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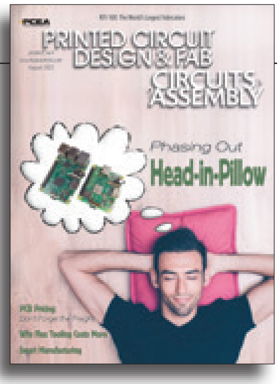
DEPARTMENTS

FEATURES



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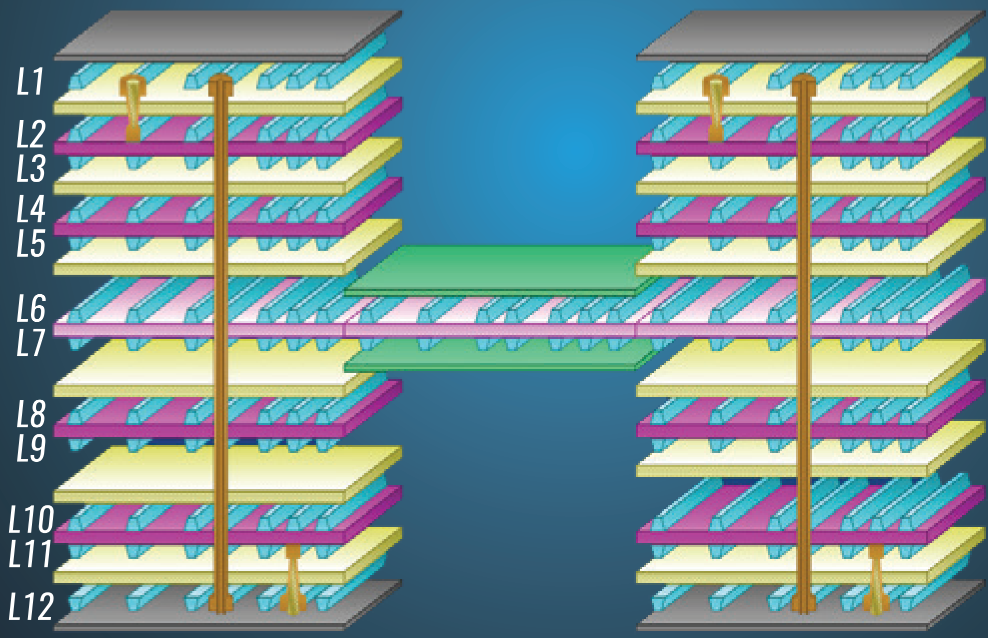

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In the Rush to Get Big, Let's Not Forget the Little Guys

FOR MORE THAN 20 years, PCD&F/CIRCUITS ASSEMBLY has been proud to be the exclusive publisher of the annual NTI - 100 list of the world's largest board fabricators.

One of the striking changes over the years has been the reshaping of the industry geographical landscape.

In this year's rankings, which begin on page 32, see how many Europe- and US-based companies are in the top 25. I'll save you the suspense. One each: AT&S and TTM Technologies, respectively. Long gone are the days when Photocircuits, Sanmina, Hadco, Viasystems and the like dominated the top of the chart.

In fact, only a combined 10 companies from the two continents (combined population: 1.2 billion) broke the $100 million threshold for making the rankings. South Korea alone (population 51 million) has 14. Taiwan (population: 23 million) has 27.

That's crazy.

Every industry goes through a maturation period. Ours is no different. As the report's esteemed author, Dr. Hayao Nakahara, points out, the 146 companies on this year's list are just 6% of the estimated 2,400 fabricators in the world, but they produce 92% in revenue value of the boards.

Consolidation is inevitable, and with that comes lots of pain.

As we went to press, the US Senate was gearing up to vote on the CHIPS Act, which would allocate billions in incentives to semiconductor manufacturers to build new plants in the US. Likewise, the Printed Circuit Board Association of America, a partner organization of PCEA, is working its magic to help breathe life back into the US bare board marketplace.

These are important measures, and not just because they could level the playing field for the manufacturers of critical products themselves. In fact, the fabricators and assemblers are just the top of a very large food chain, and we must consider the effects of slowdowns and shutdowns on all those suppliers, not just the companies that press together laminate and copper plies or solder components to substrates.

Take the auto industry. It is characterized by a few big OEMs. We all know the names. Toyota. Volkswagen. Honda. Ford. Hyundai. Nissan. The top 10 make up about 55% of the world's car sales.

But the supply and distribution channels are endless – and necessary. Countless companies make metals, plastics, components, and yes, electronics for Big Auto. And even more are involved in the sales channels.

That works especially well when a market is thriving. Have you ever heard of a large company being less than easy to deal with for smaller-volume buyers? I'm guessing you have. Sellers chase margin and they chase dollars, not necessarily in that order. More than one outside salesperson has related to me about winning a program and sending it to their company to produce, only to have it rejected because it was "only a $1 million" order, not the $5 million or greater programs the company desired.

We can debate whether those salespersons erred by chasing programs that they shouldn't have, but the point is that one size doesn't fit all. In a healthy, vibrant market there is room for all kinds of specialists. And while the extra layer means more inventory in the chain, the irony is that is just what we do during capacity crunches like this one. What smaller fab hasn't heard the dreaded A word – allocation – from a critical material vendor? An abundance of smaller regional distys can help mitigate that.

While we are building back our manufacturing base, let's not forget the supply and distribution chain that undergirds it.

About that manufacturing base. A large range of suppliers of printed circuit boards, materials, software and services can be seen at PCB West in October. This will be the first time PCB West will take place under the auspices of PCEA, and the staff and board couldn't be more excited. Visit pcbwest.com to see the exhibiting companies and peruse the more than 110 hours of technical training.

Finally, we welcome our first corporate members: EMA Design Automation, Quantic Ohmega, Polar Instruments, EIConnect, Ventec and American Standard Circuits. There are many benefits to membership; for details, visit https://pcea.net/pcea-membership.

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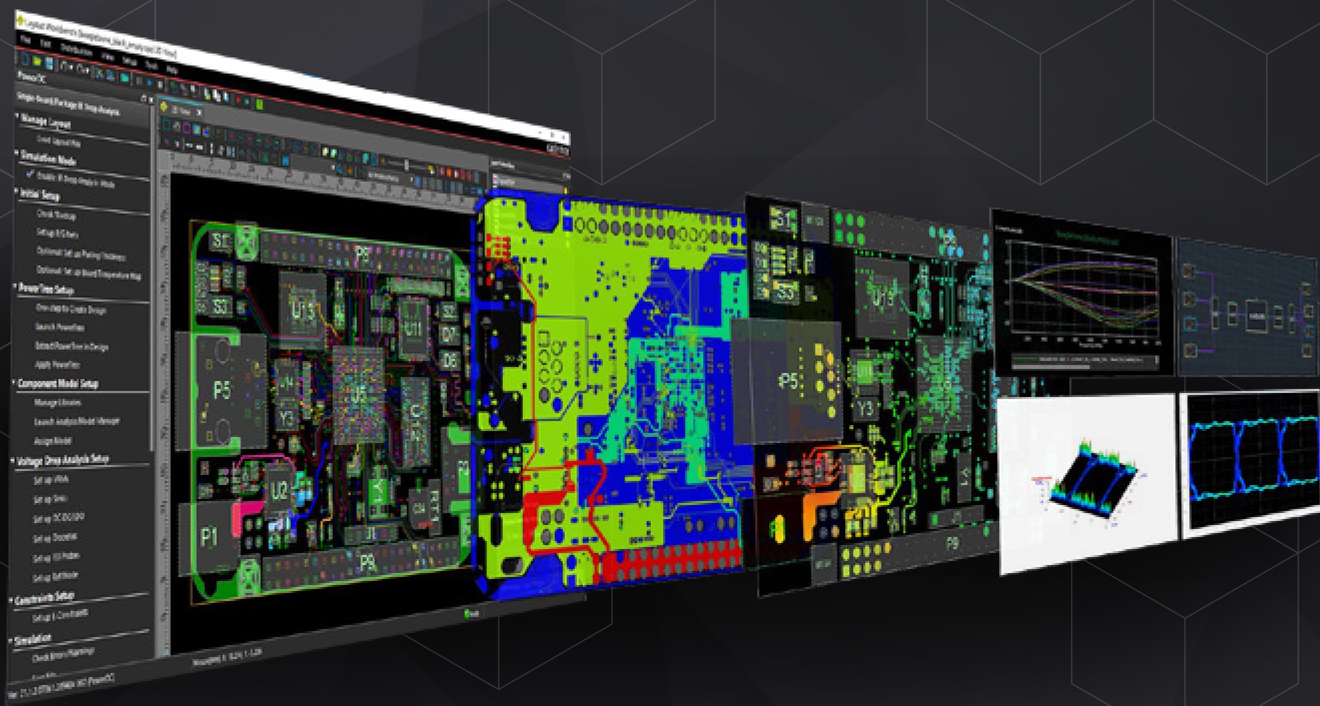

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PCDF People

Cadence named **Liz Campbell** director, inside sales. She has more than 15 years' experience in EDA and electronics with Dassault, Nvidia, Cognex, Ansys and most recently, Altair.

PCDF Briefs

American Standard Circuits installed new **Metrohm** CVS 894 equipment and software.

Celus, a software company that uses AI to streamline circuit board engineering, has raised €25 million in Series A funding.

Digi-Key has launched a manufacturing service aimed at hobbyists, makers and students to quote, source and order smaller quantities of PCBs.

University of Illinois Urbana-Champaign researchers, working with **PragmatIC Semiconductor,** developed the first commercially viable flexible plastic microprocessor chips, called FlexiCores, that can be manufactured at scale for less than a penny per unit.

Nano Dimension has closed a definitive agreement to acquire **Formatec Holding,** including its two subsidiaries **Admatec Europe** and **Formatec Technical Ceramics,** for $12.9 million (net of cash).

NCAB in June acquired 100% of the shares in **Kestrel International Circuits** from the **Merlin PCB Group** for SEK 103 million ($10.1 million). NCAB, which paid about six times EBIDTA for Kestrel, said it financed the deal with cash and loans and it is expected to be EPS-accretive in 2022.

Nexar, a business unit of **Altium,** launched Octopart CAD Model Marketplace, a free database of CAD models for electronic components.

Osaka University scientists developed a new method for the direct three-dimensional bonding of copper electrodes using silver, which can reduce the cost and energy requirements of new electronic devices. This work may help in the design of next-generation smart devices that are more compact and use less electricity.

KAUST University associate professor of material science and engineering Dr. Mario Lanza asserts it's only a matter of time before memristors become the new switching technology standard, surpassing transistors in speed and operational efficiency.

Unimicron is planning a capital investment of $20 million in mainland China for printed circuit board production.

Ventec has signed an exclusive distribution agreement to sell **Taiyo** LPI solder mask inks in mainland Europe and the UK.

Calumet to Invest $6.5M in Michigan PCB Plant

KEWEENAW, MI – Calumet Electronics is investing $6.5 million at a newly built 35,000 sq. ft. manufacturing facility in northern Michigan. The firm plans to upgrade operations and expand its staff more than 25%, resulting in 80 new jobs.

The 300-person company produces printed circuit boards for the industrial, power generation, aerospace and defense, and medical segments.

"This expansion is critical to the growth and recruitment of talented workers for a company that is in a critical industry and critical to the region," said Marty Fittante, CEO, InvestUP.

The state of Michigan is expected to provide a $600,000 performance-based grant, and Calumet will receive $2 million in Community Development Block Grant funding. (CD)

PCEA Announces Dates for PCB East 2023

PEACHTREE CITY, GA – The Printed Circuit Engineering Association (PCEA) announced dates for next year's PCB East conference and exhibition.

The three-day technical conference will take place May 9-11, 2023, at the Boxboro Regency in Boxborough, MA. The event includes a one-day exhibition on May 10.

"The return of PCB East to the Boston suburbs this year reminded everyone of just how vibrant the New England electronics design and manufacturing industry is," said Mike Buetow, president, PCEA and conference director, PCB East. "PCB East is the electronics industry's East Coast trade show, and we look forward to providing our world-class training programs, along with the largest gathering of industry suppliers New England will see."

A call for presentations will be available shortly. Visit pcbeast.com for details.

Ventec Increases Prepreg Capacity in Taiwan

TAIPEI – Ventec International is investing in new prepreg treating capacity at its Taiwan facility to expand its global manufacturing capability, control and supply chain flexibility.

The new treating equipment, which features a specially designed impregnation system, includes multiple independent pipe work and pumping systems that will significantly minimize downtime when switching between resin systems. The upgrade is in line with Ventec's strategy to offer high-mix, quickturn supply of a range of specialty prepregs and laminates to its global customer base.

"Taiwan is central to our strategy to drive long-term growth and expand our global leadership position," said Jason Chung, CEO, Ventec. "The investment in Taiwan significantly increases our manufacturing capacity, drives production efficiency and accelerates the delivery of the high reliability materials our customers demand."

Ventec's latest manufacturing upgrade is designed for production of thin-core laminates for use in demanding applications such as military, aerospace/space and other high-reliability applications. With a capacity of up to 400,000 meters per month, the new specialist equipment can handle a wide range of glass fabrics, from 1027/1037 to 7628. As such, it significantly ramps Ventec's global supply capacity directly from Taiwan for VT-901 and VT-90H polyimides as well as the full range of no-flow/low-flow prepregs for rigid-flex applications.

The new treater setup in Taiwan will be equipped with Ventec's proprietary multiple stage filtration systems on the front-end and 100% AOI for prepreg FOD-control on the back-end.

"The investment in manufacturing capacity at our Taiwan facility is driven by strong growth in demand for our high-reliability solutions manufactured on state-of-the-art machinery," said Mark Goodwin, COO, EMEA & America. "Combined with our know-how in PCB base material technologies and our strong track record in global supply chain control, the capacity increase and multiple independent pipework design further enhances our capability to switch between resin systems quickly and

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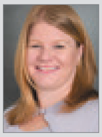


Amtech promoted **Kristen Mattson** to corporate director of strategic marketing. A 25-year veteran of the electronics industry, she most recently was marketing principal for BTU International.

Arrow Electronics named **Richard Henrick** environmental, social and governance manager. He has 35 years' experience in management and technical positions in quality management, regulatory compliance, manufacturing engineering, test and evaluation, the last 15 with Sanmina.

Aegis promoted **Paul Vassallo** to director of engineering.

Breadboard named **Juan Miguel Moreno** to its engineering team.

Escatec named **HL Wong** chief operating officer. He was formerly the general manager of Plexus in Penang.

Pillarhouse USA appointed **Deon Nungaray** Western Regional sales manager.

Project Kuiper named **Amol Kane** senior PCBA manufacturing tech development engineer.

CA Briefs

Ampère Proto shut down its EMS operations permanently in Quebec City because of a lack of staff and components, according to reports.

Arch Systems announced $15 million in new funding led by **Two Bear Capital** and joined by new and existing investors including seed lead investor **Uncork Capital**.

Bentec appointed **Sincotron Oy** to distribute XDry drying cabinets.

Cobham moved closer to UK government approval for its takeover of **Ultra Electronics**.

Delta Electronics acquired a 30-acre complex in Plano, Texas, for a new smart, green R&D and manufacturing site.

Emerald EMS installed a **Juki** FX-3RAXL placement system at its **Veris Manufacturing** facility in Southern California.

