ultimately, knowledge.

Wisdom is the ability to use knowledge to take action. In a Smart manufacturing system, data is captured and analyzed to provide actionable insights and to push corrective actions into the production data highway. However, it's essential to understand that not all data will lead to the correct action, and incorrect data can lead to incorrect decisions.

“Wisdom is the ability to use knowledge to take action.”

As Bill Gates said, “The first rule of any technology used in business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency.”

Data Quality and Integrity

For a successful Smart factory implementation, establishing a robust framework for data quality and integrity is paramount for mitigating risks associated with existing operational processes. Inconsistencies and inaccuracies in data can erode trust rapidly, leading to a loss of confidence in the information being used.

The value of data is intrinsically linked to its quality, and without proper data quality assurance, its potential remains untapped. Furthermore, when data is not integrated reliably, organizations are often compelled to fall back on traditional methods and institutional knowledge, undermining the potential for innovation and efficiency that well-managed data offers.

It is not uncommon for a deluge of data to find its way into projects and reports without undergoing the necessary validation.

Robust process controls are vital from the start to ensure data quality instead of correcting mistakes. Measurement machines must be maintained and calibrated to prevent noise or shift within the data captured. The environment around the machines should be monitored and controlled to prevent changes in temperature or humidity being reflected in the data captured.

Changes in data quality should be monitored with daily checks using known standards, and statistical controls should determine when maintenance or calibration is required rather than waiting on predetermined schedules.

Measurement systems analysis will determine the accuracy and precision of the measurement processes by verifying the differences in data are due to actual differences in the product being measured and not due to variation in measurement methods or the machine operator. It is critical the machine is set up consistently for each batch, no matter who is performing the setup. Gauge R&R methods should be used to check repeatability and reproducibility.

Enriching the Data

Within the PCB manufacturing facility, a plethora of design and manufacturing data is scattered across various locations and stored in a variety of formats. By combining data from multiple sources, it is possible to derive additional information which will aid in our understanding of the process.

Combining measurement data with design information, such as annular ring and drill to copper, we can decide whether a product meets requirements or whether process parameters need to be changed to improve yield and long-term product reliability.

Integrating relevant data from multiple sources builds our understanding of the processes and materials. Combining inner layer scale factors with measured scale errors, we can determine the total material movement for each core in the construction and compensate for it.

By comparing total material movement for materials across multiple batches and products, we can identify unexpected behavior caused by a process or material change.

Supplementing data with engineering expertise converts data into a dynamic knowledge base. If we can answer why unexpected behavior occurred, then we can truly enrich the data.

Machine Learning for a Smart Factory

The volume of data generated in the PCB factory requires automated systems to be smart and flexible. Technology roadmaps only move toward the more complex while product lifecycles are shortened, resulting in higher product mixes. This in turn increases the number of variables involved and significantly increases the number of potential combinations of materials, process, and product design.

It is not feasible to acquire the volume of data required to provide empirical data for each of the possible combinations. The average fabricator will manufacture using multiple resin systems, each having numerous core thickness and constructions, prepreg glass cloths, and resin contents. This can quickly result in tens of millions of possible combinations for even the simplest products without even considering the options for copper thickness, copper pattern, or processing routes.

Increasing technical capability will have a significant effect upon the number of potential material and process combinations: increased layer counts, number of lamination cycles, and portfolio of materials results in yet more possible combinations with little or no knowledge of how they behave.

Historical data alone will never be able to provide all the answers required, and when

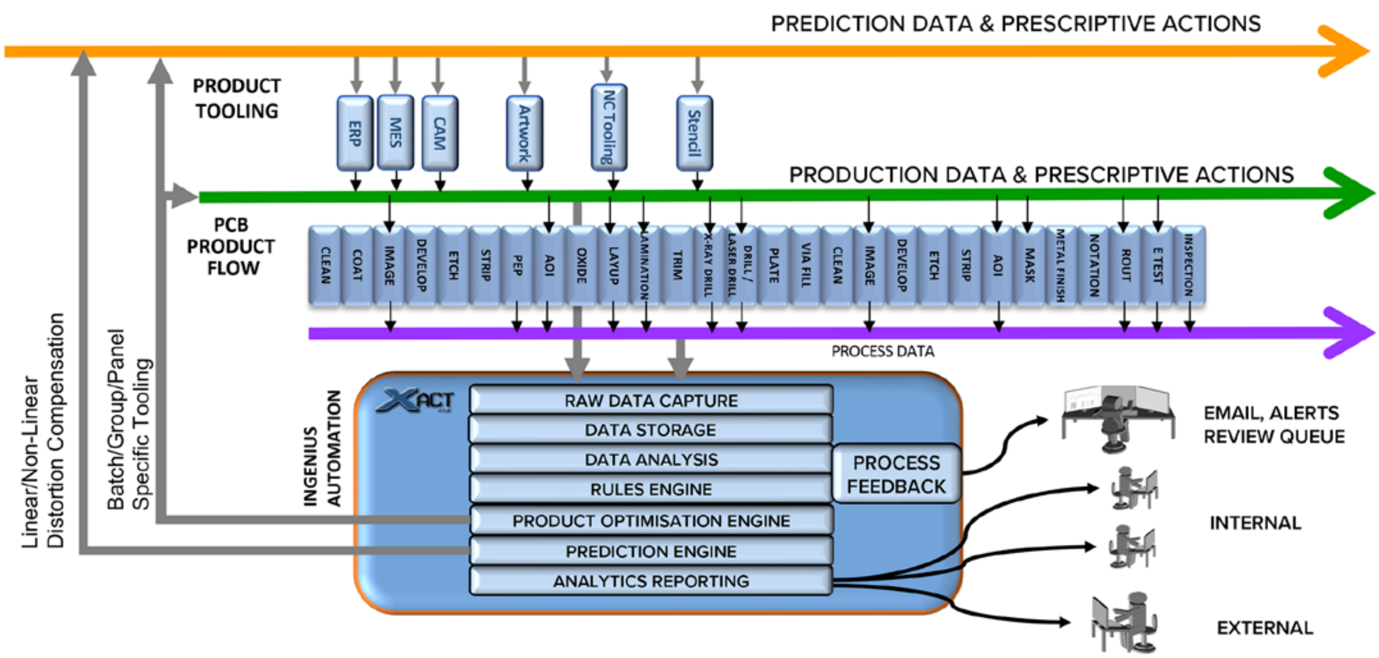


Figure 3: An example data flow that provides proactive, adaptive control and monitoring.

there is no data available, the factories turn to the relevant "experts" for advice. An expert will draw on past experiences or instigate a DOE process to provide a best estimate for what will happen. But human experts are not available 24/7, and may even leave, taking their knowledge with them. Multiple experts may have conflicting opinions, making a quick informed decision impossible. To improve, computerized experts have been developed, varying from simple spreadsheets to more complex rules-based systems.

Dynamic decision-making requires expert systems to be replaced by self-learning systems. An expert system may use a complex set of rules to make decisions, but the rules are often fixed and do not change without human intervention. Given the number of possible product and process permutations discussed previously, it is not possible to develop rules to cover every situation. Smart manufacturing requires its own embedded intelligence.

> "The Smart factory revolution in the PCB industry hinges on the effective utilization of raw data."

Machine learning can be used where it is difficult or not feasible to develop explicit rules to solve a problem. Self-learning, autonomous systems are becoming a reality in the field of manufacturing due to three primary factors:

- Availability of data from the latest generations of production equipment
- Improved machine learning and algorithms
- More powerful computers

Machine learning enables self-learning systems that adapt and evolve with the ever-changing manufacturing landscape.

Conclusion

The Smart factory revolution in the PCB industry hinges on the effective utilization of raw data. Data is not an end in itself but rather the foundation upon which intelligent manufacturing solutions are built. By implementing a robust framework for data quality, embracing machine learning, and fostering a culture of data-driven decision-making, the industry can achieve its goals of efficiency, quality, and profitability while solving complex problems like registration control. The journey toward the Smart factory is ongoing, but it is guided by data, information, knowledge, wisdom and, ultimately, decisive action. As with all journeys, it starts by deciding which direction you wish to go and taking the first step.

In the words of Arthur C. Clarke, "Before you become too entranced with gorgeous gadgets and mesmerizing video displays, let me remind you that information is not knowledge, knowledge is not wisdom, and wisdom is not foresight. Each grows out of the other, and we need them all." **PCB007**

Andrew Kelley is CTO of XACTPCB Ltd.

Performance and Registration: Coupons to the Rescue!

Happy's Tech Talk #24

Feature Column by Happy Holden, I-CONNECT007

Registration is one of the most important features for any PCB fabricator, but the capability for multilayers is a lot of work on the fabricator's part. CAM settings, multilayer lamination, X-ray analysis, AOI measurements, imaging capability, and drill accuracy all play an important part in this capability. Software and panel parametric coupons are important because they aid in registration performance.

Registration Software

Registration software (Figure 1) provides the database and files for artwork compensation for CAM tooling, as well as real-time compensation for multilayer shifting and drill variances.

Modern AOI, X-ray imaging, and IoT sensors, like confocal imaging, can be connected to registration software to provide real-time

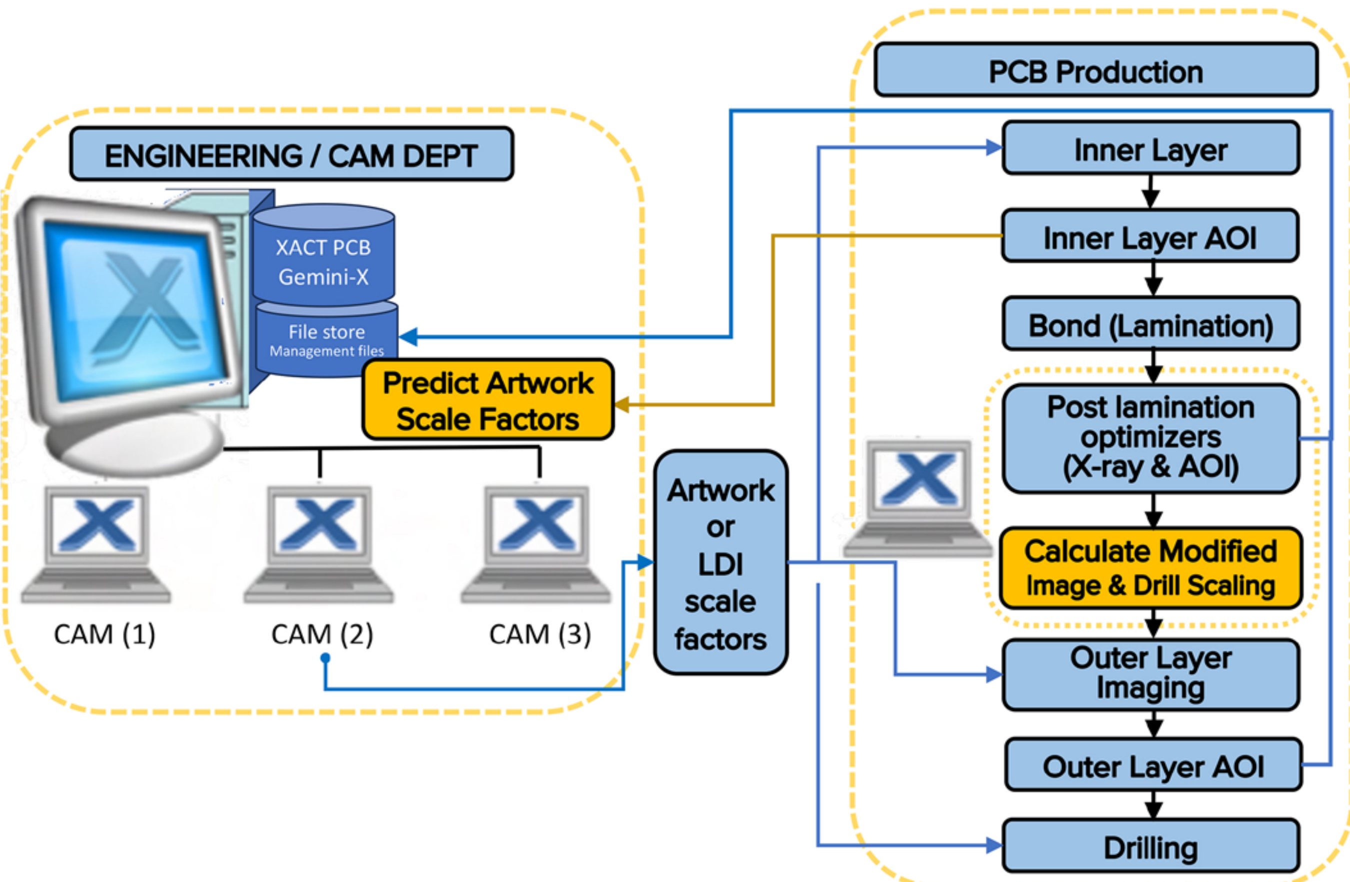


Figure 1: Performance software for PCB registration can provide superior registration[1].

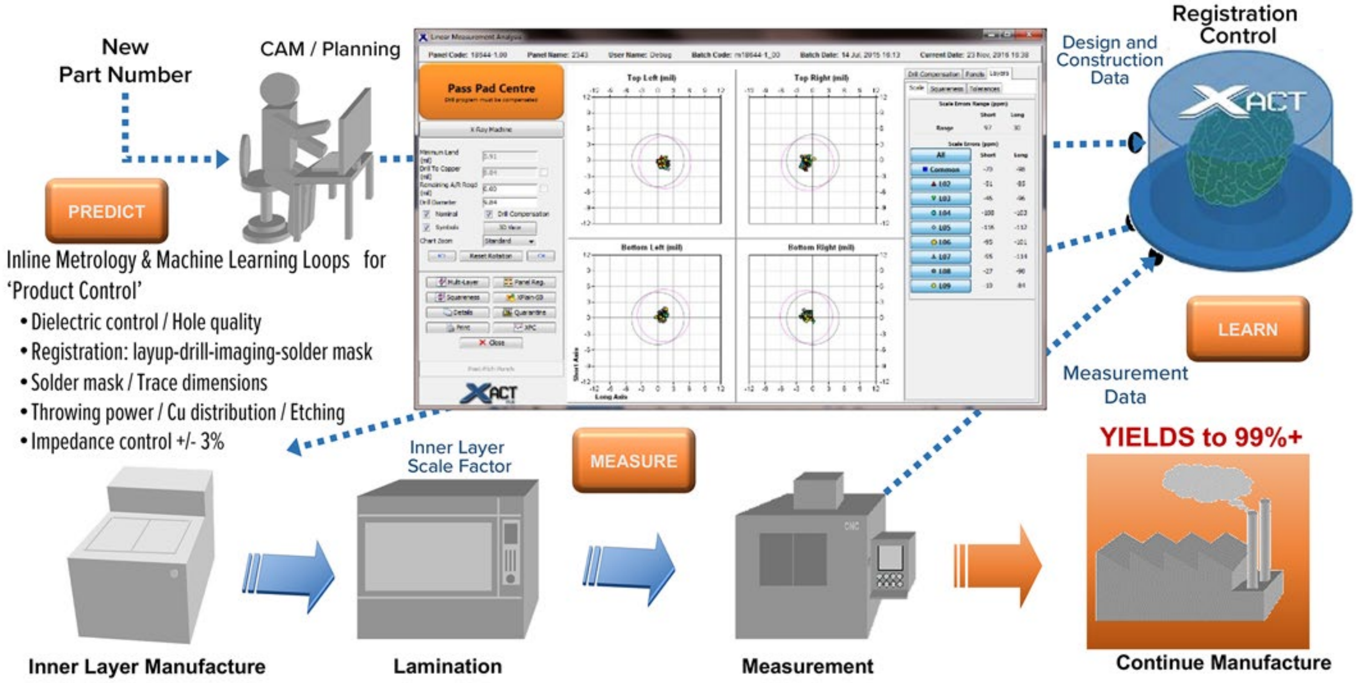


Figure 2: Registration software collects and analyzes various measurement data to improve the performance of each production panel[2].

panel measurements to calculate the best modified drill placements for any inner-layer shifting and provide those changes to outer-layer direct imaging. This can improve yields while allowing for higher precision on controlled impedances (to ± 3%) as seen in Figure 2.

Other Performance Examples

Other registration performance examples (Figure 3) provide a recap of the system now in use at the world's most modern Lean and green PCB fabricator, GreenSource Fabrication. The registration and performance software being used at GreenSource provides hindsight from production data, insight as to what's happening in real-time, and foresight into improving the performance of WIP through prescriptive actions.

Parametric PCB Coupons

There are parametric coupons that can be placed on test panels or production panels that will provide data for registration software. There are currently five available and another three can be used as references and inspiration:

- IPC D-coupons
- CAT coupons
- IPC-PCQR² benchmarking panels
- HATS™ and HATS² ™
- IST coupons

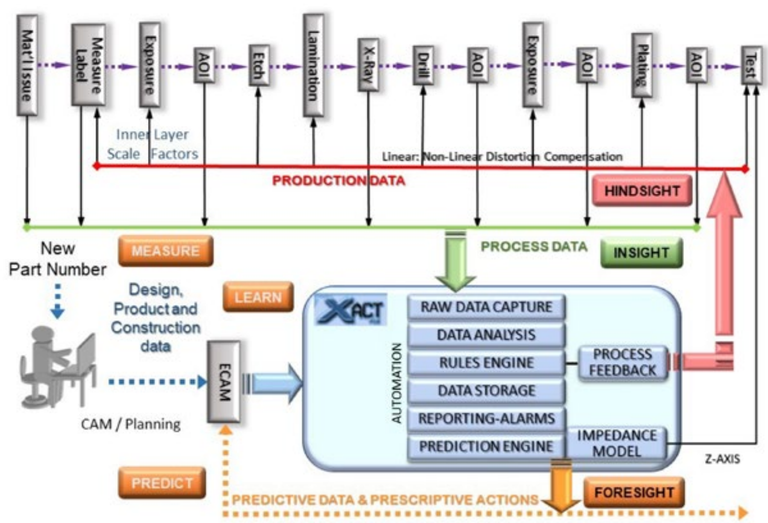


Figure 3: The registration and performance software used at GreenSource Fabrication[3].

For the DIY enthusiasts:

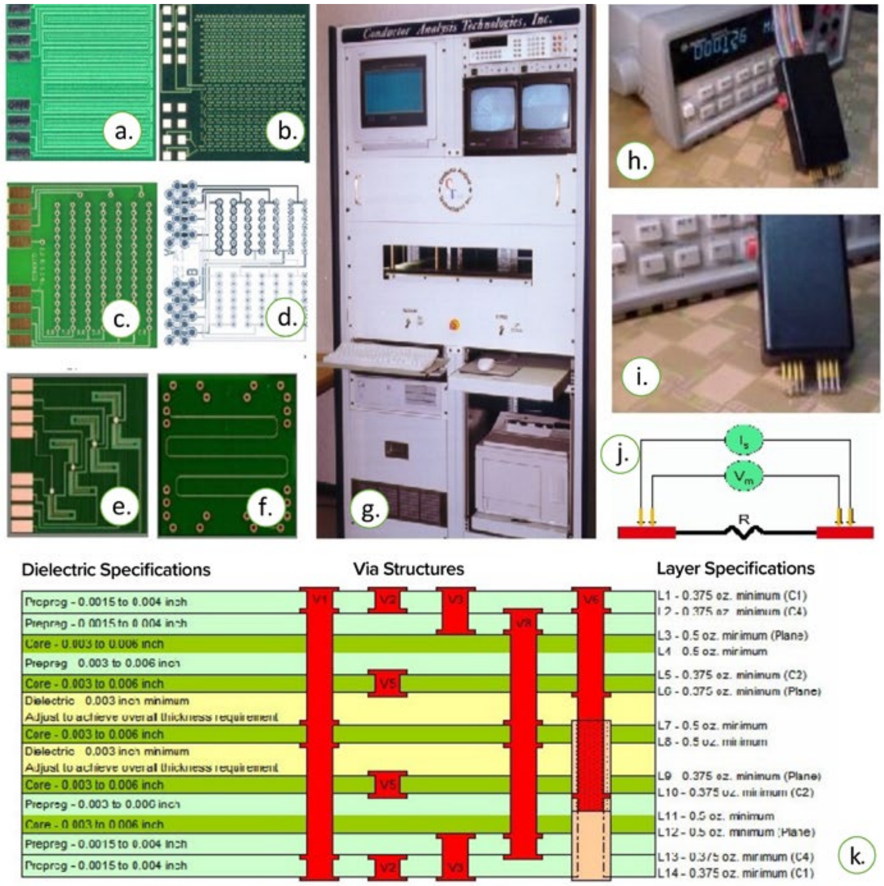
- IBM's CITC coupon
- PerfecTest coupons
- HP's PTS coupons

IPC D-Coupon

The IPC D-Coupons from IPC-2221B Appendix A are used for reliability testing of through-hole, and blind and buried vias from production panels. They are two sets of daisy-chain vias connected for monitoring resistance with the 4-wire Kelvin resistance measurements. Two Type-D coupons are shown in Figure 5g.

Conductor Analysis Test Coupons

Conductor analysis technology (CAT) is the longest running, commercially available parametric coupon system. Born out of an NCMS program with Sandia National Laboratory, founders Tim Estes and Ron Rhodes licensed the testing machine from Sandia and started CAT in 1994. The test equipment and methodology are patented under U.S. Patent No. 5,659,483. Because of the length of availability, its thoroughness, and the wealth of publications, the CAT coupons are the most used and benchmarked. Six coupons, all 25.4 mm x 25.4 mm (1.0" x 1.0") make up the primary sensors for CAT (Figure 4a-f). These are:



l.

Layer Count	TYPE	Size	Laminations	Conductors mils	Via Structure, mils	Zo
2	Rigid Board	18" x 24"	1	3 - 6	TH, 8/18	--
4	Rigid Board	18" x 24"	1	3 - 6	TH,8/18,Bl,3/11	2
6	Rigid Board	18" x 24"	1	2 - 5	TH,8/18,Bl,3/11	2
10	Rigid Board	18" x 24"	1	2 - 5	TH,8/18,Bl,3/11	4
14	Rigid Board	18" x 24"	1	3 - 6	TH,8/18,Bl,3/11	4
18	Rigid Board	18" x 24"	1	3 - 5	TH,7/16;Bl,3/11;Bu,7/1	4
10	Via Rigid Board	18" x 24"	1-2	5 - 8	TH,7/16;Bl,3/11;Bu,7/16	--
14*	Via Rigid Board	18" x 24"	1-2	5 - 8	TH,7/16;Bl,3/11;Bu,7/16	--
24	Via Rigid Board	18" x 24"	1-3	5 - 8	TH,7/16;Bl,3/11;Bu,7/16;sub	--
12	Rigid-Flex Design	12" x 18"	1	3 - 6	TH,8/18	3
4	Pkg. Substrate	16" x 18"	1	2 - 5	TH,6/16;Bl,2/10;Bu,4/12	2
6	Pkg. Substrate	16" x 18"	1	2 - 5	TH,6/16;Bl,2/10;Bu,4/12, sub	2

Figure 4: Conductor analysis technology (CAT): a) Conductor/spacing coupon; b) 4 via-nets daisy-chain coupon; c) Registration coupon; d) Drill overshoot coupon; e) Solder mask registration coupon; f) Impedance coupon; g) Sensitive AC chopped 4-wire micro-ohm test system; h) Portable coupon test system using Agilent 34401A meter; i) Close-up of coupon probes; j) Current and voltage arrangement of the 4-wire Kelvin measurement configuration; k) *14-layer via rigid board illustrated by cross-section showing thickness ranges and various through-holes, blind, buried, subcomposite and back drilled vias; l) various layers, panels, and structures available[4].

a. Conductor: Spacing
b. Via formation: Nets daisy chain
c. Registration: I/L and O/L
d. New registration: I/L and O/L
e. Solder mask registration
f. Impedance

The value of a parametric system such as CAT is its ability to capture the true capabil-

ity of a process, procedure, machine, or materials. There are numerous features on each coupon such that they can be tailored to capture current capability. Complex as these are, they cannot be inspected or sorted, so they truly represent what is going on. For novice users, the temptation is to inspect them to get perfect samples. This usually proves to be a futile activity, as some features are, by design, beyond our current capability.