Indium is partnering with **SAFI-Tech,** an Iowa-based startup that is creating no-heat and low-heat solder and metallic joining products. The companies will evaluate market applications for supercooled solder materials and explore development of new products.

efficiently. It allows us to offer high-mix quickturn deliveries of a wide range of laminate and prepreg products. The front-end proprietary filtration and back-end AOI ensure we deliver FOD-free materials and can manufacture to meet the requirements of the highest standards, such as IPC-4101 Appendix A for space applications." (MB)

Zollner Acquires EIT's EMS Unit, Expands US Presence

ZANDT, GERMANY – Zollner Elektronik has acquired Electronic Instrumentation and Technology's (EIT) EMS division for an undisclosed amount.

The deal includes EIT's three EMS facilities in Salem, NH, Leesburg, VA, and Danville, VA, and a cabling and machining operation, also in Danville. The total size of the acquired plants encompasses more than 200,000 sq. ft.

The move was not a surprise as the two companies have partnered for years.

EIT's UV measurement instruments, avionics, and applied technology consultation services will continue under the name of EIT2.0. Zollner will also provide EMS services to EIT2.0.

EIT was founded by Joe May in 1977 and serves customers in the industrial, communications, aerospace, defense, and medical markets It has ISO 9001, ISO 13485 and AS9100 certifications, and is ITAR-registered.

"We are very pleased to see our long-time business relationship with Zollner evolve," said Joe May, founder and chief technology officer, EIT. "Our customers will benefit from Zollner's strong purchasing and distribution capabilities, and Zollner recognizes that we have very talented, skilled employees; the acquisition of our EMS division is an ideal fit for all. I have great confidence that our employees and customers will see this move as advantageous to everyone."

"We are excited to have EIT as part of the Zollner Group," said Markus Aschenbrenner, member of the managing board, Zollner. "EIT brings experienced employees, skilled management, a positive corporate culture, and has a solid customer base. With this move, we can serve our existing customers in an expanded US market. We also expect to utilize Zollner's global presence to bring great advantages for EIT." (MB)

IPC: Rising Material and Labor Costs Still Affecting EMS

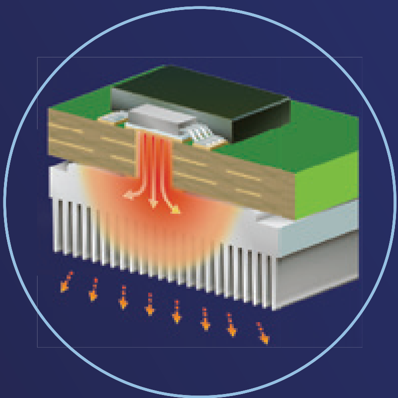
BANNOCKBURN, IL – Nine in 10 electronics manufacturers are currently experiencing rising material costs, while four-fifths are experiencing rising labor costs, according to IPC survey data released in July. Eighty percent of respondents reported they have increased pricing due to higher material and labor costs.

Data from IPC's July report indicate forces exerting pressure on the global economy, and, conversely, the electronics manufacturing industry, include growing recession uncertainties, higher gasoline and food prices, geopolitical uncertainties, and China Covid policies and lockdowns exacerbating supplychain disruptions.

"Other risks remain acute," said Shawn DuBravac, chief economist, IPC. "Inflationary pressures remain historically high in many parts of the world. While supply chains appear to be improving, pricing pressure remains stiff. This is hurting profitability for many businesses but also leading both businesses and consumers to hold off purchases in hopes that prices will normalize. Moreover, higher prices for things like gasoline are crowding out other purchases consumers and businesses might make. How these forces will evolve in the coming months adds to the long list of uncertainties around the globe that will continue to dominate the near-term outlook."

Additional survey results indicate demand remains strong. More than half of survey respondents indicate orders will expand in the next six months. While some improvements to inventory are expected, ease of recruiting/finding skilled talent are likely to remain challenging. Electronics manufacturers have expressed concern

Via Filling Solutions



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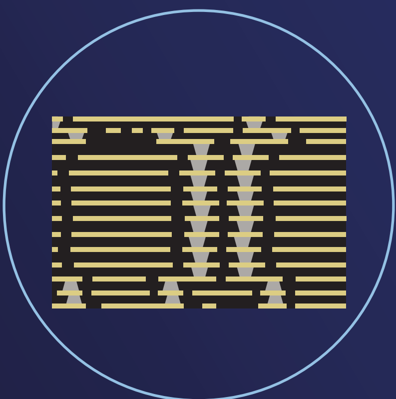
Conductive/Non-Conductive Paste AE Series are long selling products for PCB/substrate thermal release. The pastes are filled into vias of PCBs/substrates by screen printing. Solvent free Tatsuta original formulation enables void less via filling with excellent long hour workability.



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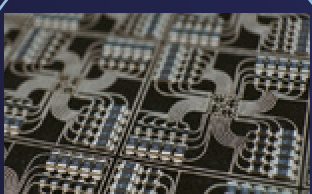
TLPS conductive Paste MP series: "Metalizing Paste" is for highly reliable connection in PCBs/substrates. "Metallizing paste" contains solder and metal particles, which form inter metallic compounds(IMC) by thermal compression bonding. The IMC results more reliable connection.



This image shows circuitry formed with SW series on glass substrate.

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around the future availability of labor, components, materials (especially metals) and semiconductors.

IPC surveyed hundreds of global companies, including a wide range of company sizes. (CD)

Note Acquires Dynamic Precision Solutions

STOCKHOLM – Note in July announced the acquisition of all shares in Herrljunga, Sweden-based electronics manufacturer Dynamic Precision Solutions for SEK20 million ($1.9 million), with adders based on profitability that could raise the total price to just over SEK50 million ($4.8 million).

The price, assuming the assumption of no debt, is about five times EBITDA.

Through the acquisition, Note gets its fourth Swedish plant and an establishment close to customers in western Sweden. DPS has about 30 employees and forecasted sales of SEK140 million ($13.3 million) for the full year 2022 and with an operating margin in line with Note's. Its customers are mainly in the communications and industrial segments.

DPS managing director Anders Gustafsson will remain in that role for Note.

Over the past 12 months, the acquisition pro forma means a growth in both sales and operating profit of approximately 5%.

"We are pleased to complete this acquisition, which in addition to adding another profitable plant to the Group, is also expanding our manufacturing capacity in Sweden," said Johannes Lind-Widestam, CEO and president, Note. "In Sweden, which is Note's largest market, we noted growth in Q1 of 45%. Together with the customers, personnel and management in the plant in Herrljunga, we look forward to continuing the profitable growth journey." (MB)

Innovative Circuits Arizona installed an **Nordson** Assure Pro x-ray component counter.

Dixon Technologies broke ground on an EMS site in Tirupati, Andhra Pradesh, India.

GJD installed a **Hanwha Techwin** SM482 Plus SMT placement machine.

Indonesia said **Foxconn** is considering investing in Nusantara, the country's new capital.

Nordson announced a business segment realignment, reorganizing into three financial reporting segments, effective Aug. 1: Advanced Technology Solutions (ATS), led by Srinivas (Srini) Subramanian, executive VP; Industrial Precision Solutions (IPS), led by Jeffrey A. Pembroke, executive VP; and Medical and Fluid Solutions (MFS), led by Stephen Lovass, executive VP.

Pektron plans to expand with a new facility at its EMS site in Derby, England, where it already has five plants.

Pro-Active Engineering installed a **Pillarhouse** Orissa Fusion selective soldering line.

Promation opened a new, larger demo facility in Kenosha, WI.

Sanmina is reportedly investing $216 million in Jalisco, Mexico, this year and will generate nearly 2,000 new jobs there, per reports.

SMT Industrial Supply opened a 2,200 sq. ft. demo facility in Barrie, ON, Canada, and expanded its PCB recycling center in Orillia, ON.

Solderking, a manufacturer of solders and chemical consumables, named **Danutek** distributor in Europe.

Topline Electronics has purchased a **Hentec/RPS** Odyssey 1750 robotic hot solder dip component lead tinning machine.

WiWynn has commenced Phase II development on a server PCB assembly plant for cloud data centers in Johor, Malaysia.

Xiaomi produced its first batch of smartphones in Vietnam.

All Circuits Expects Expanded Plant to Be Largest in France in 2 Years

MEUNG-SUR-LOIRE, FRANCE – All Circuits in July inaugurated its new electronics manufacturing factory here, where it intends to supply electronic assemblies to the automotive sector. The company will eventually install 13 SMT lines, reportedly making the plant, which operates under the MSL Circuits brand, the highest-volume EMS site in France.

The 6000m^2 (65,000 sq. ft.) expansion brings the total factory size to about 24,000m^2 (258,000 sq. ft.). The campus now employs about 600 workers and builds 200,000 electronics assemblies per day. Both figures are expected to climb as demand and the number of lines grow.

The new All Circuits factory soon might be the largest in France.

All Circuits and its subsidiaries had sales of 294 million euros ($305 million) in 2021, a figure it plans to double within two years. The company cited increased automation – the factory is an Industry 4.0 site – and higher demand for electric vehicles for the outlook.

"Quality, time to market, carbon footprint," said Bruno Racault, president, All Circuits Group. "These advantages exceed the difference of 2% to 3% on the cost of production that still exists with China." The Meung-sur-Loire plant has a defect rate of 2ppm, he noted, adding that the current trend is to place production close to the point of consumption.

The Meung-sur-Loire site was built by Valeo in 1992, then acquired by Jabil in 2002. After Jabil decided to close the site, All Circuits acquired it in 2012. (MB)

Support For Flex, Rigid Flex and Embedded Component Designs Now Available.

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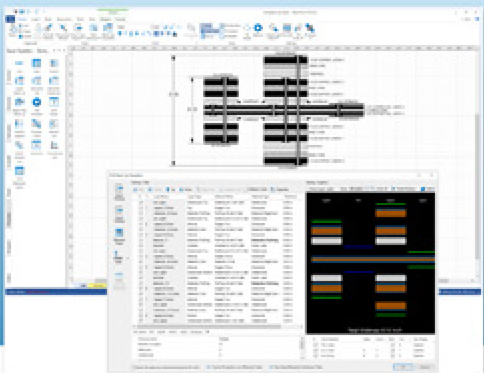
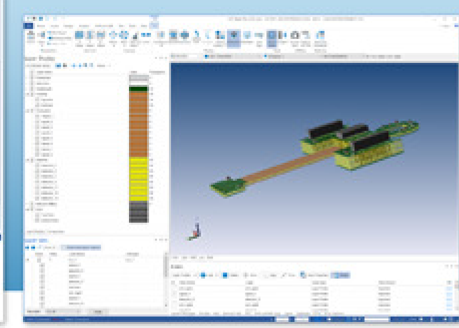
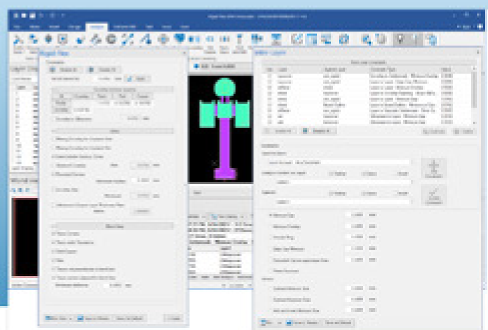


Use Stack Up Visualizer and Blueprint's Rigid-Flex Stackup template to easily manage and document rigid-flex stackups.



A rigid-flex design in 3D. Shown with layers spread to improve visualization of the layer stackup.



Use Rigid-Flex and Inter-layer DFM analysis to analyze flex and rigid-flex designs.

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N. America Component Sales Sentiment Swings Negative

ATLANTA – After a run of two years of overall positive sales sentiment and expectation for electronic components, the June Electronic Component Sales Trend Survey dropped below the benchmark level of 100, indicating negative sales growth, according to ECIA.

The index for all major component categories measured below 100, driving an overall average sales sentiment of 97.5 in June. Similarly, the end-market sentiment registered at 93.2, in line with forecast expectations in the prior month's survey.

"Two years ago, when the index dropped below 100 in July 2020, the index saw a strong rebound above 100 in the following month of August," said Dale Ford, chief analyst, ECIA. "However, that rebound came during a period of strong economic growth and overall consumer and industry optimism. The current economic environment is a polar opposite from two years ago. While it can be hoped the June results only reflect seasonal market behavior, other economic and industry indicators and expectations dim that prospect." ▫

STEADY STORAGE

Trends in the US electronics equipment market (shipments only)	% CHANGE MAR.	APR.	MAY	YTD%
Computers and electronics products	-0.3	0.6	0.3	4.8
Computers	-2.9	1.1	-0.5	-2.7
Storage devices	-0.7	6.6	0.5	12.5
Other peripheral equipment	7.2	-11.6	-2.0	2.7
Nondefense communications equipment	-3.1	1.5	0.8	9.7
Defense communications equipment	-3.3	5.9	-4.2	9.6
A/V equipment	5.0	-1.9	-8.6	40.5
Components[1]	-0.1	0.5	2.6	14.8
Nondefense search and navigation equipment	-1.8	3.6	-2.5	1.5
Defense search and navigation equipment	-1.7	0.4	0.9	0.3
Medical, measurement and control	0.3	1.2	-0.3	1.4

[r]Revised. *Preliminary. [1]Includes semiconductors. Seasonally adjusted.
Source: U.S. Department of Commerce Census Bureau, July 5, 2022

US MANUFACTURING INDICES

	FEB.	MAR.	APR.	MAY	JUN.
PMI	58.6	57.1	55.4	56.1	53.0
New orders	61.7	53.8	53.5	55.1	49.2
Production	58.5	54.5	53.6	54.2	54.9
Inventories	53.6	55.5	51.6	55.9	56.0
Customer inventories	31.8	34.1	37.1	32.7	35.2
Backlogs	65.0	60.0	56.0	58.7	53.2

Source: Institute for Supply Management, July 1, 2022

Hot Takes

- **Global virtual reality headset shipments** jumped 242% during the first quarter compared to the same period last year. (IDC)
- First quarter cross-strait **Taiwanese PCB output** totaled NT$209 billion (US$7.02 billion), up 20.6% year-over-year and a new quarterly high. (TPCA)
- Global **server shipments** are forecast to grow 6.5% sequentially this quarter, with full-year growth of 5%. (TrendForce)
- **Global fab equipment spending** for front-end facilities is expected to increase 20% year-over-year to an all-time high of $109 billion in 2022, marking a third consecutive year of growth following a 42% surge in 2021. (SEMI)
- Fabless suppliers hold a record 34.8% share of **global IC sales.** (IC Insights)
- The **global EDA tools** market will reach $28.8 billion by 2031, growing 9.6% annually from 2021 through 2031. (Research and Markets)
- The **electronic adhesives** market is poised to grow $1.43 billion in the 2022-2026 period, accelerating at a CAGR of 4.73%. (Research and Markets)
- Worldwide sales of **wearable medical devices** are expected to grow to $22.4 billion in 2022, up 22% from 2021. (Research and Markets)
- **Worldwide PC shipments** are on pace to decline 9.5% in 2022. (Gartner)
- **Total microprocessor sales** are expected to rise nearly 12% to a record-high $114.8 billion, thanks to higher average selling prices. (IC Insights)
- Total **EDA revenue** in the first quarter totaled $2.04 billion, up 5% year-over-year. (ESDA)
- Worldwide **shipments of traditional PCs** declined 15.3% year-over-year to 71.3 million units in the second quarter. (IDC)
- Global **PC shipments** totaled 72 million units in the second quarter, a 12.6% drop from 2021. (Gartner)

KEY COMPONENTS

	JAN.	FEB.	MAR.	APR.	MAY
EMS (North America)[1]	1.58	1.52	1.44	1.36	1.35
Semiconductors[2]	26.8%	26.2%	23%	21.1%[r]	18%[p]
PCBs[3] (North America)	1.18	1.16	1.05	1.03	1.03
Computers/electronic products[4]	6.46	6.38	6.45	6.38[r]	6.37[p]

Sources: [1]IPC, [2]SIA (3-month moving average growth), [3]IPC, [4]Census Bureau, [p]preliminary, [r]revised

Grounded: Short-Term Business Plans with Long-Term Consequences

A thwarted vacation provides lessons in the importance of timely communication, training and skilled staff.

SUMMERTIME WAS HERE, and after a couple years that seemed more like a couple decades hunkering down under the Covid cloud, it was finally time to take a vacation. Based on the Covid protocols at the time, we decided not to travel abroad but instead return to one of our favorite domestic vacation spots. Resort accommodations were booked, airline tickets purchased, and a rental car secured. Now we waited for the day to come for our first real pre-pandemic trip, wondering, with everything booked well in advance, what could possibly go wrong?

Communication (or lack thereof). My vacation started at 3 a.m., as I had to travel to the airport two hours ahead of my flight, scheduled to take off at 7 a.m. Half-asleep, I raced around, packed the car, drove to the airport, and parked. Preprinted boarding passes in hand, I scurried to security, then to the gate to checkin. That is when I discovered our flight had been canceled. Off to the customer service desk, which had a line about 30 deep, to see what – or if – later flights might be available. The answer was no, and I was rebooked onto the same flight the next day. Back to the car and home again, where I spent the day rearranging my itinerary. This was tough, as each place I called required navigating a user-unfriendly phone system to get through to a real person.

The next morning, I got up at 2:45 a.m. and checked the airline website for any cancellations. All good. When I arrived at the airport, however, the flight had been canceled again.

This happened two additional times. Following the fourth airport visit, I canceled my long-desired, way-overdue vacation.

Why were the flights canceled? The first three times, it was not weather; it was staffing. And the time bad weather was cited, it was because of forecasts later that day in a part of the country I was neither leaving from nor heading toward. In our industry, try to cancel or reschedule a customer's order because of staffing, such as someone calling in sick, or the possibility there "might" be bad weather *somewhere!* That would be the end of that customer!

I was reminded of how important communication is, especially timely communication. If you are nearly certain something will happen differently from the anticipated outcome, at least provide a warning events are occurring that could impact your flight – or order. Bad news communicated immediately is far better than saying nothing until it is too late.

People, training and real customer service. The lone bright spot in our four-day whirlpool was that each person I spoke with was courteous, upbeat and trying to help. At the airport, observing the scores of people from different flights the airline service people were trying to assist, I was amazed how calm and courteous personnel remained, despite some irate passengers. Ditto, when I finally emerged from the customer-unfriendly robo-phone systems, each person I spoke with was poised, friendly and accommodating. It struck me how important it is to invest in the right people for customer service positions = and their training. These folks are in the untenable situation of apologizing often for problems that management might have been able to prevent. The importance of excellent customer service in any business is critical, even more so in a stressed industry or situation.

Well-trained people can respond to customer questions, inquiries and, most important, problems. Hiring empathetic people and investing in training is a bargain when serious problems occur that, if not handled properly, could cost you a customer, if not your company's reputation.

Rightsizing the right way. The root cause of my vacation debacle was poor management decisions made a couple years earlier. Covid grounded almost all travel, especially airline business travel. Airline managements facing such a dramatic downturn made decisions to reduce staff to reduce costs. Regrettably, when making those decisions, they did not take the long view. Some staff can be cut – and added – quickly, with little impact on the core business. However, airline pilots and the like are the poster children of skilled staff and cannot be quickly or easily replaced.

A pandemic, by definition, is a temporary event. Rather than cutting all staff equally when the pandemic caused a dramatic reduction in airline passengers, a more thoughtful and strategic decision process should have been deployed. Ways to keep pilots on staff should have been thoroughly explored. Instead, a knee-jerk, shortsighted approach was pursued in which the most essential workers were furloughed or laid off the same as less critical staff. When those skills were again needed, not only was valuable time lost recruiting and hiring pilots, but the costly process of training and recertifying was required.

continued on pg. 55

PETER BIGELOW is president and CEO of IMI Inc.; pbigelow@imipcb.com. His column appears monthly.

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HDI Expedited:	5 – 12 Days

FLEX / RIGID-FLEX

Flex 1 – 6 Layers Standard:	25 Days
Flex 1 – 6 Layers Expedited:	5-15 Days
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Rigid Flex 4-22 Layers Expedited:	20+ Days
Rigid Flex HDI 2x Lam Cycles:	30 Days

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Full Freight: PCB Buyers Should Demand a Delivered Price

Shortsighted approaches lead to overspending.

MOST AIR FREIGHT – including for printed circuit boards – is hauled in the cargo holds of passenger aircraft. While the number of available flights is slowly increasing as Covid restrictions lessen, the price is still high, and getting PCBs delivered on time and at a reasonable cost remains a significant challenge for buyers.

That's why they should negotiate with suppliers for a "delivered" price.

PCB buyers often overlook fluctuating freight costs when considering total cost of ownership (TCO) of the offshore products they purchase.

I've dealt with many buyers from OEMs and EMS companies who insist on buying PCBs without any regard for or knowledge of the actual freight costs. The mentality is that freight is handled by another department and is not the buyer's concern.

Remember to factor accurate shipping costs into the PO.

But this shortsighted approach means companies are more likely to overspend on their PCB purchases.

It's always better to negotiate a delivered price, especially when it comes to high-mix, low-to-medium volume purchasing. When you have multiple part numbers, each with a different delivery date, it just makes sense to pay the delivered price and move on to your next project.

Even for buyers who need low-mix and a higher volume of product, buying at an ex-works (EXW) or FOB origin price may not be the best practice.

Here are several scenarios where failure to negotiate a delivered price will cost you:

- Without a delivered price, your company takes possession of the shipment at the factory. If, as sometimes happens, several boxes of boards are lost in transit, it will not be the factory's responsibility to replace them.
- When product comes in and does not meet your quality standards, or it's built wrong, and you've already paid for freight. Sure, you can renegotiate with the manufacturer, but that is another headache that could have been avoided.
- Two bills are to be paid: that of the manufacturer and that of the freight company; each may have different terms. The manufacturer, which ships in volume, will likely get better rates – especially with shipping rates quoted in Asia instead of the US – than you would get paying for shipping yourself.
- The PCB manufacturer – and not you – will have to absorb fuel and holiday surcharges imposed by freight companies to have the product delivered.
- Tariffs on PCBs manufactured in China are due at time of arrival, which you will pay. A negotiated delivered price would include tariffs (DDP). That means payment for the product, the freight, and the tariffs would be due at the later, pre-negotiated date.

Keep in mind that tariffs on PCBs manufactured in China are based on the factory price at time of export and *not* on the cost of any freight or overhead. PCB buyers should periodically ask for both a factory price and a delivered price to keep tabs on current freight costs and ensure tariffs are being applied correctly.

A variation of the delivered price model is to have inventory consigned, especially when it comes to larger or consistently running part numbers.

It is understandable many OEMs like to have product on the shelf, ready to be assembled on a moment's notice. But that convenience comes at a cost, as it is expensive to have already paid-for product sitting on the production floor, waiting to be shipped out.

Buyers should have a negotiated program in place permitting their PCB supplier to maintain agreed-upon inventory levels while only invoicing the purchasing company at time of use. One invoice covers the cost of the product, the freight to get it to the dock, any applicable tariffs, and the cost of having it sit on the supplier's shelf.

The more certainty buyers can build into their supply chains, the better. Working with a good board manufacturer and practicing smart PCB purchasing will help control costs year-round and increase corporate cash flow. ❑

GREG PAPANDREW has more than 25 years' experience selling PCBs directly for various fabricators and as founder of a leading distributor. He is cofounder of Better Board Buying (boardbuying.com); greg@directpcb.com.

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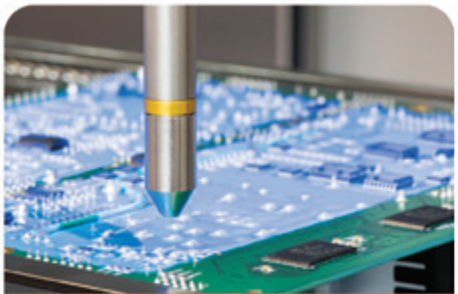

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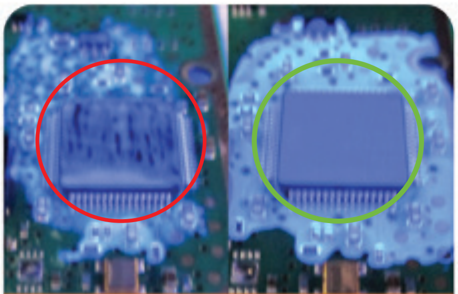

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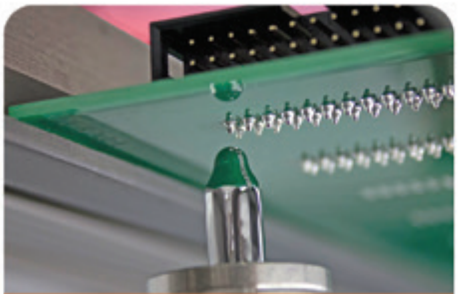

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Personnel Recruitment and Retention

Strategies for finding a long-term employer-employee fit.

ASK ANY EMS company what its top challenges are, and labor shortages are now tied with material constraints. The labor market was already in the process of a culture change pre-Covid. More than two years of Covid's impact on workplaces have made many in the workforce question their priorities in terms of work/life balance. It's an applicant's market.

On top of that, the rules of the game have changed dramatically. The younger generation has a different work ethic from previous ones that doesn't necessarily see acceptance of a job offer as a commitment to actually take the job. Some applicants try companies out for a week and leave. Others apply to multiple companies, accept the first offer, and then renege if a better offer arrives.

On the flip side, employer ads may be vague about work requirements to attract a larger pool of candidates. I recently read through a number of applicant comments about ads for remote work (sometimes in other states) that resulted in interviews for jobs that required time spent in the office. Most of those interviews ended poorly, and applicants discussed their frustration at wasted time for a job interview that didn't fit their needs.

The employer-employee relationship is an investment on both sides. While applicants can behave badly now due to the number of open jobs, the combination of recession and AI automation will likely kill a lot more jobs in the next few years than most people expect. Employers have long memories about candidates who mistreated them, and when the job market changes, résumés with short job stints may become a disqualifier. On the employer side, vague job postings on issues meaningful to employees attract a pool of bad-fit candidates and increase the possibility that applicants who need any job will accept one until they find the job they really want.

Successful recruitment and retention in the current market can benefit from a marketing approach. Most marketing strategies start by asking questions like these:

- What attracted your most recent hires?
- What are their favorite benefits?
- What keeps younger employees with longer tenures at your company?
- Are there under-recruited segments of the labor market like college students or older people reentering the workforce who may like the schedule options of shift work?
- Do similar local manufacturing firms seem to have the same challenges with hiring, and if not, what are they doing differently?
- Are there opportunities to promote your company at job fairs, schools or workforce recruitment organizations you haven't accessed?

Two decades of migration to a service economy have taken manufacturing jobs off the radar of many potential applicants. So, another question to consider is whether your target labor market is aware of your company and advantages of manufacturing jobs in terms of comprehensive benefits, more flexible, full-time scheduling options, and internal advancement opportunities. Working with local newspapers, bloggers, and local college/trade school media to publish articles that discuss careers in your organization can help brand your company positively within target labor markets. In short, you need a two-pronged approach that both continually builds awareness of the career opportunities your company represents within the target labor market as a whole, plus specific recruitment advertising for open positions.

Employee referral programs also represent a good recruitment tool. No one knows your company better than your employees. Providing employees with bonuses for referral candidates who stay a set period of time is a great way to recruit candidates who understand what the job entails.

Finding good candidates is only half the challenge. Retention, particularly in a market with labor shortages, may be even more challenging. Gluing employees to your company starts on day one. What does your onboarding program look like? Is it orientation and job training, or are there mentoring elements as well? Employees new to manufacturing will have many questions. Some companies use some form of buddy system to help them feel comfortable in an unfamiliar environment for the first few months. Do new employees understand the long-term career opportunities available to them? Helping them understand the availability of opportunities to learn new skills and get promoted helps with retention. A key goal of the onboarding process is to make employees feel comfortable and aware of the longer-term advancement path available to them.

Tuition reimbursement programs are another potential retention tool. It is a benefit that attracts employees with initiative, so it is important to consider a structure that capitalizes on that. First, there should

continued on pg. 55

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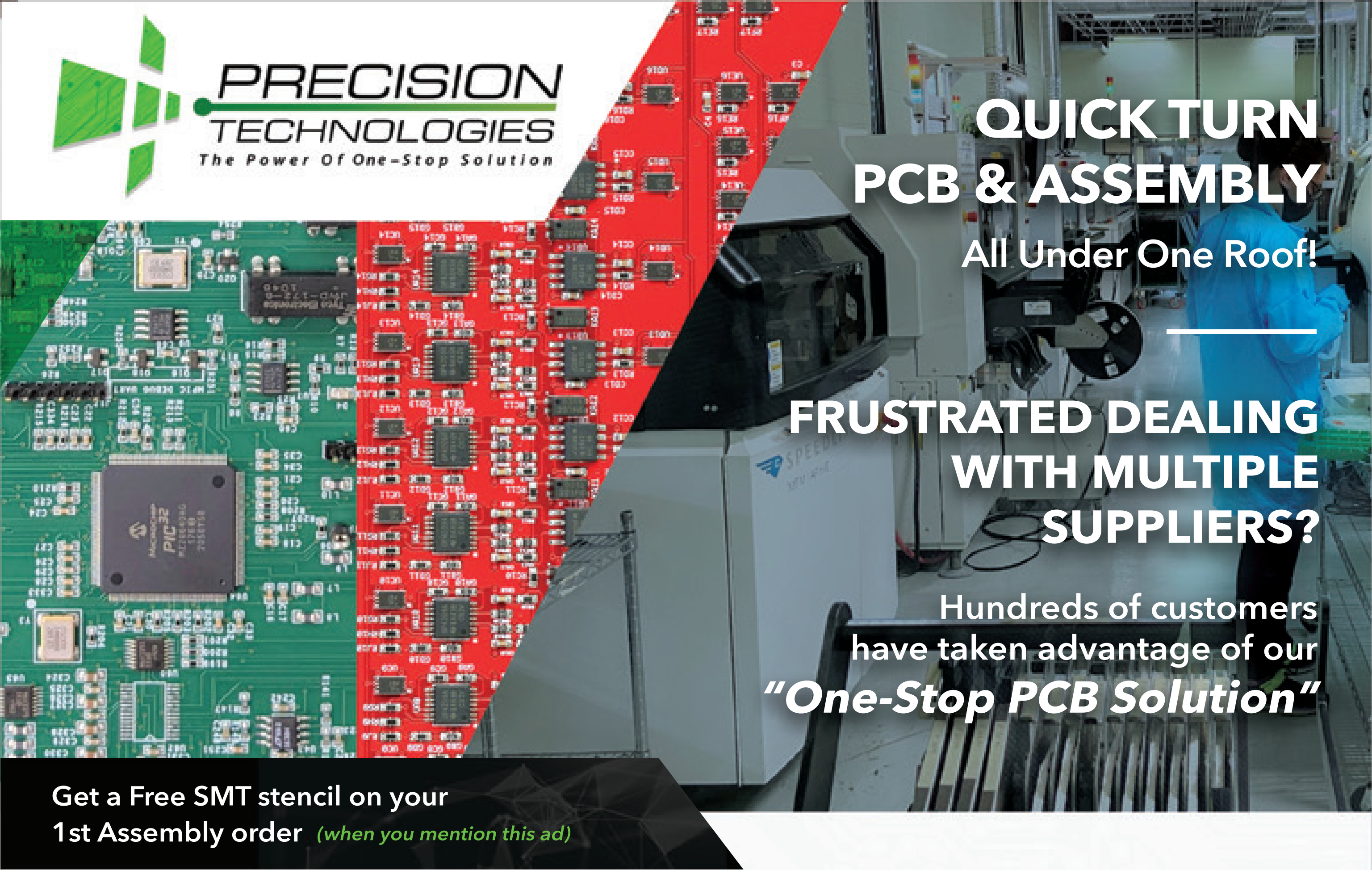

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PCB Design Requires People Skills

For emergency respins, bureaucracy sometimes prohibits on-the-fly project completion, especially when colleagues refuse to revisit schematics.