These coupons are all customizable by CAT:

- Conductor spacing (1 to 20 mils), via diameter, via land, daisy-chain sequence, number of layers, registration sensitivity and layers, via structure (through, blind, buried, skip vias, stacked, sequentially laminated, etc.)
- Impedance type (single-ended, differential, edge-coupled, broadside, coplanar, etc.)
- Overall thickness, as well as placement and panel size

Some coupons were designed to be removed and put in small testers[5].

The primary equipment is shown in Figure 4g. This was designed by Sandia and consists of an alignment system, fixtures, and a bed-of-nails connected to a sensitive AC-chopped, 4-wire Kelvin resistance measurement system (Figure 4j) feeding a PC. In 1999, a portable system was designed so that readings could be made in production, using an Agilent 34401A voltmeter (Figures 4h and 4i). The portable system has additional coupons from 0.33" x 3.0" to 0.5" x 2.0" to facilitate placing on production panels, as well as software to automatically calculate responses. To improve the impedance measurements, the Polar RITS-510 robotic probe and measuring unit were added in 2003.

IPC-PCQR² Benchmarking Panels

Figure 4k shows a 14-layer via rigid PCQR² board illustrated by cross-section showing thickness ranges and various through-holes, blind, buried, subcomposite, and back drilled vias. In Figure 4l, various layers, panels, and structures are available under the IPC PCQR² program.

HATS and HATS² ™

Highly accelerated thermal shock (HATS) was developed in 2003 and HATS² technology was released in 2020 to add the capability to perform multiple cycle convection reflow simulation up to 260°C in accordance with IPC-TM-650 Method 2.6.27B, Method 2.6.7.2c, and other custom reflow profiles. This convection reflow simulation methodology with high speed in-situ resistance measurements can detect cracks and separations in the via structures that occur during the high heat/expansion of convection reflow which could reconnect mechanically at lower temperatures and not be detectable. HATS can test up to 72 of the IPC-2221B Type D coupons (Figure 5a-g) and 36 traditional HATS or single via HATS² coupons for both multiple cycle convection oven reflow simulation and thermal shock/cycling between 55°C and 260°C (Figures 5c–g).

The seven nets in a HATS² are:

- Net 1: 36 via daisy chain of layer 1 and 2 microvia structures only (entire via structure is built on coupon but only microvia structure is measured)
- Nets 2 and 3: Single vias of layer 1 and 2 microvia structures only (entire via structure is built on coupon but only microvia structure is measured)
- Net 4: Entire via structure through the entire PCB including buried via is measured.
- Nets 5 and 6: Single vias of layer n/n-1 microvia structures only (entire via structure is built on coupon but only microvia structure is measured)
- Net 7: 36 via daisy chain of layer n/n-1 microvia structures only (entire via structure is built on coupon but only microvia structure is measured)

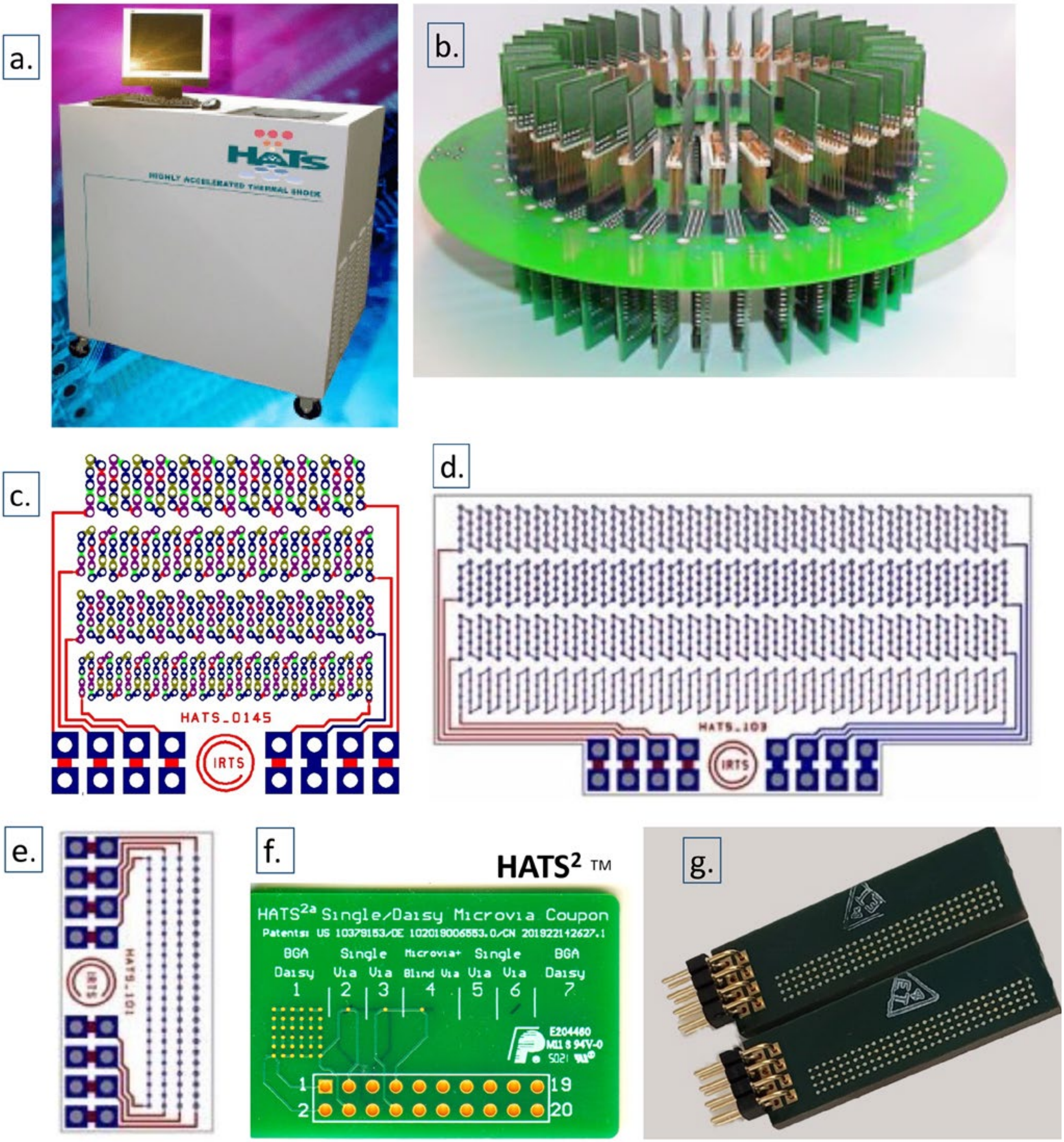
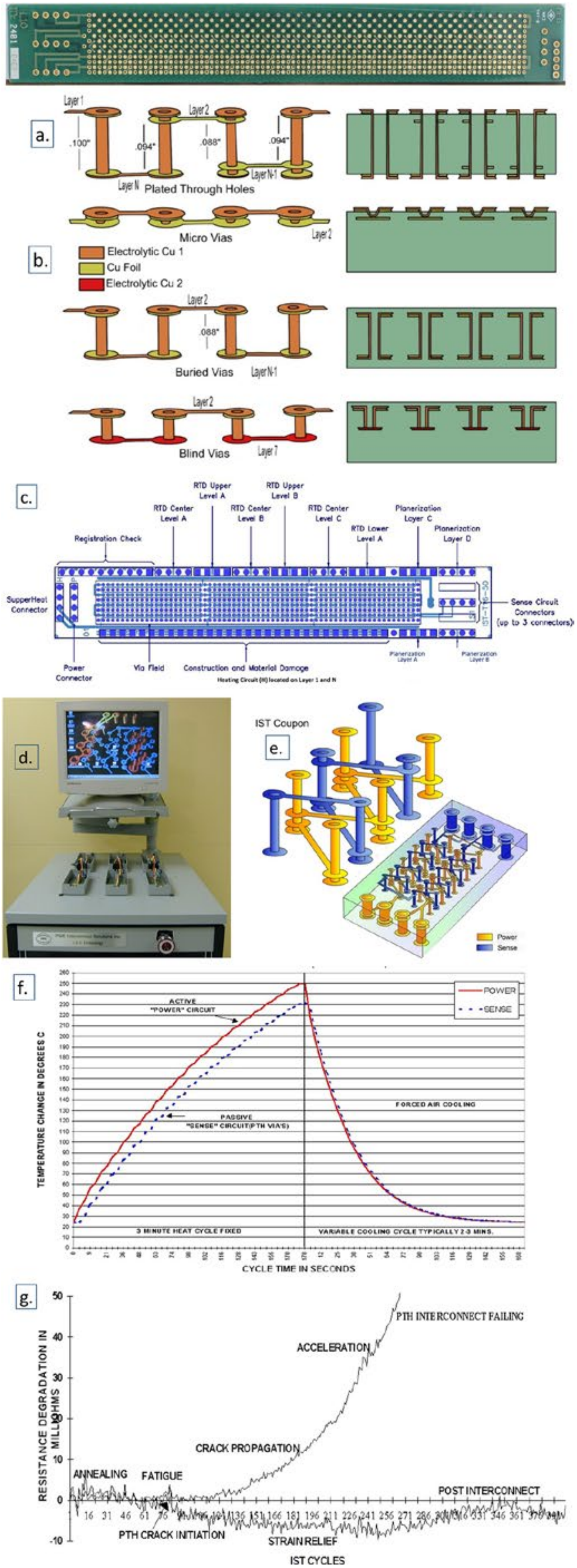


Figure 5: Highly accelerated thermal shock (HATS) is accomplished by: a) generating refrigerated and heated air passing over the test fixture which contains: b) 36 test coupons as shown; c) the 1.0" x 1.0"; or d) the 2.0" x 1.0"; or e) the 0.5" x 1.0" coupons; f) HATS;[2] g) IPC-2221 Type D[5].

Interconnect Stress Test™ (IST)

IST is the oldest and now most used accelerated thermal via reliability system in the industry. Developed in 1989 by Digital Equipment of Canada, patented in 1994, and commercialized by PWB Interconnect Solutions in 1995, over 100 systems have been installed worldwide. Used by over 120 OEMs, EMS companies, and PCB fabricators, it has six licensed service centers around the world and is standardized by the IPC-TM-650 Test Method 2.6.26, the DC current-induced thermal cycling test.

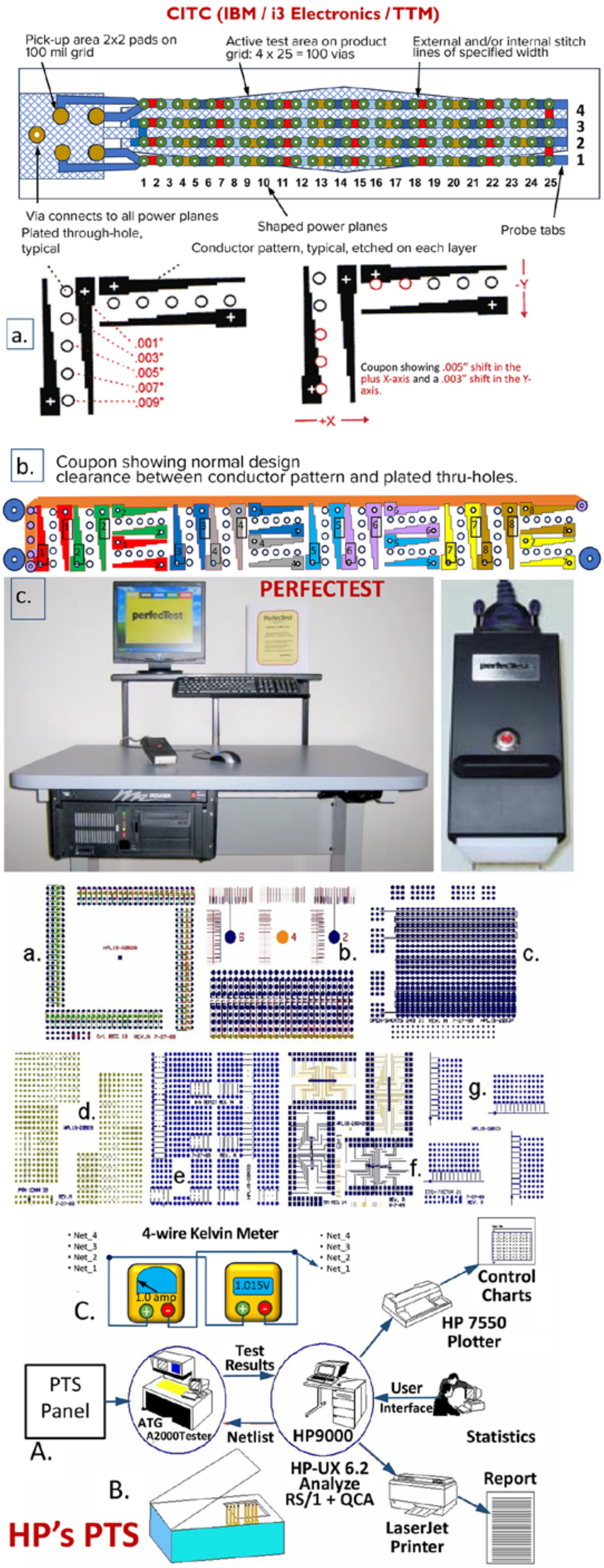


A typical coupon is seen in Figure 6a. This is one that the OEM supplies for an IPC Class 3 board. This one has through-holes, blind microvias, and buried vias using a high-Tg, low-loss laminate. Two of these coupons are built with every board, and until an approved number of IST cycles are passed, it is not assembled. Failure means a return to the fabricator for analysis.

The IST method measures changes in resistance of vias and internal layer connections as the holes are subjected to thermal cycling. The thermal cycling is produced by the application of a high current through the resistive internal layer connections of a specific group of holes, usually 200 daisy-chained vias, interconnecting through two adjacent layers called the power circuit (Figure 6c). Switching the current on for three minutes creates heat to take the connections from room temperature to a designated higher temperature. Stopping the current and with forced-air cooling, the connections cool in two to three minutes (Figure 6f). Another group of interconnects, two independent daisy chains interconnecting 500 vias through any two inner layers at various levels, the ones under test, are the sense circuits (Figure 6b). An isometric view of the two sets of interconnects, running parallel to and sequentially overlapping, is seen in Figure 6d. The equipment providing the coupon fixturing, current, cooling and resistance measurement is seen in Figure 6e.

An accelerated failure will occur because of the differential thermal expansion of the interconnect structure. Failure can occur in several locations (Figure 6g), either a via crack, post

Figure 6 (left): Interconnect stress test (IST) is a DC current-induced thermal cycling test: a) Typical 6" coupon; b) Sense circuit daisy chain; c) Description of current IST coupon; d) Isometric view of parallel and overlapping power and sense circuits; e) IST power, data acquisition, and fixturing test equipment; f) Typical heating-cooling cycle; g) Failure modes of thermally stressed interconnects[6].



separation, connection crack, or material delamination in a specific region within one or multiple areas. Cycling continues until the specific rejection criterion is achieved or the required numbers of cycles are passed.

IBM CITC/PerfecTest®/HP PTS Coupons

Plated through-hole reliability testing at IBM uses their current induced thermal cycle (CITC) PCB coupon. Covered as IPC-TM-650 2.6.26 Method B, this small, single net coupon of 100 vias is only 1.75" x 0.3" and designed by IBM to be used many times on a panel and easily adapted to in-line process monitoring. The test uses current to heat the coupon at 3 degrees per second to 245°C for a dwell time of 40 seconds and repeats the cycle for 200-700 cycles per day. The temperature coefficient of resistance (TCR) is measured continuously and used to determine the coupon's temperature. A 4-wire resistance bridge monitors the via daisy chain. The coupon is shown in Figure 7.

Figure 7 (left) : a) PerfecTest is a material movement and registration coupon system. The coupons are 0.2" x 1.73" and placed at the edges of production multilayer panels; b) How PerfecTest works; c) Testing equipment probe head[7]. The seven coupons (PTS) designed by HP: a) Outer layer registration in 0.00025" increments; b) Inner layer registration and shifting in 0.00025" increments including 0.1 mil X-ray vernier; c) Trace/trace/pad open and short circuit on multiple layers; d) Plated through-hole continuity patterns including I/L connections at various angles to the PTH; e) Artwork defects analysis in 0.00025" increments; f) Etch factor analysis in 0.00025" increments. A) HP's PTS arrangement with a continuity tester; B) Coupon test fixture for individual coupons; C) Milliohm measurement using a 1-amp power supply and digital panel meter in a Kelvin 4-wire test configuration. Gerber files of the seven coupons are available from the author upon request.

The CITC cycles were verified by FEA modeling, TMA, and moiré and has been used by IBM for 30 years. The rapid nature of the test and the small size of the coupons has led IBM and I3 Corp., to be able to characterize many important steps in the PCB manufacturing process.

PerfecTest came along in 1989 to address the problems in multilayer material movement and drill registration. The coupons (Figure 7a, b) are placed at the outer edges of the multilayer panel. The coupons work by detecting which plated through-holes have detected the movement of a particular I/L copper wedge. Figure 7b illustrates the 0.002" increments from 1 to 9 mils in the X-Y axis that the coupon will detect. Coupons can be placed on every layer or just specific ones. Although no specific testing equipment is required, Figure 7c shows the PerfecTest unit equipped with analysis and data storage software.

PerfecTest closed in 2013 but many companies around the world continue to use the coupons. A simple ET-continuity tester or home-built 4-wire Kelvin probe can be used to test panels after etching.

Hewlett-Packard's PTS-parametric test system was created by its Printed Circuit Division in 1987 based on early HP coupons that had been used in production since 1972. It was designed after HP's parametric dies that had been used in its wafer fabrication. Those early coupons focused on inner layer shifting, by using the copper on I/L's shorting to a plated through-hole, moiré patterns, and hole quality cross-sections. Additional influence came from a parametric printed circuit board used as a training and process vehicle for the first NanYa PCB facility in Taiwan, around 1983. This PCB had various design-rule technologies on it and provided feedback on how the process was improving.

The HP PTS was a group of seven coupons that could be placed on production panels or used on a parametric panel to provide a snapshot of the benchmarked capability of the process. The initial seven coupons (Figures 7a–f) were designed to test:

1. Outer layer registration
2. Inner layer registration and shifting
3. Conductors/pads open and shorts
4. Plated through-hole, I/L conductors continuity
5. Artwork defects
6. Solder mask registration
7. Etch factors

The coupons were all designed to be tested by a facility's continuity testers using the bed-of-nails open/short testing machines. In this case, the tester was an ATG2000 grid tester. The tester's fault-file was captured by an HP workstation and stored. Each coupon had a stored perfect response or netlist that was compared to the fault file, and the opens and shorts were translated to dimensional shifts or other parametric data. The RS/1 statistics program was used to produce control charts and statistical reports, as well as historic data.

This system can be seen in Figure 7a. Also seen in Figures 7b-c were the small stand-alone coupon testers that operators had to check the process immediately as a confidence indicator. These home-built milliohm meters worked with a simple one-ampere power brick, a four-digit digital panel meter and a machined-Plexiglas coupon holder with eight spring-loaded gold pins wired to a four-position rotary switch in a 4-wire Kelvin measurement scheme.

The concept was adopted by Foxconn's internal PCB fabrication group as a method of benchmarking its 16 large PCB facilities in China; the number of different coupons was extended to 24 coupons, many that, after measurements, are used for assembly performance benchmarking.

Summary

For as long as there has been printed circuit production, there have been coupons to test every factor. Many excellent coupons have been designed over the years, too many for me to address in this column. The choices now are greater than ever. Hopefully, you are using one of these systems. You can buy it, rent it, or develop it yourself. The economic pressures of competition and the impending deadline of new laws make that an imperative[8]. But without something, you will find it increasingly difficult to stay in business, either because of profitability or reliability. PCB007

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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 the author of *Automation and Advanced Procedures in PCB Fabrication*, and *24 Essential Skills for Engineers*. To read past columns, click here.

Fast Electrical Signals Mapped in Plants With New Technology

What happens inside the carnivorous plant Venus Flytrap when it catches an insect? New technology has led to discoveries about the electrical signalling that causes the trap to snap shut. Bioelectronic technology enables advanced research into how plants react to their surroundings, and to stress.

Plants have electrical signals that are generated in response to touch and stress factors, such as wounds caused by herbivores and attacks on their roots. As opposed to animals, who can move out of the way, plants must cope with stress factors where they grow.

"There is currently a great need for developing plants that are more stress resistant, for us to be able to grow food and have healthy forests also in the future. That's why it's important that we understand how plants respond to stress, and I think that this new technology may contribute in this area of research." says Eleni Stavrinidou, associate professor in the Department of Science and Technology at Linköping University, LiU and leader of the Electronic Plants group.

It turns out that in some plants electrical signals are correlated with rapid movements. The carnivorous plant Venus Flytrap (Dionaea muscipula) is used by researchers as a model system for fast electrical signalling in plants.

New measuring technology lets the researchers discover new information. One of the most important aspects of this study is that we show that bioelectronic technologies, which are extensively used in biomedical research, can be applied to plant physiology research as well, therefore opening possibilities for new discoveries" says Eleni Stavrinidou.

(Source: Linköping University)

Amitron's Leap Into the AI Frontier

Feature Interview by Nolan Johnson
I-CONNECT007

In a conversation with Aidan Salvi, Amitron's chief transformation officer, he spoke of the interaction of machine learning on registration. Amitron has been modernizing much of its manufacturing equipment, and Aidan points out that improving registration is a key objective. He sees registration as a holistic system. To make smart improvements, you need data. To get data, you need equipment and sensors which capture the data. To make sense of the data, you need analysis and, eventually, predictive tools.

Aidan, you're leading a transformation at Amitron, and you've shared that registration improvement is one of the objectives of your modernization. Where do you see machine learning and AI contributing?

Aidan Salvi: There are steps to making AI impactful. It all starts with gathering the data. We operate our process with nearly 60 different pieces of equipment that do different functions. When looking at what the future of AI could be, the biggest challenge is how we consolidate that data. How do we create standards? How do we create scalable hardware that can store and retrieve the data? This is a tremendous amount of data; companies need to look at their data infrastructure and assess how to integrate and pull it all together. That is the first hurdle I see for AI in the future.

When it comes to bringing AI into the PCB factory, is this a hardware processing horsepower and data storage challenge, or maybe one with software tools or people and skills? Where do you start using machine learning and AI appropriately for registration?

There are at least three things I see as the cornerstones of this challenge. First, it's integration with the equipment. You must deal with quite a few manufacturers to extract the neces-

sary data out of the equipment in a consistent way. That doesn't exist in our industry as well as it could. Second, it's not necessarily computing horsepower, but more of an infrastructure design issue. We're dealing with quite a bit of real-time data that needs to be transported over networks, stored, and processed. In other words, it's designing infrastructure that can handle the future needs of AI computing. The last piece is cloud integration, where much of AI is built. That starts moving us away from the physical component, and into looking at how we can start processing the data at scale and building data systems in a virtual cloud architecture. These are challenging things to put in place because of the overall cost and knowledge gaps that exist.

> "AI is a learning tool."

Of course, when you are gathering and analyzing data, you're operating post-facto or in a reactive way. When it comes to registration, that tends to be more of a predictive, proactive activity—planning ahead for the variations and such. How do we move from one to the other?

AI is a learning tool. We need to collect data on how individual companies' systems and processes operate. As more information is learned and interpreted, the decisions will become better over time. The predictive ability comes after we're able to store, catalog, understand, and then predict where that next similar job will be from a scaling point of view.