RUSH JOBS CAN be a pain. They usually come in the form of a small, simple board or a seemingly minor revision to something more substantial. The common thread is somebody wants it *right now.* Normally, this means setting aside your current project and whipping out a quick spin. It's a cumulative thing that stretches the longer-term projects.

Meanwhile, some departments or people within the company move at their own pace. You may not have the clout to jump the line for whatever it is they do. An example is having the circuit simulated for signal or power integrity. It could just be the librarian creating the symbols. These are the things you need to get started as early as possible in the process.

For one top engineering department, the process involved us only generating a fabrication drawing if there was an outline drawing for that specific board's part number that was already released to the system. It wasn't enough for the mechanical engineer to provide the geometry, even if it was a square with four symmetric holes or a straight-up copy of something else.

The documentation was automated in ways that ensured the board would have all the connectors, mounting holes and other touch-points exactly how they were intended. The outline and other geometry were extracted from the released outline drawing. Most places I have worked neglected the outline drawing until the end-customer demanded it. All we typically saw during development was from a data dump by the mechanical engineer and maybe a 3-D screencapture. No docs.

The bureaucracy of the system meant the designer could not possibly start and complete a project in a single day. Many times, I had to remind someone we didn't even have a part number in the system, let alone a completed drawing approved by all the stakeholders. While it wasn't as agile, the tradeoff was we didn't have to respin boards because a connector was mirrored to the secondary side of the board.

My next stop was Chromebook main logic cards. My first one was finally complete with its two USB type-C connectors. Based on the .emn file, I placed them on the wrong side, where they created fewer design rule issues. We were performing the final design review when my manager pointed them out. This triggered an emergency respin with all the superspeed traces rerouted to swap lanes and polarity of the data bus. At least there was the exact amount of space required to pull this off. It was a lesson to learn about working without a pristine placement. Chances are this would have been caught earlier if I had shared the placement to a wider audience before doing the rest of the work.

For sure, this would not have happened at the previous job. In fact, someone did use the wrong half of a stacking connector pair on their schematic at one point. We'll call him "Guy." The result was pin one was on the wrong side of the connector compared to the outline drawing in the document-control system.

The mechanical engineer who provided the outline was reusing a standard form factor for test fixtures with the new part number. I had seen this same outline before and knew it was correct. I recall it was two 80-pin connectors that went on the bottom, but I couldn't get them to line up the signals if they were placed where they belonged.

Guy was informed we needed to update the connectors so the polarity matched the drawing. He refused to revisit the schematic! I did something I'd never done before: routed all the connections except those that went to the connectors, and then refused to

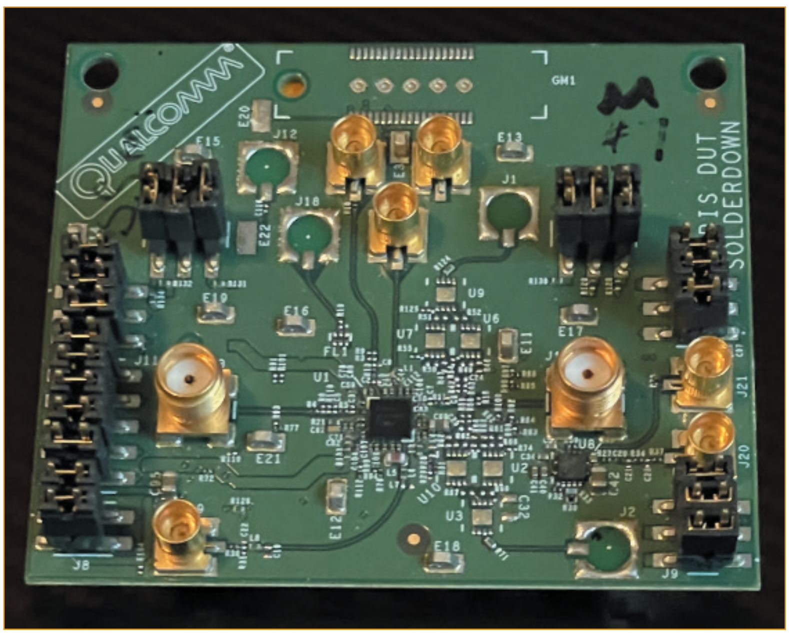

FIGURE 1. A simple, predetermined outline is a good vehicle for design reuse.

JOHN BURKHERT JR. is a career PCB designer experienced in military, telecom, consumer hardware and, lately, the automotive industry. Originally, he was an RF specialist but is compelled to flip the bit now and then to fill the need for high-speed digital design. He enjoys playing bass and racing bikes when he's not writing about or performing PCB layout. His column is produced by Cadence Design Systems and runs monthly.

FIGURE 2. Team-building required for five-on-five Foosball might spill over to a more cohesive workforce – in theory.

complete the board, informing anyone who would listen.

One of those who listened had based his own inter-board connections on the false information provided by my EE, so he joined the chorus. To say the least, he was not happy. I had already escalated to our manager, and now it went further, until the director of my department and the director of Guy's had a sit-down. After that, he finally fixed the connector polarity.

At the design review, I learned everyone at the table had made suggestions without getting any traction. So it wasn't just me, which was a bit of a relief.

Here comes the plot twist.

The boards came in, and another episode came to light. A little backstory: On day one, I told Guy we had two nets with almost the same name, the difference being TCK on one pin and CLK on the other, with the rest of the net-names matching. I pointed that out as a bullet point on the first status report. No update forthcoming. It became a topic of its own, consuming the next report.

FIGURE 3. A similar board with the infamous stacking connector pair that brought the design to a standstill.

Having worked on this chip before, I knew what to expect. It seemed so apparent it was a typographical error that needed cleanup on the schematic. I brought it up the next time Guy was in my office. He said, "Don't worry about it." At that point, I still assumed good intentions, and I dropped the matter.

So, with boards in-house, Guy came over with a somewhat ashen complexion. I could tell something was wrong. He asked if I knew the clock was an open circuit.

"Oh yeah, you're right, Guy, and I told you about it a few times, but you told me not to worry about it, so I didn't," I said.

The clock issue was totally forgotten in the struggle with something even bigger.

No blowback came my way, but I think Guy got a bit of "head-shaping." Given this fellow's reputation, my ECAD teammates seemed to vaporize anytime Guy had a job for us. I was stuck for the clocked-up board and two more follow-on boards with him. I got through those boards by setting a boundary that went like this: "Guy, this is the fifth time I've told you this, and I'm not going to mention it ever again."

He acted on the ultimatum, but not on the first four notifications. In that strange and tortured way, we were able to get through the rest of the projects. Guy's manager was aware of the issues and not inclined to babysit. Adjusting to the situation was the only way forward, or so it seemed.

Sometimes, we do whatever we have to do to make it work in the end. In terms of problem-solving, one size does not fit all. Identify risks and develop a mitigation strategy, and remember: It's not all Tetris and Connect the Dots. □

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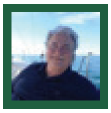

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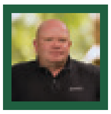

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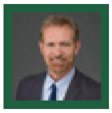

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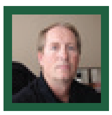

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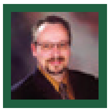

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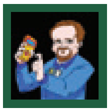

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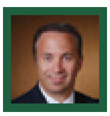

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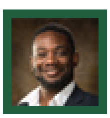

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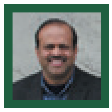

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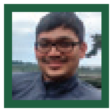

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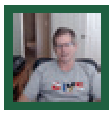

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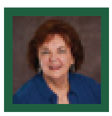

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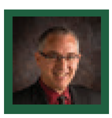

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Machine Learning at the Edge

AI is spreading quickly into sensors and will drive an even greater appetite for data.

THE MENTAL HEALTH issues surrounding the pandemic are affecting people's attitudes as they contemplate returning to work. Surveys have shown that people are somewhat concerned about their safety as they begin to mix with others in the workplace once more. For generations now, many of us have gone to work expecting to catch no more than a cold, at worst, from our colleagues. Our work environments have been designed accordingly: although conventional hygiene is catered to, there have been minimal precautions to prevent transmission of airborne viruses.

With the pandemic, measures were hastily put in place. Semi-permanent transparent screens have become commonplace in retail settings, as well as limitations on occupancy and direction of movement in stores and public places. Were they effective? Probably. Could they be better? Almost certainly.

We now have an opportunity – some may call it an imperative – to re-engineer our systems and practices with distancing and minimizing contact as a basic principle. The opportunity applies to almost every context, including retail, transportation, and work environments.

Although working from home has delivered great flexibility to large numbers of people, team building is effective by bringing everyone together in the same place at the same time. Businesses depend on this, although people are understandably concerned for their safety and well being. There is a feeling that smart buildings equipped to control ventilation, air quality and occupancy, as well as access to areas and resources such as meeting rooms and equipment, can offer a safe environment for employees to coexist.

Technologies like AI have a role in ensuring we get this re-engineering right. During the pandemic, AI-enhanced cameras were introduced in London to monitor social distancing on streets and in public spaces. Although used only for assessment and surveying, if facial recognition were added this kind of technology could be used to enforce distancing rules and bring prosecutions. Technologically speaking, this would be only a small step, although of course there are major ethical issues.

On the other hand, the same technology is being used to help with urban planning by analyzing the patterns of pedestrians and road users around various features like crossings and cycle lanes. The pattern matching and anomaly detection skills of AI can help to identify where features are being used as intended and where they are failing. With this information, planning and design can be improved to ensure systems are delivered that serve users optimally and deliver the best results for all stakeholders. It could help ensure better urban schemes and more efficient local-government spending.

The maturing of AI and its infusion into the fabric of life is fundamentally changing computer and system architectures, from the cloud to the edge. Google's Tensor Processing Unit (TPU) is one example, an architecture specifically developed to handle certain types of AI algorithms. Google points out that the venerable CPU is well suited to fast prototyping and handling AI workloads that involve small and simple models, while larger models are suited to the inherently more parallelized GPU architecture. Applications for the TPU include handling very large models that require a long training period. As the most ambitious applications migrate towards TPU-based platforms in the cloud, this should ensure fewer and smaller data centers are needed to provide cutting-edge and high-value services in the future and could therefore save significant energy and so enhance sustainability.

Now, hot on the heels of the cloud TPU, comes the Edge TPU; optimized for machine-learning inferencing on low-power devices. Its arrival is part of a migration of intelligence towards the endpoints of the IoT, also seen in the advent of intelligent inertial sensors that contain a small DSP optimized for machine-learning and deep-learning algorithms. These can perform tasks like sound classification and activity detection locally, consuming a fraction of the power needed to run a comparable application in the host controller.

Future generations, I am sure, will significantly extend the sensor's local inferencing capabilities. By configuring networks of such sensors, developers will be able to unleash yet more of the potential of cyber-physical systems that bring together sensing, computation, control and networking in physical objects connected to the internet and to each other. They will transform the way we manage factories (in Industry 4.0 use cases), as well as our homes and buildings, services like healthcare and transportation, and smart cities. These smarter-than-smart sensors will also need to become physically more resilient as they penetrate uncontrolled industrial and street-level environments.

The ability to provide initial filtering and event classification will enable us to capture even larger quantities of data in almost any context and quickly separate the meaningful from the meaningless. Ulti-

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ALUN MORGAN is technology ambassador at Ventec International Group (ventec-group.com); alun.morgan@ventec-europe.com.

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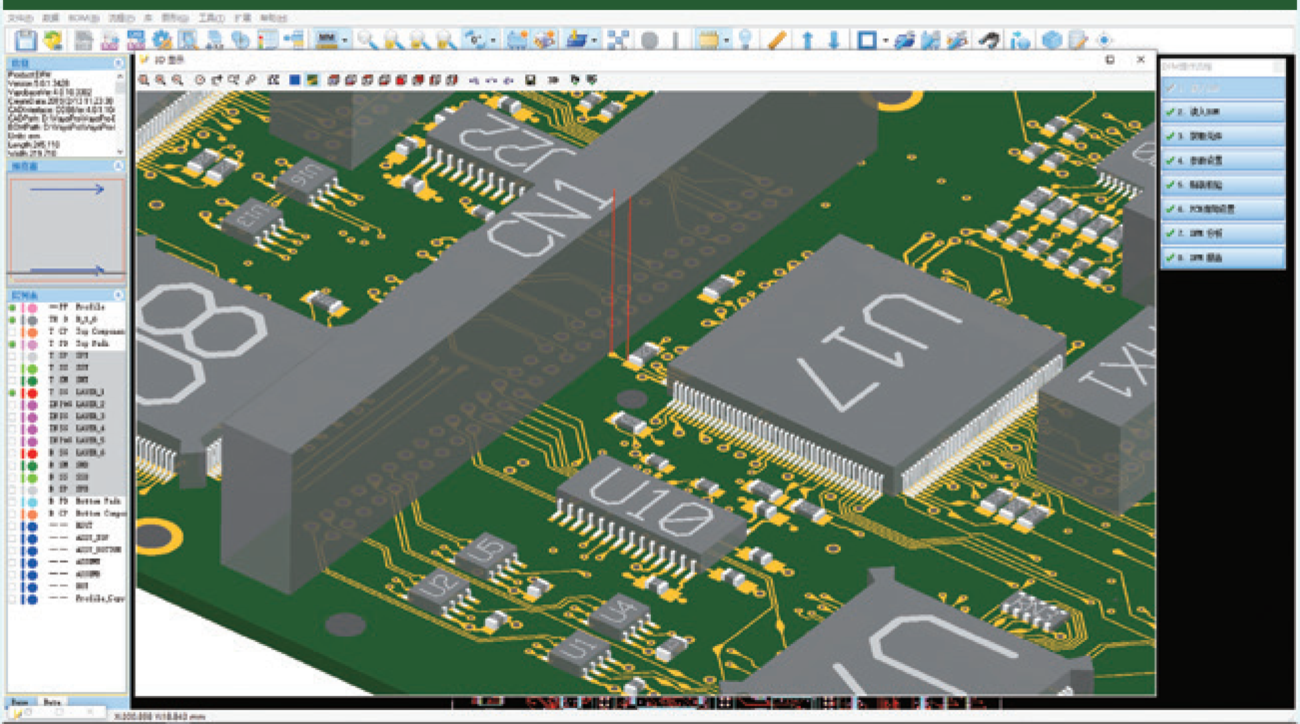

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A DESIGNER COMPLETED their first flex circuit design and sent it to several suppliers to quote. When the quotes came back, they noticed all of them had nonrecurring engineering/tooling costs that were higher than normally seen on a quote for a rigid PCB. Is this typical, or did something in the design cause this?

Flex circuits almost always have higher NRE/tooling costs than a comparable rigid PCB. And while some suppliers may opt to absorb some of these costs to win business, most costs are passed on to the customer. While it is possible that a specific design may have contributed to *additional* elevated NRE/tooling costs if unrealistic tolerances (part outline, etched feature to outline, stiffener placement, etc.) are specified, it is more likely this is just the true additional cost of building flex circuits. Following are several potential items that will drive up the costs of flex tooling and NRE beyond what those seen with a rigid PCB.

NRE. It is very common with flex and rigid-flex to have features such as unbonded regions, bikini (cut back) covers, pre-punched inner layer substrates/adhesives, etc., none of which is ever used on rigid PCBs. All these features require additional engineering time and resources to develop the build sequence, die design, drill programs, and assembly instructions. Extra time equals extra cost.

Bare flex tooling. Virtually every single- or double-sided and multilayer flex will require at least one die that will be used to cut the final part outline. Rigid PCBs are usually excised from the processing panel using a CNC router, so no outline die is required. Due to the very thin nature of flexible circuits, they do not route well and are prone to tears and edge stringers after a routing operation. Plus, CNC routing is much slower than punching. For this reason, either a steel rule die (for smaller volumes) or a hard tool (larger volumes, see FIGURE 1) is used to remove circuits from the panel. The exception is rigid-flex construction. Since rigid-flex circuits have rigid areas that often don't punch well, these circuits are typically routed. Most rigid-flex circuits have many flex layers that add thickness and improve edge quality after routing. If the rigid-flex design has very few internal layers, the fabricator may choose to either punch (another die) or laser the flex areas, then route the rigid areas.

FIGURE 1. Hard punch and dies are complex and expensive tools that require precision machining, and near perfect alignment of the upper punch and lower die in order to produce good results on thin materials like flexible circuits. It is not uncommon for a flex circuit hard tool to weigh 100-200lbs.

Unbonded (loose leaf) construction. On multilayer flex and rigid-flex that requires unbonded areas to improve flexibility, an additional die is required to punch away the unbonded areas of internal adhesive films prior to lamination. Again, these may be either steel rule dies or hard tool punch and dies, depending on production volume.

Cut back (bikini) covers – rigid-flex only. Rigid-flex construction almost always requires the removal of thermosetting adhesive films in the rigid areas. Due to the excessive z-axis expansion of these adhesives, their use in through-holes and vias is discouraged for reliability reasons. Most of the thermosetting adhesive layers in rigid-flex stackups are due to the adhesive-clad polyimide cover materials. Removing polyimide covers in the rigid areas effectively eliminates these adhesives in plated through-hole areas. When cut back covers are required, two additional dies will be necessary. The first die will punch away the cover material in the rigid areas containing through holes and vias. The other die will punch the prepreg adhesives that will fill the void left by the previous punching operation. Because there is overlap of the cover material and the prepreg in the transition areas, it is not possible to use the same die for both operations.

Component assembly. Assembling components onto flexible circuits is not easy. Unlike rigid PCBs, flex circuits cannot run through the SMT process without tools and fixtures to support the flexible substrates.

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MARK FINSTAD is director of engineering at Flexible Circuit Technologies (flexiblecircuit.com); mark.finstad@flexiblecircuit.com. He and co-"Flexpert" NICK KOOP (nick.koop@ttmtech.com) welcome your suggestions. They will speak at PCB West in October.

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The Unsinkable, Unstoppable PCB MARKET

Political and supply-chain issues could not slow printed circuit growth in 2021. by DR. HAYAO NAKAHARA

The author attended his first IPC meeting in 1966. At that time, the consensus was the world PCB output was $500 million. Some "knowledgeable" experts predicted PCB output would dwindle since semiconductors were rising rapidly and PCBs would not be needed. If that $500 million assessment was correct, in 55 years the PCB market grew 192 times, to $96 billion!

It is with that in mind that the author embarks on another attempt to establish the value of the world's printed circuit board market, culminating in the NTI-100 list of the largest fabricators.

In fact, the author thought he would cease the NTI-100 report a few years ago. However, his curiosity about the world PCB industry (2022 is his 57th year in this industry) remains a motivator, and once again he made the NTI-100 list. Every year he wants to quit, but does not want to disappoint the industry. So, he may continue to compile the NTI-100 data so long as his brain has the capacity to be patient and functional.

When the author first compiled what is now known as the NTI-100 list, "100" implied the top 100 fabricators. Around 2005, he realized the top 100 fabricators did not cover the full scale of world PCB production. He decided to change 100 from "100 top fabricators" to "fabricators with revenue of $100 million or greater." Hence, "100" of NTI-100 means "$100 million."

Exchange Rates

We begin this report with the exchange rates of major currencies against the US dollar. As in the past, exchange rates are calculated using exchangerate.com. This website describes daily exchange rates of various currencies during weekdays (265 days). The author added the exchange rate of each of 265 days, summed, and divided the sum by 265 to arrive at the exchange rates shown in TABLE 1.

Most of the currency fluctuations have been relatively small. But since around March, the value of the yen started to decline rapidly against the US dollar. As of this writing, it is

TABLE 1. Average Exchange Rates: Local Currency/USD

Currency	2015	2016	2017	2018	2019	2020	2021
China yuan (RMB)	6.284	6.634	6.758	6.616	6.910	6.903	6.402
Japan yen	121.06	107.84	112.93	110.44	109.01	106.77	108.98
Taiwan dollar (NTD)	31.777	32.25	30.44	30.16	30.93	29.47	27.64
S. Korea won	1,132.33	1,160.80	1,130.59	1100.8	1165.7	1,180	1,136
Thailand baht	34.253	35.290	33.92	32.32	31.03	31.27	31.76
Singapore dollar	1.375	1.440	1.334	1.349	1.364	1.38	1.333
Malaysia ringgit	4.120	4.100	4.32	4.035	4.123	4.203	4.11
Vietnam dong	21,920.68	22,763.00	22,721.03	23,001.08	23.202.59	23,201	22,879
Philippines peso	44.520	47.300	50.44	52.7	50.82	49.62	49.94
Indonesia rupiah	13,749.27	13,320.00	13,440.00	14,236.00	13,798.61	14,559.25	14,195
Canada dollar	1.279	0.997	1.297	1.296	1.327	1.34	1.244
India rupee	64.235	67.800	64.87	68.43	70.39	71.12	73.36
Mexico pesos	15.792	19.05	18.95	19.00	19.25	21.5	20.13
Russia ruble	61.195	57.4	58.31	62.78	64.69	72.412	73.12
Switzerland franc	0.962	0.997	0.98	1.022	0.994	1.38	0.967
UK pound	0.655	0.74031	0.81	0.75	0.784	0.78	0.721
Euro	0.902	0.904	0.886	0.844	0.894	0.8677	0.839

Source: NTI summary from exchangerates.com traded at about ¥136/$1. If this rate is persistent, Japanese fabricators' ranking will be pushed down considerably in NTI-100 2022 edition. We shall see. Every year, there must be errors, which are the sole responsibility of this author. The rankings are reasonably accurate, hopefully. Please view them merely as reference.

Data Collection

Data are collected from annual reports for stock-listed fabricators. For privately owned companies, data compiled by TPCA and CPCA are used. For many others, the author's industry friends helped. Using this opportunity, he would like to express his gratitude to those organizations and individuals for their able assistance.

A big challenge was to convert English names to local names and vice versa. Here, his knowledge of Chinese characters helped. Chinese companies have many names. To be clear, internationally recognized or recognizable names are used for English.

Simple comments are included in the last column of the table for those fabricators the author is familiar with. For many Chinese fabricators, their websites are substituted for comments because the author is not intimately familiar with them. For room, some descriptions are shortened. For example, IC PKG Sub stands for IC package substrate, which Taiwan and China call a "carrier board." Likewise, Auto PCB refers to automotive PCB, and so on.

Simple Analysis

Of the 146 fabricators in the 2021 NTI-100, the author is personally quite familiar with about half. He visited their factories many times, and they are also well publicized. Brief comments are included to highlight their status. They are mostly publicly traded, and detailed information can be extracted from their websites.

The 2021 world PCB production value was $96 billion, which is the best estimate by this author. The value is derived from the NTI-100 list and from unranked companies. That sum includes about $9 billion of estimated assembly value, mainly made by flex circuit fabricators. But, in recent years, rigid board makers are also moving into this business arena. Of some 600+ Chinese makers this author investigated, about half are engaged in assembly and claiming a "one-stop-shop." In many cases, their assembly business is larger than the bare board business. But most are small- to medium-sized companies and are not in the NTI-100. What the author is driving at is that it is impossible to accurately separate the assembly business from the total PCB output (bare board plus assembly). The bare board value was an estimated $87 billion in 2021.

TABLE 2. NTI-100 Ranking by Region

Region	No. Entries	2020 Rev.	2021 Rev.	YoY Change	Share
Tawian	27	24,407	28,873	18.3%	32.8%
China	69	22,221	27,634	24.3%	31.3%
Japan	23	12,355	15,174	22.8%	17.2%
S. Korea	14	8,383	9,594	14.5%	10.9%
US	5	2,790	3,017	8.1%	3.4%
Europe	5	2,013	2,611	29.7%	3.0%
SE Asia	3	1,004	1,242	23.7%	1.4%
World Total	**146**	**73,173**	**88,145**	**19.8%**	**100.0%**

In $US million. Source: N.T. Information Ltd., July 4, 2022.

IC package substrates. Looking at growth companies, those with the highest growth in 2021 were IC package substrate specialists. Seven fabricators have IC package substrate revenue greater than $1 billion: Unimicron ($2.08 billion), Ibiden ($1.96 billion), SEMCO ($1.53 billion), Shinko ($1.39 billion), LG Innotek ($1.27 billion), Nanya PCB ($1.23 billion) and Kinsus ($1.09 billion). The author's estimate of worldwide IC package substrate production in 2021 was $15.6 billion, or 17.9% of the total bare board production of $87 billion. From 2019 to 2025, IC package substrate makers have committed more than $25 billion to expand existing plants or build new ones, mostly the latter. AT&S' Malaysia plant will cost $2.2 billion. Ibiden will spend about $4.5 billion during this period. (Investment information is publicly available.) In the PCB industry, ROI is said to be 1:1. So, one can imagine what that $25 billion (all earmarked for Asia Pacific) will do in terms of IC package substrate production value when all those plants go into full production.

Automotive PCBs. Despite the component shortage, automotive production rose modestly in 2021 to 83 million units, from 78 million in 2020. Electric vehicle (EV) unit sales rose to 6.5 million units, up 3.5 million units year-over-year. The increase in EVs, which use three times as many PCBs as conventional internal combustion engine cars, coupled with the higher selling prices due to copper-clad laminate price increases, boosted automotive PCB production to $9.3 billion in 2021 from $7.8 billion in 2020. Automotive's share of bare board sales in 2021 was 10.8%. Automotive PCB fabricators benefited from these developments. Major automotive PCB makers in 2021 were Meiko ($672 million), CMK ($665 million), Nippon Mektron ($640 million), Chin Poon ($560 million), TTM Technologies ($511 million), Unimicron ($440 million), Kingboard ($420 million), Tripod ($408 million), KCE ($350 million), and Dynamic ($296 million).

In early 2000, the flex printed circuit (FPC) share of total PCB sales was only 4%. In 2021, the total FPC output was $18 billion, of which $13 billion was bare board. Hence, the FPC bare board share was 14.9%. Many top fabricators are FPC makers, such as Zhen Ding, DSBJ, Nippon Mektron, Kinwong, Young Poong Group, etc.

Computing. Fabricators of motherboards for smartphones, PCs and tablets did well because of demand for these products for work and school. As students returned to classrooms and enough PCs were made and distributed, however, motherboard demand for these products seems to be slowing.

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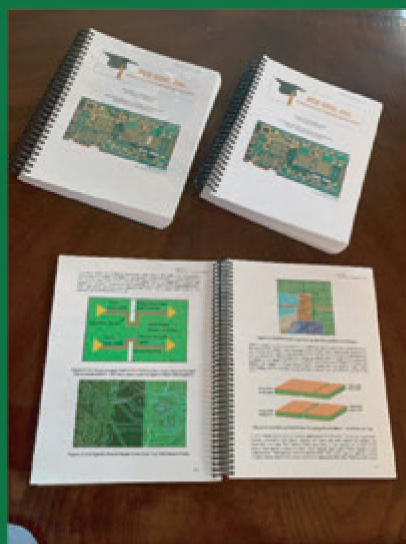

AUTHORS

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Printed Circuit Engineering Professional

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TABLE 2 shows the geographic distribution of the NTI-100. Total world PCB production was $96 billion. Of that, $57 billion was produced in China by Chinese nationals and foreign transplants. Broken down further, domestic Chinese fabricators accounted for 60%, or $34 billion, of the $57 billion, Taiwan transplants 29% ($17 billion) and the rest, $6 billion (11%), was made by AT&S, TTM, and Japanese and Southeast Asia transplants. Taiwan once had 35% of the PCB production in China. Although the Taiwanese production in China is growing, growth by Chinese fabricators is outpacing that of their Taiwanese competitors in China. Therefore, the gap between Taiwan and Chinese makers will widen.

Looking at Table 2, if the revenue of the top Taiwan and Chinese fabricators is added (28,873+27,634), the sum is $56.51 billion, or 64% of the world output (56,507/87,765). Taiwan's total PCB output by fabricators from Taiwan, China and Thailand was $29.3 billion in 2021.

If Taiwan's and China's total outputs are added, the sum is $63.3 billion. That is, Taiwan's and China's "total output" is 66% (63.3/96) of the world production. This ratio is very close to the total share (64%) of the Taiwan and China fabricators on the NTI-100 list. With 100 or more new PCB projects pending over the next several years in China, many on a grand scale (if realized), China's and Taiwan's share of global production will exceed 70%.