It's important to remember that the power of AI comes from the ability to take in so many variable factors—which we human beings are challenged to compute—and put that all into a model. With that model, now we're able to take, say, 50 data points that were independent and compute them for the next job to get a recommendation, such as "This is where we need to be for scaling factors based on all the different permutations of those 50 data points. That's AI interpreting over 100,000 different permutations." Over time, those data points become more numerous and converge on good solutions. That's how AI could be impactful for our future.

Are the tools available to provide this sort of predictive functionality?

AI models generally need some research and engineering; the tools must be developed. As part of our Factory 5.0™ modernization steps, we're looking at standardizing data, data warehousing, and ways to integrate with each one of our equipment manufacturers. It all must be custom built for our industry because there currently is no model out there that understands how our industry operates.

There's an opportunity here, but there are challenges before it can truly create impactful value. We'll have to overcome those challenges to translate that into something impactful in our manufacturing lines, creating more advanced manufacturing processes as a result. I think it will take time, collaboration, and a lot of resources and knowledge from people to truly make it a part of our industry.

Do you see the transition over time to AI techniques as mandatory?

Like anything else, we all need to compete in the industry. We must stay relevant, and there are companies looking to advance their technology more assertively than others, whether by need or desire. Eventually, just like in the rest of the world, AI will become an integral piece of the ecosystem, but it's just a piece of the total ecosystem. There will always be people; we still must exist. There will be engineers and production work staff. We just have to find the middle ground, the collaboration. How can we be better at delivering what we're trying to build here with the tools we have?

Agreed, good thoughts. Thank you, sir.

Thank you, Nolan. **PCB007**

A Conversation with Congressman Blake Moore

Material Insight

by **Preeya Kuray, Ph.D.**, AGC MULTI MATERIAL AMERICA

On May 11, 2023, Reps. Blake Moore (R-UT) and Anna Eshoo (D-CA) introduced the Protecting Circuit Boards and Substrates (PCB) Act to Congress. This bipartisan legislation aims to support and incentivize American PCB manufacturing through the following stipulations:

1. Provide a 25% tax credit for the purchase or acquisition of American-made PCBs.
2. Establish a financial assistance program, modeled on the CHIPS for America Act, for American facilities manufacturing or researching PCBs.
3. Authorize appropriations of $3 billion to carry out the program.

In October, I had the great pleasure of discussing the bipartisan Protecting Circuit Boards and Substrates Act with Congressman Moore, who represents Utah's First Congressional District. He shared his thoughts on how supporting and investing in the domestic PCB industry can help bolster American security.

Preeya Kuray: Thank you so much for taking the time to meet with us today. The Protecting Circuit Boards and Substrates Act is bipartisan legislation that allocates for investment in domestic PCB manufacturing facilities and provides tax incentives to companies that purchase or acquire domestic PCBs. What was it about the PCB industry that compelled you to introduce this law to Congress?

Blake Moore: I have seen the United States and our allies make headway on something critically important for our national security: rejecting Huawei (the Chinese telecommunications firm) from infiltrating and entering our market. From an intelligence perspective, this was not about rejecting the latest foreign technology. This legislature came from a place of rejecting the development of infrastructure and telecommunication capabilities outside the United States from a nation that we are often adversarial with. The United States used to hold a huge market share of global PCB manufacturing, but we have gradually ceded a huge portion of that to the Chinese market. I believe that is dangerous and that we need to pull that market back. The best way to do that is to manufacture the most sensitive defense-related PCBs in the U.S. We have a model for it, and we have the need for it.

So, this legislation came from a standpoint of bolstering American security?

Definitely, and with a secondary interest of shoring up PCB manufacturing and pulling the market share back to the U.S. economy for growth. I would want more of our commercial world to engage in PCBs manufactured in the U.S. and our ally nations.

How did the PCB Act come to fruition? Most of our readers have a technical background within the PCB industry but are not necessarily well versed on technology-related government affairs. The legislative aspect is of great interest to our community.

In addition to what we discussed (where national security concerns have been a large driver), we worked closely with the Printed Circuit Board Association of America (PCBAA). Once we identified what the legislation would look like (tax incentives for U.S.-made PCBs and investments in infrastructure), the next level was to gain Congressional support, which stemmed largely from my work on the Armed Services Committee and expanding it from there. Congress is a funny place. It is difficult to implement legislation when there are still so many other things going on. But supporting PCBs makes sense. This legislature is bipartisan, and people understand its importance. Because this is a problem that has developed and grown over the last 30 years, we can't solve it all today. But what we can do is create an opportunity for small success by establishing a focus area and then building out from there.

"Congress is a funny place. It is difficult to implement legislation when there are still so many other things going on. But supporting PCBs makes sense."

The PCB Act is modeled after the CHIPS Act, which includes incentives for R&D as well as programs to increase the work force and create jobs. In the 1980s, the PCB industry in the United States was at its peak, having 30% of the global market share[1]. Over the past 30 years, PCB manufacturing gradually shifted from the United States to overseas. Will there be any legislation in the PCB Act to help bolster the PCB workforce development in manufacturing?

Look at this PCB legislation as part of the larger effort of the CHIPS Act. I like the PCB Act more than CHIPS because I think it can be more targeted and you can experience more success in an earlier timeframe. To answer your question, yes, there will be invest-

ment in the infrastructure. The general fund will go to building in the equipment, investing in workforce, and getting other infrastructure in place. Then it will be directed toward incentivizing buying. There will be tax incentives for those that are purchasing from U.S. PCB manufacturers. When you look at that opportunity for a tax incentive for a broader potential customer base, there is real potential. For example, a company in my district needs more workforce for the volume of work that they can do. If the government incentivizes more customers, we can grow those businesses more quickly. They already have the factories and facilities that are needed to scale more quickly. All things being equal, people would purchase from a U.S. manufacturer, so to what extent can we achieve economic growth through tax incentives? Ultimately, going in that direction is where the success of this act comes from: investing in both the building and the buying.

Where does the PCB Act stand now?

A markup on this bill has not yet been scheduled, but I am working diligently in the meantime to garner more support for this important effort. PCB007

References

1. "Leadership Lost: Rebuilding the U.S. Electronics Supply Chain," by Joe O'Neil, ipc.org.

Preeya Kuray, PhD, is a material scientist at AGC Multi Material America. To read previous columns, click here.

Progressing Toward a Factory 5.0 Future

Aidan Salvi, chief transformation officer, updates Nolan Johnson on the modernization activity underway at Amitron. The company has added 62 different pieces of new equipment on their production floor, and Aidan shares details on what that means for Amitron's production capabilities, data management, and progress toward a Factory 5.0 future.

MEET THE IPS WORKFORCE:
Inoa Wahinehookae

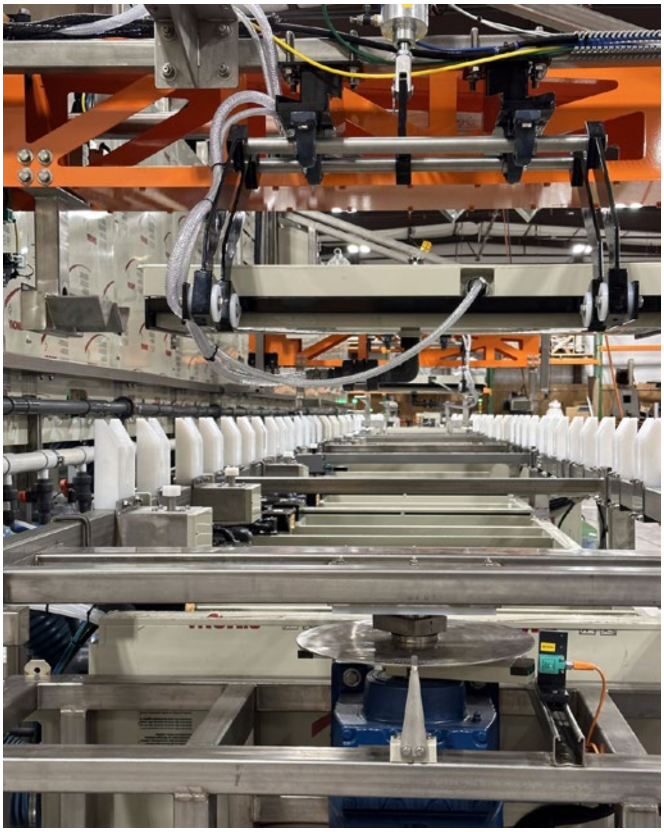
Interview by Barry Matties
I-CONNECT007

As the workforce continues shifting to the next generation and the lack of appeal for manufacturing careers persists, we feel it's important to share the voices of those who have chosen manufacturing as their career. We believe this will raise awareness and inspire others to consider manufacturing as a strong and viable career path.

I recently went to Cedar City, Utah, where I visited IPS, which has been manufacturing wet process equipment for printed circuit board fabrication for over 30 years. While there, I conducted candid one-on-one interviews with several of the IPS team members, who shared their views on manufacturing, as well as their roles, challenges, and advice for others looking at manufacturing as a career.

In this video, you will meet mechanical design engineer Inoa Wahinehookae, who graduated two years ago from Southern Utah University with a bachelor's degree in mechanical engineering and a minor in CAD/CAM. He started his career with IPS, and now, as project manager, Inoa is already in charge of some of the largest projects at IPS. His current project is a state-of-the-art, fully automated ENEPIG

Click below to watch Inoa's video interview.



line that will soon be installed at TTM. Inoa has been the project manager from the start of the entire process and will be onsite for the installation and customer training.

The ENEPIG line is 75 feet long and features a side-arm dual hoist; X-Y oscillation; double-jacketed nickel, gold, and palladium tanks; vibration; bump; and all the latest in filtration, along with day tanks engineered into the line that can later be relocated to accommodate new processes on the horizon.

When it comes to bath maintenance, such as stripping the nickel tank, the line is equipped with a completely automated bath transfer system, eliminating the need for someone to move the chemistries with drum pumps. This includes adding the chemistry back into the tanks. IPS also collaborated with the chemical supplier to integrate their control system into the line. Other features include built-in UV sterilization, and cooling systems for incoming water to maintain critical rinses that cannot get overheated. In addition, IPS's software team has developed and implemented a 4.0 software package that manages the line and captures all the necessary data to integrate it into the customer's MES system.

Inoa is responsible for providing customers with weekly progress updates and managing any special request the customer may have along the way. It was evident that he is a bright young engineer who takes his role seriously. He clearly understands the design and manufacturing process. **PCB007**

Teach the Terminology

The New Chapter

by Paige Fiet, TTM-LOGAN

Imagine you've just graduated college and are off to start a career at an electronics manufacturer. Week one is filled with meeting the team, orienting your way around the floor, and learning the general flow of PCB manufacturing. Wow, there are so many steps! The next week is off to a similar start but with a team meeting to review a new part. Suddenly, the friendly team you met is speaking what sounds like a foreign language. Words are thrown around, such as buried vias, 370HR, back drill, and routed plated edges. None of these terms were taught during the college education you've just completed. Then, an overwhelming feeling kicks in, and you wonder if you will ever learn to speak this new language as fluently as your team.

There is often a similar disconnect between employers looking for qualified graduates and eager graduates in search of a career. A higher education cannot begin to teach the dictionary used in each industry a student may join. So, how is this terminology gap better bridged for the success of all parties involved? Fortunately, there are several initiatives that may be taken by a company to reduce the time it takes for an employee to learn the necessary terminology required for job performance.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1. A PCB Reference Guide

Let's face it, if all the words used daily in a fab house were written down, a new Webster's Dictionary could be created around circuit boards alone. Having a document with images and definitions to describe the most common vocabulary allows an employee to make a quick reference without having to "bother" a colleague for the difference between ENEPIG and EPAG for the fourth time in a week. A document like this creates confidence in the employee to learn at their own pace between onboarding activities. PCB reference guides may include a basic process flow, animated/real images of defects and basic definitions for the top 100+ words and phrases. One good resource is IPC-T-50N, "Terms and Definitions for Interconnecting and Packaging Electronics Circuits."