Twenty-five fabricators achieved revenue greater than $1 billion in 2021, with 10 topping $2 billion **(TABLE 3)**. In 2002,

TABLE 3. PCB Fabricators in 2021 with Revenue ≥$100M

Rank	Maker Name	Nationality	Local Name	YoY chng	2020	2021	Brief Comments
1	Zhen Ding Technology	TW/China	臻鼎科技	18.1%	4,749	5,609	60+% from FPC & FPCA, Into IC PKG Sub
2	Unimicron	TW/China	欣興電子	19.0%	3,178	3,783	IC PKG Sub: $2.08B, HDI: $945M
3	DSBJ	China	東山精密	9.2%	2,932	3,201	Mflex+ Multek, 80% FPC & FPCA
4	Nippon Mektron	Japan	日本メクトロン	13.9%	2,585	2,944	100% FPC & FPCA, No. 1 Auto PCB
5	Compeq	TW/China	華通電脳	4.2%	2,189	2,281	75% made in China, China plants expanding
6	Tripod	TW/China	健鼎科技	18.4%	2,010	2,279	96% made in China, China plants expanding
7	TTM Technologies	US	TTM Technologies	6.8%	2,110	2,249	New plant under construction in Penang
8	Shennan Circuits	China	深南電路	20.2%	1,812	2,178	$1.5B investment on IC PKG substrate
9	Ibiden	Japan	イビデン	42.7%	1,524	2,174	IC PKG Sub: $1.9B?
10	HannStar Board	TW/China	瀚宇博德	24.7%	1,654	2,062	Includes GBM, which contains ELNA
11	AT&S	Austria	AT&S	33.8%	1,416	1,895	$2.2B IC PKG Sub in Malaysia, $500M in Austria
12	Nanya PCB	TW/China	南亜電路	35.6%	1,393	1,890	IC PKG Sub: $1.23B, 65% of total revenue
13	Kingboard PCB	China	建滔集団	31.4%	1,390	1,828	Includes E&E, Techwise, Glory Faith, etc.
14	SEMCO	S. Korea	삼성전기	7.6%	1,551	1,669	IC PKG Sub: $1.41B, $1B in Vietnam
15	Shinko Electric Ind.	Japan	新光電気工業	49.5%	1,040	1,554	100% IC PGK Sub and expanding
16	Kinwong	China	景旺電子	35.0%	1,101	1,489	Into high-end HDI and high-layer-count MLB
17	Young Poong Group	S. Korea	영풍그룹	18.7%	1,253	1,487	YPE, Interflex & Korea Circuit ($840M FPC)
18	Meiko	Japan	メイコー	26.8%	1,092	1,388	$672M automotive; into IC PKG Sub in Japan
19	LG Innotek	S. Korea	LG이노텍	26.2%	1,095	1,382	100% IC PKG Sub
20	WUS Group (TW+CN)	TW/China	楠梓電子(滬士電子)	1.1%	1,337	1,352	Taiwan Wus plus China Wus
21	Kinsus	TW/China	景碩科技	31.6%	980	1,291	90% IC PKG Sub, new plant in Taiwan
22	Flexium Technology	TW/China	台群科技	19.0%	1,082	1,287	100% FPC & FPCA, 63% made in China
23	Simmtech	S. Korea	심텍	11.8%	1,057	1,200	New IC PKG Sub plant in Penang
24	Victory Giant	China	勝宏科技	32.7%	875	1,161	Rapid growth in HDI, IC PKG Sub to Nantong
25	AKM Meadville	China	安捷利美維	32.7%	846	1,123	AKM & AKM Meadville combined
26	Taiwan Techvest (TPT)	TW/China	志超科技	20.4%	827	995	PC motherboards
27	Gold Circuit (GCE)	TW/China	金像電子	13.8%	846	956	High-layer-count MLB
28	Suntak	China	崇達科技	37.3%	682	937	Into IC PKG Substrate
29	BH Flex	S. Korea	베에이치플렉스	43.8%	635	913	100% FPC & FPCA, plants in Vietnam
30	Daeduck Electronics	S. Korea	대덕전자	8.1%	815	881	65% IC PKG Sub, more toward PKG Sub
Top 30 Total				**20.4%**	**46,056**	**55,438**	

In $US million. Source: N.T. Information Ltd., July 4, 2022

TABLE 3. PCB Fabricators in 2021 with Revenue ≥$100M (Continued)

Rank	Maker Name	Nationality	Local Name	YoY chng	2020	2021	Brief Comments
31	Nitto Denko	Japan	日東電工	71.0%	514	879	$100% FPC and expanding
32	Fujikura	Japan	フジクラ	-21.0%	1,051	828	100% FPC almost all in Thailand & Vietnam
33	Shenzhen Fast Print	China	深圳興森快捷電路	24.9%	630	787	IC PKG Sub is increasing with new investment
34	CMK	Japan	日本シーエムケー	16.5%	641	747	80% automotive PCB
35	ASK PCB	China	奥士康	52.4%	455	693	New plant is contributing
36	Kyocera	Japan	京セラ	38.0%	500	690	$2.6B IC PKG Sub including ceramic Sub
37	Chin Poon	TW/China	敬鵬工業	19.0%	554	659	80% automotive PCB
38	Mutara Manufacturing	Japan	村田製作所	16.4%	550	640	MetroCirc, LCP-based FPC
39	Olympic	China	世運電路	48.2%	396	587	Automotive increasing
40	Shengyi Electronics	China	生益電子	-0.4%	576	570	Huawei orders nose-dived
41	Dynamic Electronics	TW/China	定穎電子	24.9%	456	570	More than 50% from automotive PCB
42	Sumitomo Elect Ind.	Japan	住友電気工業	0.4%	562	564	Dormant
43	Wuzhu	China	五株科技	20.3%	456	560	HDI & FPC
44	Bomin Electronics	China	博敏電子	26.4%	435	550	Into IC PKG Substrate
45	APEX International	TW/China	泰鼎電路	25.1%	428	535	Plant only in Thailand, investing more
46	Career Technoogy	TW/China	嘉聯益科技	-8.5%	580	531	100% FPC and FPCA
47	Sun & Lynn	China	深聯電路	37.8%	369	508	slpcb.com
48	Founder PCB	China	方正印刷電路	-0.3%	502	501	What is going on at Founder?
49	Hongxin Electronics	China	弘信電子	21.1%	412	499	100% FPC & FPCA
50	Unitech	TW/China	燿華電子	-6.2%	521	488	RFC did not do well
51	KCE	Thailand	KCE Electronics	31.0%	370	483	70%+ is from automotive, new plant
52	Gul Technology	Singapore	Gul Technology	21.6%	393	478	HDI & automotive PCB
53	China Eagle (CEE)	China	中京電子	25.9%	366	460	Into IC PKG Substrate
54	Ellington	China	依頓電子	12.5%	404	454	Automotive increasing, new plant
55	CCTC	China	汕頭超声印製板	16.3%	387	450	Conservative. Automotive PCB & HDI
56	Guangdong Junya	China	広東駿亜電子	15.8%	368	426	Bought Sumitomo Denko in Shenzhen
57	SI Flex	S. Korea	에스아이플렉스	4.7%	406	425	100% FPC & FPCA, plants only in Vietnam
58	Kyoden	Japan	キョウデン	25.8%	333	419	25% automotive
59	Isu-Petasys	S. Korea	이수페타시스	-8.8%	453	413	High-layer-count MLB
60	Lincstech	Japan	リンクステック	23.8%	323	400	Former PCB Div of Showa Denko
61	ASE	TW/China	日月光	34.7%	282	380	100% IC PKG Sub, Kaoshiung & Shanghai
62	Red Board	China	紅板	17.0%	319	373	Ji'An plant expanding
63	GD Keixiang Kingshine	China	広東科翔電子	40.6%	250	352	gdkxpcb.com
64	Guangdong XD Group	China	広東興達鴻業電子	3.8%	318	330	xdgroup.com
65	STEMCO	S. Korea	스템코	10.0%	300	330	CoF, JV between Samsaung & Toray of Japan
66	Sanmina	US	Sanmina	10.0%	300	330	Plants in US, China & Singapore
67	APCB	TW/China	競国実業	9.3%	301	329	Taiwan, China & Thailand
68	Delton Technology	China	広州広合科技	28.2%	258	324	delton.com.cn
69	FICT	Japan	エフアイシーティー	25.8%	244	307	Purchased by a Japanese fund; expanding
70	Transtech	China	江蘇伝芸	8.5%	276	300	?
71	Shenzhen Sunshine	China	深圳明陽電路	48.6%	202	290	Two plants in China & subsidiary in Germany
72	MFS	Singapore	MFS Singapore	16.6%	241	281	Two plants in China and one in Malaysia
73	Shirai Denshi	Japan	シライ電子	31.7%	205	270	Three plants in Japan and one in Zhuhai
Top 31-73 Total				**17.4%**	**17,887**	**20,990**	

In $US million. Source: N.T. Information Ltd., July 4, 2022

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TABLE 3. PCB Fabricators in 2021 with Revenue ≥$100M (Continued)

Rank	Maker Name	Nationality	Local Name	YoY chng	2020	2021	Brief Comments
74	DAP	S. Korea	디에이피	0.8%	265	267	HDI specialist
75	Leader-Tech	China	深圳上達電子	41.7%	187	266	FPC & FPCA, chip-on-flex
76	Palwonn	TW/China	競華電子	17.9%	223	263	Plant in Shenzhen & Suzhou, no plant in TW
77	Onpress	China	安柏電路	33.9%	192	257	Heavily into automotive PCB
78	Daisho Dennshi	Japan	大昌電子	11.7%	230	257	IC PKG Sub & high-density PCB
79	Kunshan Huanxing Grp	China	昆山華新電子集団	11.0%	229	254	kshuanxin.com.cn
80	ACCESS	China	珠海越亜半導体	73.5%	143	249	100% IC PKG Sub, new plant in Zhuhai
81	Taihong Circuit Industry	TW/China	台豊印刷電路工業	17.1%	205	240	China plant was sold
82	Ichia Technology	TW/China	毅嘉科技	17.7%	199	234	100% FPC & FPCA
83	SZ Jove Enterprize	China	深圳中富電路	33.1%	169	225	jovepcb.com
84	Würth Elektronik	Germany	Würth Elektronik	21.0%	178	215	Three plants in Germany and Chinese partners
85	Camelot PCB	China	金涤電路科技	67.6%	124	207	camelotpcb.com
86	Forewin FPC	China	福菜盈電子	42.7%	143	204	forewin-flex.com
87	Shenzen Minzhenhong	China	深圳明正宏電子	33.3%	150	200	mzhpcb.cn
88	Somacis	Italy	Somacis	11.1%	180	200	Italy, China, San Diego and U.K.(?)
89	Guangzhou GCI	China	広州杰賽科技	20.4%	164	197	chinagci.com
90	Kyosha	Japan	京写	23.3%	159	196	Japan, China, Indonesia and now in Vietnam
91	Ji'An Munkan Technology	China	吉安満坤科技	-0.3%	192	186	mankun.com
92	Jiangxi ZLE	China	江西中絡電子	7.5%	169	182	zlepcb.com
93	Toppan Printing	Japan	凸版印刷	28.6%	140	180	100% IC packaging substrate
94	Summit Interconnect	US	Summit Interconnect	24.1%	145	180	Bought Royal Circuit in 2022
95	Oki Printed Circuit	Japan	沖PCB	8.5%	165	179	OKI Printed Circuit & Circuit Tech merged
96	Dongguang Hongyuen	China	東莞康源電子	33.7%	133	178	hongyuen.com, expanding
97	Liang Dar	TW/China	良達科技	6.1%	165	175	Two plants in Taiwan and one in China
98	Haesung DS	S. Korea	해성디에스	35.2%	125	169	haesungds.co.kr, Leadframe & PKG Sub
99	Brain Power	TW/China	欣強科技	7.7%	156	168	Plant only in China
100	Changzhou Auhong	China	常州澳弘電子	21.4%	138	167	czauhong.com
101	Jiangsu Suhhang	China	江蘇蘇杭電子集団	18.4%	140	166	suhang.com.cn
102	Glorysky	China	惠州市特創電子	40.9%	118	166	glorysky.de
103	Shihui Fushi	China	四会富仕電子科技	61.4%	102	164	fujiprint.com; collaboration with CMK
104	Xusheng Electronics	China	江西旭昇電子	13.1%	145	163	xushengpcb.com
105	Hyunwoo	S. Korea	현우	29.0%	135	162	?
106	Jiangsu Difeida	China	江蘇迪飛達電子	27.5%	124	159	dfd338.com/cn
107	Sichuan Intronics	China	四川英創電子	11.0%	111	157	iqpcb.com
108	TLB	S. Korea	티엘비는	-3.1%	162	157	New plant in Vietnam
109	Amphenol PCB	US	Amphenol PCB	6.9%	145	155	Plants in the US, UK and China
110	KSG	Germany	KSG	27.0%	122	155	Plants in Germany and Austria
111	Longyu PCB	China	龍宇電子	51.3%	102	154	longyupcb.com
112	Jiangxi Union Gain	China	江西聯益電子科技	23.2%	124	154	uniongaincn.com
113	CHPT	TW/China	中華精測科技	0.8%	152	153	Maker of probe cards & burn-in boards
114	Kunshan Wanzhen	China	昆山万正電路板	-4.5%	155	148	wzpcb.com
115	Schweizer Electronics	Germany	Schweizer Electronics	25.0%	117	146	80% automotive, plants in Germany & China
116	SZ Xinyu Tengye	China	深圳新宇騰跌電子	-0.5%	145	144	zefpc.com
Top 74-116 Total				**21.2%**	**6,767**	**8,198**	

In $US million. Source: N.T. Information Ltd., July 4, 2022

TABLE 3. PCB Fabricators in 2021 with Revenue ≥$100M (Continued)

Rank	Maker Name	Nationality	Local Name	YoY chng	2020	2021	Brief Comments
117	Theme Int'l Holdings	China	栄暉国際集団	51.6%	95	144	?
118	Trustech	China	全成信電子	25.0%	112	140	trusttechpcb.com
119	New Flex	S. Korea	뉴플렉스	6.1%	131	139	FPC & FPCA; plants in S. Korea & Vietnam
120	SDG Precision	China	三德冠精密	-0.2%	140	137	sdgprecision.com
121	Plotech	TW/China	柏承科技	15.3%	118	136	HDI
122	Welgao	China	江西威尔高電子	46.3%	92	134	welgaopcb.com
123	Yamamoto MFG	Japan	山本製作所	24.8%	105	131	High-layer-count MLB
124	Jia Li Chuang (Zhuhai)	China	先進電子(珠海)	80.0%	72	130	jlc.link
125	Zejiang Leuchtek	China	浙江羅奇泰克科技	96.0%	65	128	leuchtek.com.cn
126	Fuchnagfa	China	信豊福昌発	25.5%	102	128	fcfpcb.com
127	Aikokiki	Japan	愛工機器	10.7%	112	124	Bought one of Kyocera's plants, PKG Core exp.
128	First Hi-Tech	TW/China	高技企業	35.2%	90	122	fht.com.tw
129	HT Circuit	China	永捷電子	22.2%	96	117	HT Electronic Tech (Tianjin)
130	Benlida PCB	China	江門奔力達電路	8.1%	107	116	benlida.com
131	Concord Electronics	China	江蘇協和電子	9.2%	96	115	xiehepcb.com
132	Shenzhen QD Circuit	China	深圳強達電路	39.8%	79	111	qdcircuits.com
133	SZ Jing Cheng Da	China	深圳精誠達電路科技	15.8%	95	110	jcdpcb.com
134	Tianjin Pulin	China	天津普林	52.9%	72	109	HDI
135	Kingbrother	China	深圳金百澤電子	20.2%	91	109	kingbrother.com
136	Tonglin Anbo Circuit	China	銅陵安博電路板	46.7%	74	108	onhole.com.cn
137	Longteng Electronics	China	湖北龍騰電子	52.0%	70	107	ltepcb.com
138	ACCL	TW/China	博智電子	-0.4%	105	105	accl.com.tw
139	Gangzhou Beyond PCB	China	贛州超跌	28.3%	83	104	en.pcb-beyond.com
140	Kingshen	China	贛州金順科技	15.0%	91	104	jskingshenpcb.com
141	Kunshan Huaxing	China	昆山華新電子	34.3%	77	103	kshuaxin.com.cn
142	APCT	US	APCT	14.4%	90	103	Consisting of four units
143	Dingcheng Electronics	China	深圳鼎成億鑫電子	6.3%	96	102	?
144	Sanwa Electronics Circuit	Japan	三和電子サーキット	5.2%	96	101	Wide variety of PCB up to high-layer MLB
145	Shinko Manufacturing	Japan	伸光製作所	7.4%	94	101	Subsidiary of Sumitomo Mining
146	Shin Asahi Denshi	Japan	新旭電子	12.2%	90	101	SSB and HDI
144	Sanwa Electronics Circuit	Japan	三和電子サーキット	5.2%	96	101	Wide variety of PCB up to high-layer MLB
145	Shinko Manufacturing	Japan	伸光製作所	7.4%	94	101	Subsidiary of Sumitomo Mining
146	Shin Asahi Denshi	Japan	新旭電子	12.2%	90	101	SSB and HDI
Top 117-146 Total				**24.1%**	**2,836**	**3,519**	
NTI-100 Total				**19.8%**	**144,256**	**172,771**	**Growth areas: IC PKG Substrate & auto PCB**

In $US million. Source: N.T. Information Ltd., July 4, 2022

no company exceeded $1 billion. The top fabricator that year was Ibiden, with $932 million in revenue. A decade ago, in 2012, 13 fabricators had revenue exceeding $1 billion, of which four topped $2 billion.