2. Internships

Internships are the best way to ease an employee into the industry. They create a lower pressure environment for students to work on projects relevant to potential careers whilst unconsciously picking up on new terminology. Along with the increased recruitment opportunities for the employer, internships are a wonderful opportunity for interns to work in multiple areas of a manufacturing facility with members of their future team. By the end of the summer, an intern will have the experience and understanding of PCB manufacturing not commonly held by their peers.

> "Internships are the best way to ease an employee into the industry."

3. Mentorships

This is my personal favorite because I believe all good training programs involve a level of mentorship. Mentors can provide a verbal explanation with real examples in a timely manner. The mentee in this relationship will learn deep skills of the craft over a designated amount of time. While mentees may learn more vocabulary centered on certain areas of the manufacturing process, they will develop a general repertoire used by their colleagues. Note: A mentorship approach should be paired in conjunction with another approach to increase the knowledge base across the manufacturing processes.

4. PCB 101 Class

A PCB 101 course is a quick and easy way for all levels of employees to quickly learn the basic terminology heard on the floor. Both operators and technical positions can benefit from a one- to two-hour crash course into the makings of a PCB. A PCB 101 class is best when completed within the first three months of employment to allow the employee to connect what they are seeing each day. A bonus with this approach is that everyone participating in the class is at the same knowledge level with the course being taught. IPC offers a video course which may suit this need, titled, "Fundamentals of PCB Fabrication & Assembly."

5. A Day With Final Inspection

Spending time with the final inspection department is one of the best opportunities to learn about defects in the manufacturing process. Just a couple of hours in the final inspection department is a lesson into conformance vs. non-conformance with reasoning why. An experienced final inspector can define the differences between measling, crazing, and haloing, or inkjet splatter and bleeding. These team members use industry standards and language to determine "good" vs. "bad." Frankly, they are an invaluable resource from those who have seen (most of) it all while bringing the PCB process full circle. If you're looking for a

reference guide for inspection, IPC-A-600K, "Acceptability of Printed Boards," is a good place to start.

Conclusion

Terminology can be troubling for new hires but there are ways to prevent it from becoming a barrier between employer and employees. Unfortunately, most employees will not come into a PCB manufacturing environment from another industry or higher education with the terminology base needed to succeed. If employers can quickly provide employees with the tools needed to speak their common language with one or two simple programs, both the employer and employee will reap the benefits. What tools can your company use to reduce the terminology barrier? PCB007

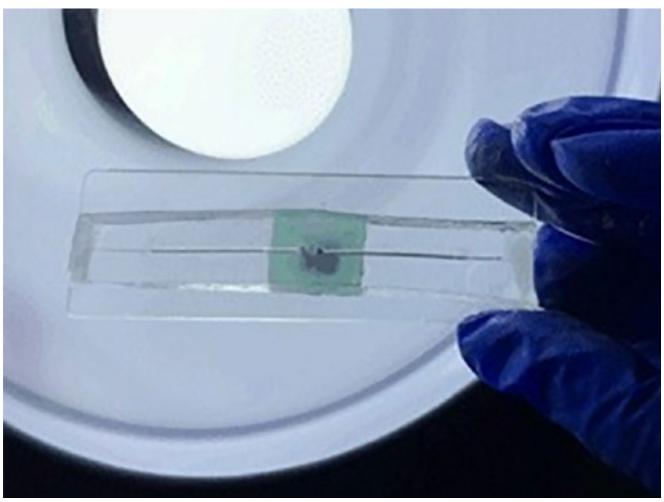
Paige Fiet is a process engineer at TTM-Logan, and in the IPC Emerging Engineer Program. To read past columns, click here.

Researchers Use Liquid Metal and Laser Ablation to Create Stretchable Miniature Antennas

Researchers have developed a new method for making tiny stretchable antennas from a hydrogel and liquid metal. The antennas could be used in wearable and flexible wireless electronic devices to provide a link between the device and external systems for power delivery, data processing and communication.

"Using our new fabrication approach, we demonstrated that the length of a liquid metal antenna can be cut in half," said Tao Chen from Xi'an Jiaotong University in China. "This may help downsize wearable devices used for health monitoring, human activity monitoring, wearable computing and other applications, making them more compact and comfortable."

In the Optica Publishing Group journal *Optics Express,* the researchers describe their new technique, which involves injecting eutectic gallium-indium—a metal alloy that is a liquid at room temperature—into a microchannel created with a single-step femtosecond-laser ablation process. They used this method to create an antenna measuring 24 mm × 0.6 mm × 0.2 mm embedded into a 70 mm × 12 mm × 7 mm hydrogel slab.

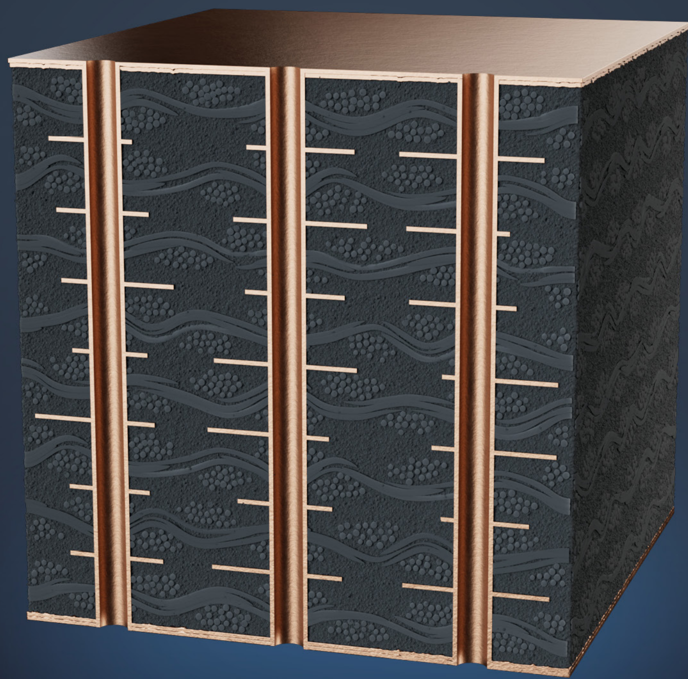


"Stretchable and flexible antennas could be useful for wearable medical devices that monitor temperature, blood pressure and blood oxygen, for example," said Chen. "Separate mobile devices could connect to a larger control unit via the flexible antennas—which would transfer data and other communications—forming a wireless body-area network. Since the resonance frequencies of the flexible antennas vary with applied strain, they could potentially also be used as a wearable motion sensor."

Making a Stretchable Antenna

To demonstrate the new fabrication approach, the researchers prepared stretchable dipole antennas and measured their reflection coefficients at different frequencies. These experiments showed that the pure hydrogel reflects almost all the incident electromagnetic wave energy, while the liquid metal dipole antenna embedded in hydrogel radiates most of the incident electromagnetic wave effectively into free space, with less than 10% reflected at the resonance frequency. They also showed that by varying the applied strain from 0 to 48%, the resonant frequency of the antenna can be tuned from 770.3 MHz to 927.0 MHz.

(Source: OPTICA)



PCBAA MEMBER PROFILE:

Hari Pillai

President, Technology Components, Sanmina

American Made Advocacy

by Travis Kelly, PCBAA

How did your career bring you to your current position at Sanmina?

I think I've had a good dose of luck throughout my career. But beyond luck, I had a vision to become a general manager as far back as my undergraduate years. I made all my career decisions based on that. My evaluation criteria was always, "How does this opportunity get me closer to my goal?" Sometimes opportunities come from unexpected places. For example, my first entry into the EMS business and first general management role came by chance when I met an executive from one of the EMS industry's leading companies at a barbeque in 1991. This brought me into the industry and eventually led to me joining Sanmina in 1994 to lead what is now our Integrated Manufacturing Services (IMS) group.

Over 15 years, I took on additional leadership roles and became president and chief operating officer of the company for a few years. I left Sanmina for a few years to work in private

Hari Pillai with Travis Kelly, chairman of PCBAA, outside the Capitol.

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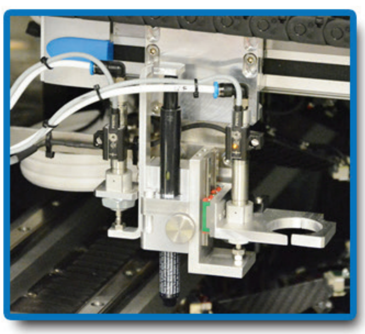

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Hari Pillai

equity, leading two companies before returning to Sanmina in my current role. A big part of my return to Sanmina was and is the strong conviction that PCBs are an exciting product critical to the company and strategically important to the country.

What are the unique challenges facing the industry? Where are things headed?

On the economic business side, this industry has been decimated over the past 20 years. The U.S. shrunk from about 25% of the world's supply to 4% today. The U.S. suffered because of offshoring and lost the infrastructure and innovation that other countries invested heavily in. We need to get that back. This is why the PCB Act is so important. On the technology side the U.S. is dealing with finer lines and spaces that traditional techniques struggle to keep up with. The U.S. needs to invest more in R&D to innovate the future. This is easier for large companies like Sanmina. Our PCB business is part of a multi-billion-dollar company. We have the benefit of being able to draw on an astonishing array of engineering and scientific resources. The reality is that it is much harder for small companies that don't have the financial resources and breadth that Sanmina has. But with the potential benefits of the PCB Act on the horizon, it could give small to medium companies the resources they need to invest in the future and keep pace with the march of technology.

How can the PCB Act bring manufacturing back to this country?

I am optimistic that the legislation could result in two or three new PCB fabs in the industry. We will need this capacity to handle all the reshoring that is going on. It has been great working with PCBAA and member companies to get the attention of legislators and policymakers in Washington. What we are asking for in the bill is much less than the CHIPS Act. In reality, our bill protects the investment that the government and private companies are making via the CHIPS Act. Without concurrent increases in PCB manufacturing, we will remain dependent on other countries for most of the PCBs needed to support the semiconductor fabs being built over the next few years. PCBAA is making a difference by addressing the entire ecosystem. We need both a vibrant manufacturing and supplier base to rebuild an industry that has been in a downward spiral for so many years. That ecosystem includes material suppliers and equipment manufacturers and I look forward to reversing the trends of the last decades and rebuilding the PCB ecosystem.

You have spent time on Capitol Hill. What was your message when you met with members of Congress and their staff?

My message was that this is a larger issue than just PCBs. It is about ensuring the vibrancy of the entire technology ecosystem. I reminded them that electronics govern all aspects of modern life. PCBs are pervasive in every facet of modern life, especially in mission critical applications like those found in national defense systems and critical infrastructure like telecommunications, aviation, medicine, and computing. We need reliable and secure sources of electronics in this country. Con-

gress needs to take a holistic view and pass legislation and make policy decisions that address the entire ecosystem.

What needs to be done to attract new workers?

I think every employer faces a challenge in attracting and retaining talented employees. While Sanmina has been able to win more than our fair share, it has not come easily. We need great employees that are similar to the makeup of American society in general. Sanmina is always looking for strong technical talent, but we also need people with a high school education who are willing to work with us to train and develop their skills. Sanmina does a lot of our own training and have found that our investment in people creates a stable environment. We really put down roots in communities and stay a very long time given the investments we make in our people and the fabs that we build. PCB007

Travis Kelly is CEO is Isola-Group and current chairman of the Printed Circuit Board Association of America. To read past columns, click here.

New High-power Thermoelectric Device May Provide Cooling in Next-gen Electronics

Next-generation electronics will feature smaller and more powerful components that require new solutions for cooling. A new thermoelectric cooler developed by Penn State scientists greatly improves the cooling power and efficiency compared to current commercial thermoelectric units and may help control heat in future high-power electronics, the researchers said.

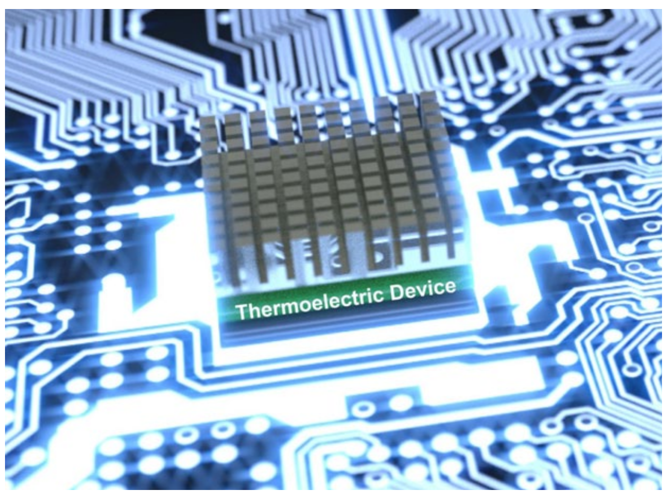
"Our new material can provide thermoelectric devices with very high cooling power density," said Bed Poudel, research professor in the Department of Materials Science and Engineering at Penn State. "We were able to demonstrate that this new device can not only be competitive in terms of technoeconomic measures but outperform the current leading thermoelectric cooling modules. The new generation of electronics will benefit from this development."

Thermoelectric coolers transfer heat from one side of the device to the other when electricity is applied, creating a module with cold and hot sides. But as those components become more powerful, thermoelectric coolers will also need to pump more heat, the scientists said.

The new thermoelectric device showed a 210% enhancement in cooling power density compared to the leading commercial device, made of bismuth telluride, while potentially maintaining a similar coefficient of performance (COP), or the ratio of useful cooling to energy required, the scientists reported in Nature Communications. The new device is made from a compound of half-Heusler alloys, a class of materials with special properties that show promise for energy applications like thermoelectric devices. These materials offer good strength, thermal stability and efficiency.

"This solves two out of the three big challenges in making thermoelectric cooling devices," said Shashank Priya, vice president for research at the University of Minnesota and a co-author on the paper. "First, it can provide a high cooling power density with a high COP. This means a small amount of electricity can pump a lot of heat."

(Source: Penn State)



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MilAero007 Highlights

Airbus Helicopters Pioneers User-friendly Ways to Fly eVTOLs ▶

Airbus Helicopters' demonstrator FlightLab has successfully tested an electric flight control system in preparation of a new human machine interface (HMI) that will equip CityAirbus NextGen, Airbus' eVTOL prototype. This milestone represents an important step toward ushering in a new generation of electric powered urban air mobility aircraft.

NASA Science, New Airlock Heads to Space Station on SpaceX Cargo Spacecraft ▶

The Dragon resupply spacecraft launched on a Falcon 9 rocket from Launch Pad 39A at Kennedy and is scheduled to arrive at the space station around 1:30 p.m. Monday, Dec. 7, performing the first autonomous docking for SpaceX and remaining at the station for about a month. Coverage of arrival will begin at 11:30 a.m. on NASA Television and the agency's website.

CACI Awarded NASA Contract for Human Spaceflight Systems, Simulation and Software Technology III ▶

CACI International Inc announced that it has been awarded a four-year single-award, indefinite delivery indefinite quantity expertise contract worth up to $150 million to continue its support of spaceflight systems, simulation, and software for NASA Johnson Space Center (JSC). The program provides advanced aerospace engineering for crewed spacecraft systems, development of simulation and Virtual Reality (VR) applications, and software in support of human space flight. This award builds on more than three decades of CACI's dedicated support for JSC's mission.

Accelerating Interoperability Standards for Commercial Lunar Infrastructure ▶

Lunar exploration is expanding at a rapid pace, and a robust lunar economy within the next decade is coming quickly into focus. It's clear that many shareable, scalable commercial systems will be needed to support a future lunar ecosystem. Yet a key question remains: How will these systems interface?

Sierra Space, NASA Prepare for Revolutionary Dream Chaser Spaceplane's Debut Mission to Space Station ▶

Sierra Space, a leading pureplay commercial space company, announced the successful completion of the first mission Flight Operations Review at NASA's Johnson Space Center, a crucial step in preparation for the inaugural Dream Chaser mission to the International Space Station.

Northrop Grumman Selected to Deliver Nearly 40 More Data Transport Satellites for SDA ▶

The Space Development Agency (SDA) awarded Northrop Grumman Corporation an agreement with a total potential value of approximately $732 million to design and build 38 data transport satellites. These satellites will support Tranche 2 Transport Layer –Alpha (T2TL-Alpha), the latest iteration of SDA's low-Earth orbit Proliferated Warfighter Space Architecture (PWSA).


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The Next Wave of Wearable Health Monitor Innovation

The Doctor's In

by Henry Crandall, UNIVERSITY OF UTAH/IPC STUDENT BOARD MEMBER

In the ever-evolving world of healthcare, wearable health monitors will likely play an increasing role. Once relegated to basic step counting and heart rate tracking, these sleek devices are now on the cusp of a technological revolution. The driving force behind this transformation? Advanced electronic hardware. In this column, I'll provide a glimpse of the new electronics that promise to drive the next wave of wearable health monitor innovation.

E-Textiles

Move over rigid sensors and bulky straps; e-textiles are here to revolutionize the world of wearables. Electronic textiles (e-textiles) are fabrics interwoven with conductive threads or embedded with microelectronics. They are the future of wearable comfort and functionality.

Imagine a shirt that not only monitors your heart rate but also detects changes in your skin's conductivity, which can indicate your stress levels. What about a pair of socks that tracks your gait and pressure points, helping prevent foot ulcers in diabetic patients? E-textiles seamlessly integrate electronics into our clothing, making health monitoring a natural part of our daily lives.

Flexible Circuits

Flex circuits are the unsung heroes of wearable technology. Traditional rigid PCBs are being replaced with flexible counterparts that can be bent, twisted, and even folded. This flexibility allows for more versatile and comfortable form factors.

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Insulectro, the largest distributor in North America of materials used in the manufacture of printed circuit boards and printed electronics, provides game-changing precision cutting tools to our customers.

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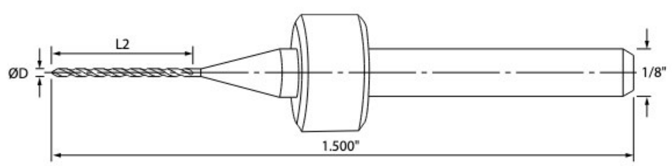
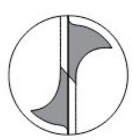
Kyocera designs and manufactures tight tolerance precision carbide cutting tools for PCB applications. Products include drills, routers, end mills, and specialized cutting tools ranging from: 0.05mm to 6.70mm diameters (0.0020" - 0.2638").

Drills, End Mills, Routers, Specialty Tools

Kyocera's renowned array of drills, routers, end mills, and specialty tools offer many benefits and advantages to customers for all their drilling and routing needs. Kyocera's tool reliability and design flexibility are key strengths of their products, along with a complete R&D facility in the US, new tool manufacturing capability, and local technical resources, all available to support customer needs.





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.

In the future, your health monitor might resemble a sleek band that molds itself to your wrist's contours or a patch that adheres comfortably to your skin. Flexible circuits enable these innovative designs, making wearables more discreet and user-friendly than ever before.

Advanced Sensors

Sensors are the heart and soul of any health monitor, and the next generation of wearables is poised to introduce an impressive array of advanced sensors. Imagine a device that measures your heart rate and detects early signs of dehydration by analyzing the electrolytes in your sweat, or a wearable that tracks your blood glucose levels in real-time, providing invaluable data for people with diabetes. Advanced sensors, including optical, biochemical, and environmental sensors, will take health monitoring to unprecedented levels of accuracy and usefulness.

Stay tuned for a future article previewing my cutting-edge PhD research on a smartwatch blood pressure sensor.

Energy Harvesting

One of the perennial challenges for wearable devices has been power management. Nobody wants a health monitor that needs charging every few hours. Enter energy harvesting technologies, such as piezoelectric materials and solar cells, that can convert ambient energy sources like body movement and sunlight into electrical power. This means your wearable health monitor could charge itself as you move or bask in the sun, reducing the hassle of frequent charging and ensuring continuous monitoring.

Smart Algorithms

It's not just about collecting data; it's about making sense of it. Advanced algorithms, powered by artificial intelligence (AI), will play a crucial role in wearable health monitors of the future.

These algorithms will analyze your health data and provide actionable insights. For example, they could detect irregular heart rhythms and recommend when to seek medical attention or suggest personalized exercise routines based on your fitness goals and health status. With AI-driven algorithms, wearables will become true health partners, helping you make informed decisions about your well-being.

Connectivity and Data Security

Another critical aspect of monitoring health is connectivity and data security. Soon, wearables will seamlessly sync with your smartphone and share data with your healthcare provider, ensuring that you receive timely feedback and support.

However, this connectivity also raises concerns about data privacy and security. The future of wearable health monitors will include robust encryption and data protection measures to protect your health information from prying eyes.

A Wearable Health Monitor Renaissance

As we peer into the future, it's clear that wearable health monitors are on the brink of powerful developments. E-textiles, flexible circuits, advanced sensors, energy harvesting, smart algorithms, and robust connectivity are converging to create a new era of personalized health monitoring. These electronic innovations promise to make wearables more comfortable, more user-friendly, and empower individuals to take charge of their health in unprecedented ways. So, watch the horizon for the next wave of wearable health monitor innovation. **PCB007**

Henry Crandall is the IPC Student Board Member. He is a graduate of University of Utah and currently pursuing a PhD in electrical engineering as the Advancing Research in College Scientists Graduate Fellow. To read past columns, click here.

Dartmouth: Taking a Human-centered Approach

The Knowledge Base

by Mike Konrad, SMTA

This is a highly technical industry that relies on universities and trade schools to feed the pool of candidates that companies are looking to hire. I recently interviewed Dr. Alexis Abramson, dean of the Thayer School of Engineering at Dartmouth College, on my podcast titled Reliability Matters. Here are excerpts from our conversation.

Tell me about the ethos of the Thayer School of Engineering at Dartmouth College. How does it differ from other schools?

Alexis Abramson: When I talk to prospective undergraduate students, I always say this will be the weirdest information session you will have with a school of engineering. I mean that in a good way. At some universities, you're largely doing engineering- or STEM-related courses. Here, we believe strongly in integrating the liberal arts.

We encourage our students to take philosophy, anthropology, English, and studio art. We want them to figure out how to integrate those learnings into engineering. We're all about bringing all that together.

We offer a Bachelor of Arts in Engineering degree. Because of that integration, you can also get an accredited Bachelor of Engineering degree, which is more like what you would get at other institutions, but isn't it nice to be

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able to have that flexibility in our undergraduate program?

Sometimes, particularly in the sciences, there's a lot of depth, but not a lot of breadth, and sometimes that reflects later in life in one's personality and social skills.

Absolutely. I love the idea of providing a liberal arts view on a science education, because where does science go?

Science goes to serve humanity. Humanity is much wider than the science itself.

You're speaking our language. We do "human centered engineering" and that means two things. One, that we're thinking about the impact on society, the classrooms, and the education we deliver and the research that we do.

We're also thinking about the humans in the classroom. How do we meet everybody's educational needs? People come from diverse backgrounds, so bringing those pieces together takes a unique approach to educating engineers.

"People come from diverse backgrounds, so bringing those pieces together takes a unique approach to educating engineers."

Historically, engineering has been a male dominated profession. Go back in time long enough and nearly all occupations were male dominated. But for some reason, engineering has clung on to that concept. Is that changing?

I hope so. When I started in 1990 as an undergrad, there were about 10% women engineers in the workforce, with a little higher percentage in some other disciplines. We're now closer to 15% to 20%, and a little bit higher in some disciplines. Disciplines like environmental and biomedical engineering have the largest representation of women in engineering. The lower proportions are in more conventional disciplines like mechanical and electrical engineering.

Why is that? There is a whole slew of reasons why it was that way and why haven't we grown even more than we have today? Why is it still at 20%? One way to attract more women is to bring in that human piece I was speaking about, that human centeredness, the societal impact has been shown in research. Here at Dartmouth, 53% of the 2023 graduating engineering majors were women, so we're at gender parity. We really point to that idea of having that human centered focus on inclusion and belonging.