While the 146 companies on this year's NTI-100 represent only 6% of the estimated 2,400 fabricators in the world, they produced 92% of the output. As we say, the big get bigger every year. Without investment, growth will be limited. There are some unrealistic remarks made that PCB will be replaced by just chips. What do you think? PCB output will continue to increase, at least in the lifetime of this author.

Due to the US-China trade and political tension and supply-chain disruptions in China caused by frequent and prolonged lockdowns, some fabricators are reluctant to put all their proverbial eggs in one basket (China). Work has begun on PCB plants in Malaysia, Thailand and Vietnam. PCB production in 2021 in these Southeast Asian countries, plus production in Singapore and the Philippines, was $7.8 billion. Soon production will exceed $10 billion annually. The rate of growth in China will be larger, however.

TABLE 4 summarizes the top 25 fabricators by country.

Finally, based on NTI-100 2021 data and additional data from Europe provided by data4pcb (Michael Gasch), **TABLE 5** shows the world PCB output in 2021. ❑

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TABLE 4. Top 25 Fabricators in 2021 by Country

Rank	Country	No. of Makers	Share	Total Revenue	Rev Share
1	Taiwan	9	36%	21,819	43.0%
2	China	6	24%	10,989	21.6%
3	Japan	4	16%	8,060	15.9%
4	S. Korea	4	16%	5,744	11.3%
5	US	1	4%	2,249	4.4%
6	Austria	1	4%	1,895	3.7%
	Total	**25**	**100%**	**50,756**	**100.0%**

In $US million. Source: N.T. Information Ltd.

TABLE 5. World PCB Production* by Region

Region	2018	2019	2020	2021
Americas	3,160	3,220	3,200	3,400
Germany	940	841	743	845
Other Europe+Russia	1,330	1,250	1,210	1,370
Africa & Middle East	142	143	120	130
West Total	**5,572**	**5,454**	**5,273**	**5,745**
China	42,430	45,420	49,280	57,100
Taiwan	8,140	7,850	7,570	11,630
S. Korea	7,415	7,220	6,800	7,200
Japan	5,940	5,830	5,750	6,900
Thailand	3,130	2,810	2,650	3,175
Vietnam	2,700	2,890	2,900	3,010
Other Asia	1,670	1,590	1,450	1,280
Asia Total	**71,425**	**73,610**	**76,400**	**90,295**
World Total	**76,997**	**79,064**	**81,673**	**96,040**

*Production includes assembly by PCB makers, particularly FPC. In $US millions.
Sources: N.T. Information Ltd., Europe by Michael Gasch; June 30, 2022.

Material Gains, continued from pg. 28

mately, that information can reveal much greater and deeper insights into our surroundings, bringing numerous benefits.

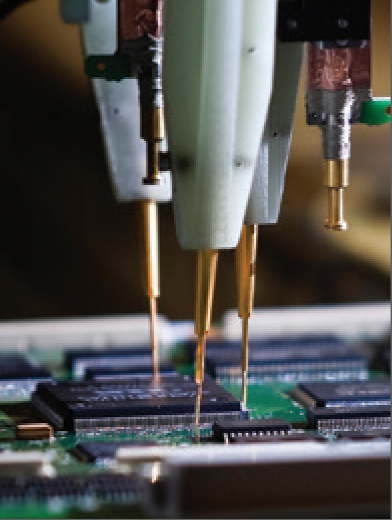
In our post-pandemic world, we can appreciate the opportunity for smarter, healthier buildings in which to live and work. But there is much to come. Some examples include smart agriculture, benefiting from greater intelligence about soil conditions for growing crops and managing water. We can also improve the delivery of healthcare services, such as elderly care with in-home behavioral monitors that can help anticipate changing support needs.

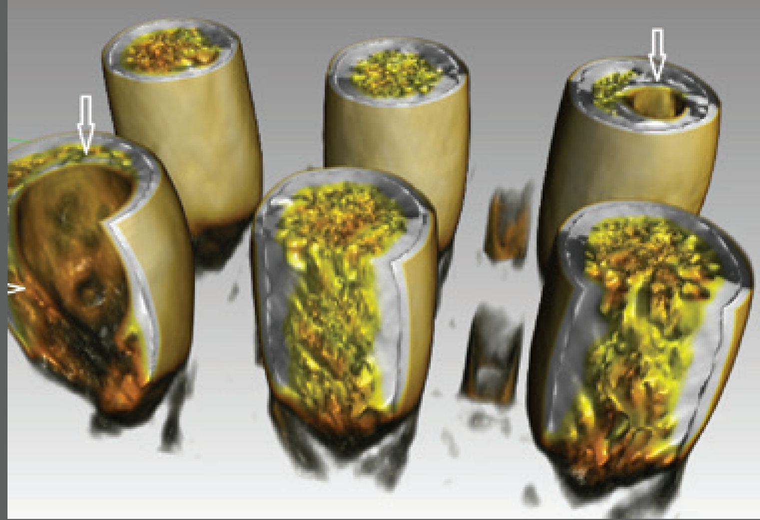
AI has quickly spread from the data center to the IoT edge and, with the advent of machine-learning sensors, is poised to enhance our understanding and control of the world around us to an unprecedented degree. ❑

Flexperts, continued from pg. 30

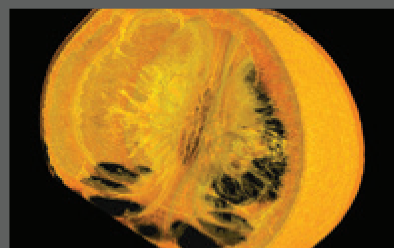
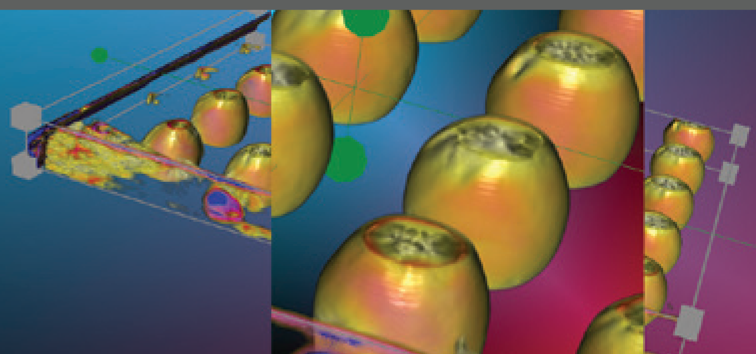
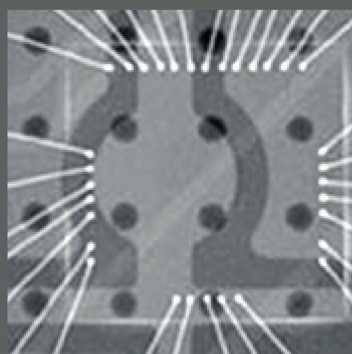
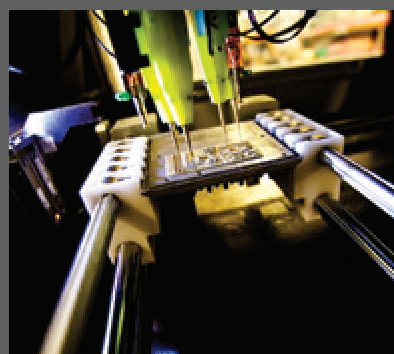
The complexity of these fixtures varies among suppliers, but even the simplest tools are still plenty expensive. Each tool is custom to a specific part, so there is little opportunity for a fixture to be used for multiple parts. Worse, the supplier is going to need a *lot* of these fixtures to assemble the circuits. Each assembly fixture will be tied up through the entire assembly process from component placement through reflow, AOI, and post-cleaning. It is possible that a fixture could be tied up for 15 to 30 minutes or longer per cycle, depending on number of components, queue time, etc. So, the fabricator is faced with either building a small number of fixtures and dedicating significant time to assembly (the cost of which will be passed on to the customer) or, building enough SMT fixtures to effectively fill up the SMT line, and then charge for the additional tools.

It should be noted that flexible circuits can be built with virtually no tooling by using CNC drills and lasers in place of punch tools and flying probe testing in lieu of an elaborate bed-of-nails test fixture. The problem with this approach is that it takes *much* longer to build a flex without tools, so the unit price goes way up. For prototype and small quantity projects, the total cost is usually considerably less if you forego tooling and just pay the added processing time. Waiting until after the parts are qualified is also a smart move because once a tool is built, you own it, for better or worse. If after the prototypes are built a change is necessary – the outline, for example – a new tool must be built (which the customer pays for). Once the flex design is validated, tools can be made without worrying about them immediately becoming obsolete. It is always a good idea to discuss the timing of the tooling build with the flex manufacturer. They can help determine with the best plan for a specific project. ❑






Varied Problems Many Unique Solutions

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Tackling HEAD-IN-PILLOW DEFECTS with Vapor Phase Reflow

An EMS finds VPS dramatically reduced HiP in BGA/LGA connectors. by **HUNTER PULLISHY, SANDY YIMBO and JOSE PINEDA**

Head-in-pillow (HiP) defects are one of the most common issues that affect printed circuit boards containing ball grid array/land grid array (BGA/LGA) packages. These defects can result in costly repairs and reduce a component's lifespan. HiP defects are compromised solder joints often attributed to undesired environmental factors during the reflow process. These factors include reflow in an oxygen-filled environment, exposure to temperatures surpassing a component's thermal limit, and uneven thermal distribution across the PCB.

Exploration of innovative reflow processes has led to the renewed adoption of vapor phase soldering within electronics manufacturing. Vapor phase soldering introduces an oxygen-free environment and a unique heating process that could address the cause of HiP defects. Collecting images and data from a reflowed BGA/LGA hybrid connector in a convection oven, then using vapor phase soldering (VPS) for rework, we investigated whether vapor phase reflow addresses this defect. The data showed a noticeable improvement in solder quality, as well as increased coplanarity after vapor phase rework. These findings offer preliminary support for the benefits offered when reflowing PCBAs using VPS.

BGA/LGA hybrid connectors function much like the human body's nervous system. They permit the microprocessor – the brain – to interface with all other components on the PCBA. The sensitive digital cortex has a low tolerance for faults, and a PCBA without its brain is little more than some copper and silicon.

One common fault that threatens a system's integrity is the head-in-pillow defect. These defects have become increasingly common with the adoption of lead-free alloys in BGA-style components. Although HiP defects can result in immediate intermittent failure of a PCBA, the more common outcome is a failure in the field due to moderate or thermal stress. The defects tend to form during the reflow process, and a few factors that often contribute to their formation include exceeding a component's thermal limitations, the unequal distribution of heat during reflow, and exposing a component to an oxygenated environment. This less-than-ideal environment, and the subsequent development of HiP defects, has plagued the industry for years.

Before the late 1980s, the preferred reflow method was VPS because of its enhanced heat transfer capabilities.[1] Speculation over its negative environmental impact, however, led to the abandonment of vapor phase technologies in mainstream electronics manufacturing. Modern innovations in the vapor phase reflow process have resulted in the adoption of perfluoropolyethers (PFPEs), which have a reduced environmental impact. This has caused a resurgence in the use of VPS in many industries, especially those with low tolerance for electrical failures.

The changes in the reflow process between convection and vapor phase put into question which process is more favorable regarding HIP defects. Research by Leicht and Thumm indicated the reflow environment observed when using VPS reduced the conditions that cause HiP defects.[2] To investigate the impact of changing the reflow environment, a comparison was made between convection and vapor phase processes. The discrepancy between the two processes supports the conclusion that using vapor phase technology reduces HiP defects, addressing its key causes and making it an effective countermeasure.

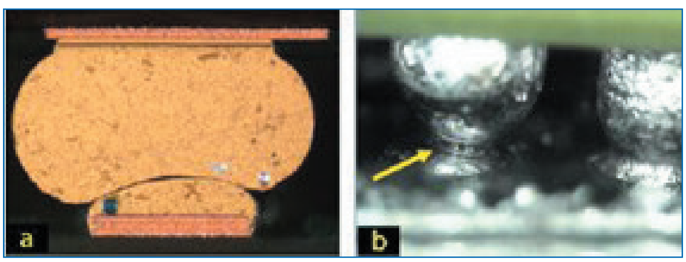

FIGURE 1. Example of a head-in-pillow defect where image A is the optical micrograph of a solder joint. This defect is likely caused by an oxide layer forming between the pad and lead. Image B is the side view of the HiP defect affecting a BGA solder ball.[3]

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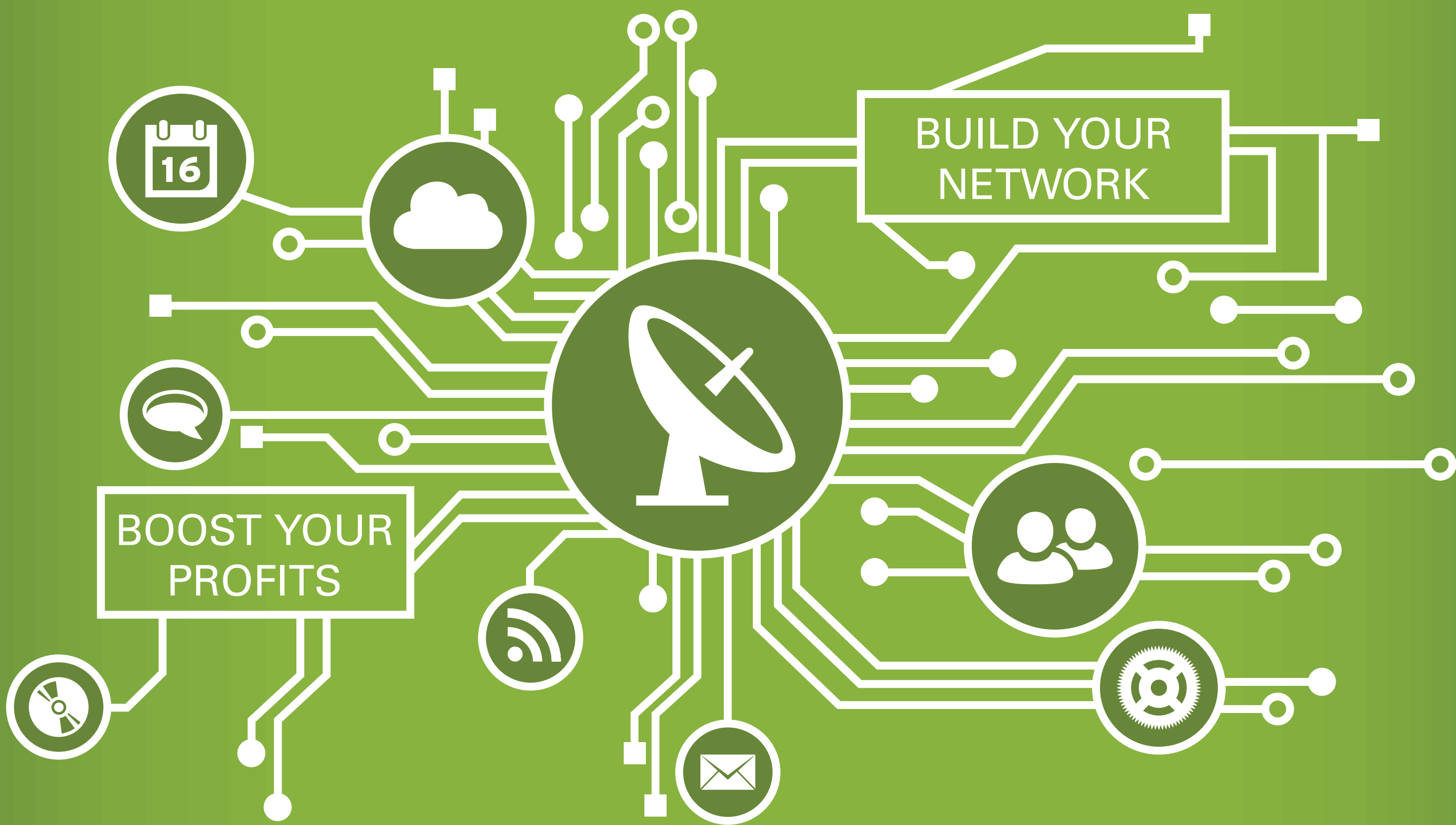

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The HiP Defect

As illustrated in **FIGURE 1,** head-in-pillow defects are mechanically weakened solder joints. These defects are most common on BGA/LGA-style packages. They often retain electrical integrity, which permits them to pass functional tests. Yet, they still result in in-field failures.[4,5,6] These failures are due to mechanical or thermal stresses exerted on the defective component. Due to the nature of BGA packages, these defects can be costly.