You made a comment several months ago, stating, "We don't do engineering in silos." Explain more about that.

At Thayer School of Engineering, we purposely don't have engineering departments. We have a school of engineering; we have program areas like biomedical and electrical engineering, but we're not set up like a traditional school of engineering with siloed departments. This approach better enables, better catalyzed interdisciplinarity.

The problems we're facing in society today are not simple problems. We're not figuring out how to make a wheel as cave people did eons ago. These are very complex, multidisciplinary problems around health care and AI, climate mitigation, batteries, solar, and data analytics.

These multidisciplinary problems require people who are trained in thinking across disciplines. By having nontraditional departments, it enables rich collaboration and connection.

I know I'm getting old when I start any sentence with the phrase, "Kids these days." In your view, what is the state of the current generation of students vs. past generations?


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I'll name a few things. One, they're always moving fast, and that's good for our world. We need fast solutions.

This new generation is more committed to work-life balance than any prior generation, so companies need to figure out how to accommodate that. That's a good thing. As we know, this generation is more prone to anxiety as well, so we need to think about how to address that. We can't just deny it. They're also more equipped to use social media and tech in unique ways. Higher education and companies need to support the newer generation and their needs.

An example is remote work; providing more people with flexibility in where they work, if it can be done that way. Another example is having a more inclusive workplace, where people can feel good about being their true selves, contributing to the mission of the organization and communicating that to their employees. That's a little different from prior generations. The more we do that, the more it will benefit everybody, help push products forward. By embracing some of those characteristics and ensuring we're taking that human-centered approach, we can arrive at a quicker or better solution than we otherwise would have.

Once a student graduates, what advice would you give them to pursue a career within their chosen field?

Do something that makes you excited, that gets you out of bed every day. If you've studied engineering and you love engineering, make sure your job aligns with that passion. Sometimes students take the highest salary and then leave quickly because they're not aligned with their passion. The most fulfilling thing I see is when somebody graduates with an engineering degree, gets a good salary, and works for a nonprofit using those technical skills to benefit society. I always am so thrilled when I see our students following those passions to the benefit of society. That's the strongest piece of advice that I would give.

Next, look at the culture of the organization. As you change jobs ask, "Am I a good fit? Does this company align with my values or not?" Hopefully, you'll come out the other end being a contributor to something you really believe in. **PCB007**

The full podcast interview with Dr. Alexis Abramson is available here.

Mike Konrad is founder and CEO of Aqueous Technologies, and vice president of communications for SMTA. To read past columns, click here.

Happy's Tech Talk #22: Computer-aided Bare Board Testing, Revisited

Happy Holden brings back out a paper he gave at an IPC conference in 1983. While the technology to implement testing systems may have evolved, the basic principles Holden outlined then still hold true today.

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.

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

Recently, Schweitzer Engineering Laboratories' Moscow, Idaho facility took delivery of 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.

It's Only Common Sense: Don't Fall in Love With Your Marketing

In the end, all that matters is what your customers think. Emphasize and prioritize your customers' needs over your own. Be completely customer focused. Fall in love with your customer. If you want to succeed in sales, this has to be your number one goal.

Dan Beaulieu

Fall Issue of *IPC Community* Now Available

IPC Community launches its fall issue, with more than 100 pages of must-read content that spans the globe to bring you compelling stories, conversations, fun facts, coverage of recent IPC events, and more. Click here to get your personalized copy of *IPC Community*.

Reducing Waste Makes Good Business Sense


Alex Stepinski

Alex Stepinski, president of Stepinski Group, and Mike Brask, president of IPS, announce a new partnership to bring Alex's latest generation zero liquid-discharge (ZLD) waste control systems to market.

Material Insight: The Material Science of PCB Thermal Reliability

From a materials perspective, what is happening to the copper and dielectric during thermal shock testing? What causes copper to separate from the organic dielectric layer in the first place? To answer these questions, Preeya Kuray takes a closer look at each component at the molecular level during testing.

Forecasting the Wind: IPC's Expert Economist on the Impact of Inflation Rates

Tightening monetary policy has pushed interest rates up across the entire yield curve, and this impacts the economy in several ways. The yield on the 10-year Treasury bond is the highest it has been in 16 years. The rate was over 100 basis points lower just this spring. The elevated interest rates can act as a dampener on both consumer spending and business investment, leading to slower economic growth.

American Made Advocacy: What We Learned at PCB West

For the first time since we launched in 2021, the Printed Circuit Board Association of America participated in the PCB West trade show in Santa Clara, California. We were proud to join thousands of our colleagues to discuss the innovations driving our business and the very real challenges facing the American microelectronics industry.

LPKF's Business Development In Q3 Gains Significant Momentum

The business development of LPKF Laser & Electronics SE has gained significant momentum in the last three months. The technology company's order situation also remains positive. In the third quarter, the company reached the upper end of its forecast for this period.

For the latest news and information, visit **PCB007.com**

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- Follow up all enquiries for products and services; convert them into contracts/orders.
- Provide technical support – remotely and onsite.
- Be widely recognised and acknowledged as an "Industry Expert."
- Technical Sales and Account Management skills from an electronics background is desirable.
- Excellent sales, customer service, communication, presentation and negotiation skills.
- Recognised qualification in Electronics Engineering or related field.
- Knowledge of the electronics/SMT assembly process.
- Excellent written and verbal communication skills in English.
- Competent user of Microsoft Office applications.
- Ideally living in the Southern half of the UK.
- Willing and able to travel within and outside UK.
- A full, clean UK driving license is essential.

To apply, please contact John Barraclough at john.barraclough@gen3systems.com or by using the link below.

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- Assist in strategic planning initiatives.
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- Entrepreneurial spirit, positive, high energy, and desire to win.
- Proactive and self-motivated work strategy to develop and win business for all business units.
- Excellent written and oral communication skills in German and English
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- Proven track record securing new business at OEM accounts.

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ViTrox

Technical Support Engineer

USA Region

ViTrox aims to be the world's most trusted technology company in providing innovative, advanced, and cost-effective automated Machine Vision Inspection Solutions for the semiconductor and electronics packaging industries. Located in Hayward, California, ViTrox Americas Inc. is actively looking for talent to join our expanding team.

Key Responsibilities:

- Delivering excellent and creative problem-solving skills for servicing, maintaining, machine buy-off, and troubleshooting advanced vision inspection machines at customer sites. Providing remote customer support to minimize machine downtime.
- Cultivating strong customer relationships and ensuring comprehensive customer service to drive repeat orders and support business development in machine evaluation.
- Proactively understanding customer needs and feedback to drive continuous improvement in existing technologies and new product development.

Qualifications & Requirements:

- A recognized diploma/advanced diploma/ degree in Science and Engineering, preferably in Electrical & Electronics/Computer Science/ Computer Studies or equivalent.
- 3+ years of relevant experience in servicing automated inspection equipment (SPI, AOI, and AXI).
- Strong communication and troubleshooting skills.
- Willingness to travel extensively across the USA.
- Positive attitude and flexibility to accommodate conference calls with headquarters.
- Applicants from the USA and Canada are welcome to apply.
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TTCI is adding electronics technician/engineer to our team for production test support.

- Candidates would operate the test systems and inspect circuit card assemblies (CCA) and will work under the direction of engineering staff, following established procedures to accomplish assigned tasks.
- Test, troubleshoot, repair, and modify developmental and production electronics.
- Working knowledge of theories of electronics, electrical circuitry, engineering mathematics, electronic and electrical testing desired.
- Advancement opportunities available.
- Must be a US citizen or resident.

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Europe Technical Sales Engineer

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1. Maintain existing business and pursue new business to meet the sales goals
2. Build strong relationships with existing and new customers
3. Troubleshoot customer problems
4. Provide consultative sales solutions to customers technical issues
5. Write monthly reports
6. Conduct technical audits
7. Conduct product evaluations

QUALIFICATIONS / SKILLS:

1. College degree preferred, with solid knowledge of chemistry
2. Five years' technical sales experience, preferably in the PCB industry
3. Computer knowledge
4. Sales skills
5. Good interpersonal relationship skills
6. Bilingual (German/English) preferred

To apply, email: BobW@Taiyo-america.com with a subject line of "Application for Technical Sales Engineer".

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IPC instructors will primarily conduct training at our public training center in Longmont, Colo., or will travel directly to the customer's facility. It is highly preferred that the candidate be willing to travel 25–50% of the time. Several IPC certification courses can be taught remotely and require no travel or in-person training.

Required: A minimum of 5 years' experience in electronics manufacturing and familiarity with IPC standards. Candidate with current IPC CIS or CIT Trainer Specialist certifications are highly preferred.

Salary: Starting at $30 per hour depending on experience

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Experience: Electronics Manufacturing: 5+ years (Required)

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Willingness to travel: 25% (Required)

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Requirements:

- Bachelor's degree in electrical engineering or related field with a basic understanding of engineering theories and terminology required
- Basic knowledge of schematic design, PCB design, and simulation with experience in OrCAD or Allegro preferred
- Candidates must possess excellent writing skills with an understanding of sentence structure and grammar
- Basic knowledge of video editing and experience using Camtasia or Adobe Premiere Pro is preferred but not required
- Must be able to collaborate well with others and have excellent written and verbal communication skills for this remote position

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A technical degree is preferred, along with strong verbal and written communication skills. Read and interpret schematics, collect data, write technical reports.

Valid driver's license is required, as well as a passport for travel.

Must be able to travel extensively.

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Technical Service & Applications Engineer

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Responsibilities

- Provide support, preventive and corrective maintenance, process audits, and related services
- Train users on proper operation, maintenance, programming, and best practices
- Recommend and oversee operational, process, or other performance improvements
- Effectively troubleshoot and resolve machine, system, and process issues

Skills and Qualifications

- Bachelor's in a technical discipline, relevant Associate's, or equivalent vocational or military training
- Knowledge of electronics manufacturing, robotics, PCB assembly, and/or AI; 2-4 years of experience
- SPI/AOI programming, operation, and maintenance experience preferred
- 75% domestic and international travel (valid U.S. or Canadian passport, required)
- Able to work effectively and independently with minimal supervision
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Our facility employs state of the art production equipment engineered to provide cost-effective and flexible manufacturing capacity, allowing us to respond quickly to customer requirements while meeting the most stringent quality and tolerance demands. Our manufacturing site is ISO 9001: 2015 registered, and through rigorous quality control practices and commitment to continual improvement, we are dedicated to meeting and exceeding our customers' requirements.

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Insulectro, the largest national distributor of printed circuit board materials, is looking to add superstars to our dynamic technical and sales teams. We are always looking for good talent to enhance our service level to our customers and drive our purpose to enable our customers to build better boards faster. Our nationwide network provides many opportunities for a rewarding career within our company.

We are looking for talent with solid background in the PCB or PE industry and proven sales experience with a drive and attitude that match our company culture. This is a great opportunity to join an industry leader in the PCB and PE world and work with a terrific team driven to be vital in the design and manufacture of future circuits.

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- Performing preventive maintenance
- Providing virtual and on-site training
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More About Us

MivaTek Global is a distributor of Miva Technologies' imaging systems. We currently have 55 installations in the Americas and have machine installations in China, Singapore, Korea, and India.

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APCT currently has opportunities in Santa Clara, CA; Orange County, CA; Anaheim, CA; Wallingford, CT; and Austin, TX. Positions available range from manufacturing to quality control, sales, and finance.

We invite you to read about APCT at APCT.com and encourage you to understand our core values of passion, commitment, and trust. If you can embrace these principles and what they entail, then you may be a great match to join our team! Peruse the opportunities by clicking the link below.

Thank you, and we look forward to hearing from you soon.

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COVER DESIGN: **SHELLY STEIN**

COVER IMAGE: **ADOBE STOCK © KAKAJI**

PCB007 MAGAZINE

PCB007 MAGAZINE®
is published by IPC Publishing Group, Inc.
3000 Lakeside Dr., Suite 105N, Bannockburn, IL 60015

November 2023, Volume 13, Number 11
PCB007 MAGAZINE is published monthly
by IPC Publishing Group., Inc., dba I-Connect007

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