Many factors can result in HiP defects. One of the primary causes is the occurrence of a common solder defect known as poor wetting.[4,5] This issue is often the result of oxidation during the soldering process. Oxidation is the chemical reaction between oxygen molecules and exposed metal that results in the formation of oxide layers. These layers cause imperfections in the solder joints that lead to the aforementioned defects. Traditionally, flux is used to break down these oxide layers, albeit without complete effectiveness.

Another factor that can cause HiP is warpage. Warpage is the deformation of the components or the PCB.[5,8] Different materials expand at different rates when exposed to high temperatures. This is exaggerated if the heat is disproportionately distributed across the surface of the material.

As PCBs and components are soldered, they undergo a heating cycle that uses different temperature zones to gradually heat the PCBA. This can lead to uneven thermal distribution, as one end of the PCBA is heated before the other, subsequently leading to PCB warpage. The different temperature zones require a higher peak temperature, as the PCB must be held above the solder paste's melting point for up to 30 seconds. This is often achieved by increasing the maximum applied temperature up to 35°C, per the solder paste manufacturer's specifications. The use of this overhead is to ensure thicker PCBs and high-mass components reach and exceed the solder paste's melting point.[2] Applying peak temperatures of this magnitude disrupts the functionality of BGA/LGA-style packages due to the component's internal material composition. These higher temperatures often exceed the limitations of the component, which cause it to unevenly expand and subsequently warp. As the PCB and/or component warp, the solder balls disengage from the pads. This leads to defective solder joints, as either oxides form in between the pad and ball, or the pad and ball cool at different rates and fail to form a proper solder joint (Figure 2). Both these effects lead to the creation of HiP defects.

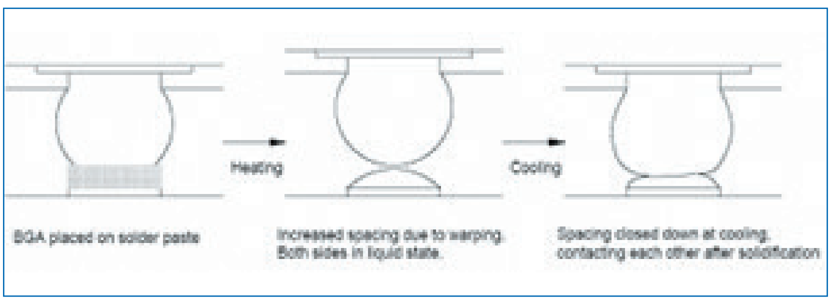

FIGURE 2. Diagram representing one cause of HIP defects. As the solder melts, the land pad and BGA ball disengage. After the solder starts cooling, they make contact again, yet do not form a bond.[7]

What is Vapor Phase?

Dr. Robert C. Pfahl at Western Electric developed the vapor phase reflow process in 1974.[2] Widely used in the early '80s, vapor phase reflow was the process of choice because of its exceptional thermal transfer characteristic. In 1987, around the time of the adoption of the Montreal Protocol, the technology was cast aside over environmental concerns. This policy banned the emission of chlorofluorocarbons (CFCs), which, at the time, were the favored chemical used for the vapor phase process. Infrared and convection ovens replaced vapor phase reflow in mainstream manufacturing. The process became limited to the production of more difficult assemblies, such as PCBAs with higher mass components or PCBAs with a mix of high- and low-mass components. Today, VPS has addressed the ban on CFCs and instead uses non-toxic PFPEs.[2] The process is primarily found in industries with a low tolerance for defects, such as aerospace or defense.

The vapor phase reflow process, illustrated in **FIGURE 3,** works by using an inert chemical as a heat-conducting medium. The PCBA is placed in a chamber above the inert chemical, commonly Galden PFPE in liquid form. The Galden PFPE is then heated to form a layer of vapor that displaces the oxygen due to its higher density. The PCBA gets lowered into the vapor layer, permitting the vapor to encapsulate it. As the vapor contacts the PCBA, it forms a film of condensation. This film acts as a layer of protection against oxidation, while simultaneously conducting its thermal energy.[2,9] The vapor continuously condenses, constantly renewing the protective film and further conducting heat. As the film encompasses the PCBA, it homogeneously transfers heat. The transfer of thermal energy to the PCBA is also more efficient, which permits manufacturers to employ a lower overhead temperature during reflow. Vapor phase has a max peak temperature dependent on the type of chemical used. This controlled peak temperature, coupled with an improved thermal transfer process, allows it to target the solder's specified reflow temperature to within a couple degrees.[2] Overall, this low temperature process reduces the risk of thermally sensitive components warping during reflow, especially BGA/LGA-style packages.

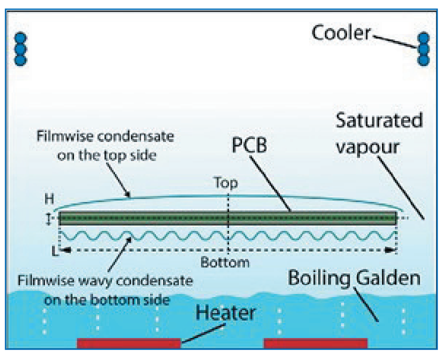

FIGURE 3. Diagram representing the process of vapor phase reflow. Vapor condenses to form a film around the PCBA, which protects it from oxidation. This film continues to be replaced as more vapor condenses. This process heats the board as the hot vapor undergoes conduction with the PCBA.[10]

VPS Effect on HiP

The major benefit of vapor phase reflow is its ideal soldering environment compared to that of the convection reflow process. Because this ideal environment is oxygen-free, it eliminates any chance of oxidation, while also permitting homogeneous heating of the PCBA. In traditional convection ovens, the PCBA is gradually heated as it passes through different temperature zones, which causes different parts of the board to experience unequal levels of heat. When using vapor phase reflow, the Galden PFPE film distributes heat evenly, which reduces the chance of warpage. Additionally, the process has a limited peak temperature due to the type of Galden PFPE used. This low-temperature solution is only viable as the heat transfer process is much more efficient and accurate with vapor phase reflow. Overall, this process addresses the primary environmental factors that cause HiP defects.

Experimental Methodology

To demonstrate the capabilities of vapor phase reflow, one can look to a real-world application of the process. A client requested services regarding an issue they encountered during PCBA manufacturing. Post-production, five to 10% of the batch of boards had a HiP defect, and the client wanted to rework the PCBAs. Vapor phase reflow was used to repair the defects, and a comparison, before and after the rework, reveals the differences between the processes. (The solder on the PCBA was RoHS-compliant and lead-free.)

Starting with the convection reflow process, a PCBA containing a BGA/LGA connector was reflowed and, subsequently, developed HiP defects. Once it arrived in the facility, it underwent functional testing, which resulted in intermittent failures of the component. Images of the connector's solder joints were taken, in addition to a delta height measurement. The delta height measurement is the difference between the height of either side of the component relative to the plane of the PCBA substrate **(FIGURE 4)**. This measurement can be used as an indication of coplanarity and assist in the analysis of HiP defects. Data were recorded for each side of the connector **(TABLE 1)**.

The defective BGA/LGA connector was then reworked using the vapor phase reflow process. Both images and delta height measurements of the reworked connector were taken and recorded. **FIGURE 5** compares the difference in solder ball quality between the results from the convection reflow process and the vapor phase reflow process.

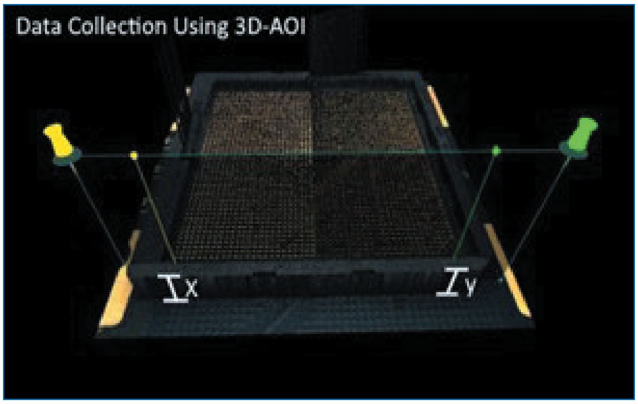

FIGURE 4. Image seen in 3-D AOI during inspection. Measurements x and y were taken relative to the plane of the PCB. Delta height is the difference between the x and y measurements. These measurements were repeated for each side of the BGA/LGA hybrid connector.

Data Analysis

When analyzing the data, the change in delta height was an indication of improvements in the solder ball quality and, therefore, the lack of presence of a HiP defect. From the results in Table 1, between the convection and vapor phase reflow processes, a large change is noted in the delta height for each side of the BGA/LGA connector. For example, through the convection process, Side A measured to be 113μm, whereas

TABLE 1. Coplanarity Comparison

	Convection (μm)	Vapor Phase (μm)
Side A	113	1
Side B	143	2
Side C	199	9
Side D	134	46
Average	**147.3**	**14.5**

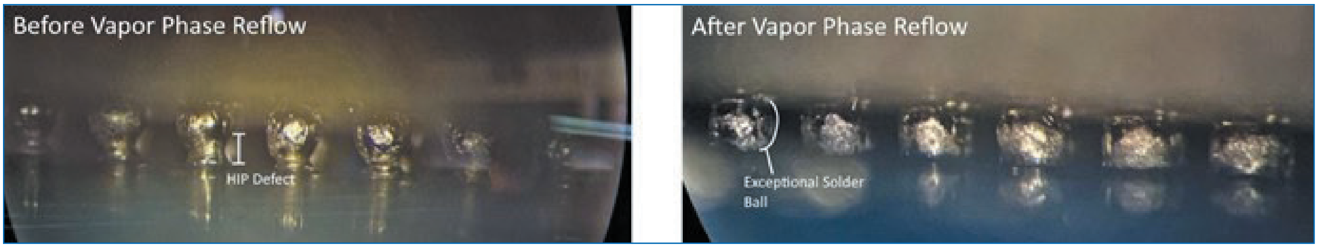

FIGURE 5. Two images of solder joints of a BGA/LGA hybrid connector. The left image is after the convection oven reflow with HiP defects. The right image is after the vapor phase rework. Inspection of the solder balls revealed elongated solder joints and HiP defects. After the rework, the solder joint formed an exceptional solder ball.

through the vapor phase process it was 1μm, a 112μm decrease in the delta height measurement.

Using these results, we calculated the average delta height of the components for each process. Overall, a difference of 132.8μm was recorded in the delta height – a 90.2% decrease, which indicates a drastic increase in coplanarity. A visual inspection of the solder balls after rework showed all solder bonds greatly improved. Functional testing revealed the component was operating as expected. These results can be attributed to the VPS process. The increase in coplanarity is likely a result of even heat distribution and low temperature peaks, which limits the warpage and permits concurrent solder bonding. The increased coplanarity assists in the reduction of HIP defects, as solder joints don't stretch to connect leads to the PCB.

Limiting the stretching also reduces the amount of solder and pad that is exposed to oxidation. Along with limited exposure is the elimination of an oxygenated environment. The protection against oxidation enables an ideal reflow environment. Results indicate vapor phase reflow improved the reflow environment and eliminated HiP defects.

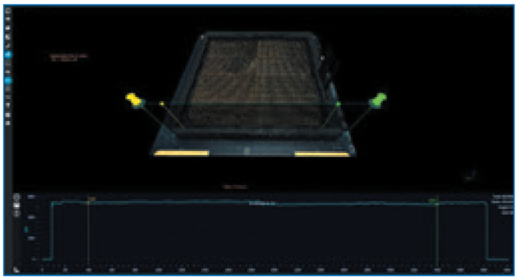

FIGURE 6. 3-D AOI rendered image of side A before rework. Calculations made by pins seen in image.

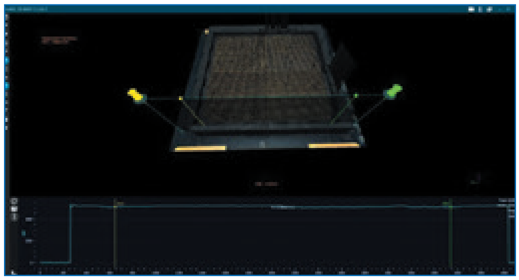

FIGURE 7. 3-D AOI rendered image of side A after rework. Calculations made by pins seen in image.

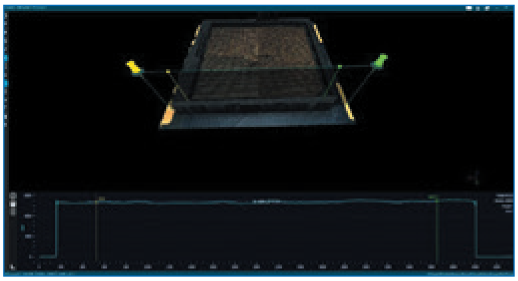

FIGURE 8. 3-D AOI rendered image of side B before rework. Calculations made by pins seen in image.

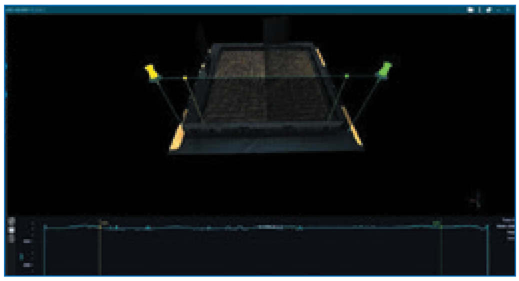

FIGURE 9. 3-D AOI rendered image of side B after rework. Calculations made by pins seen in image.

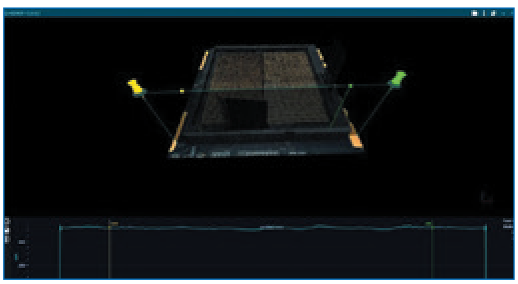

FIGURE 10. 3-D AOI rendered image of side C before rework. Calculations made by pins seen in image.

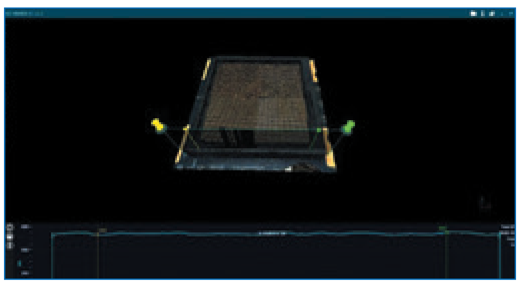

FIGURE 11. 3-D AOI rendered image of side C after rework. Calculations made by pins seen in image.

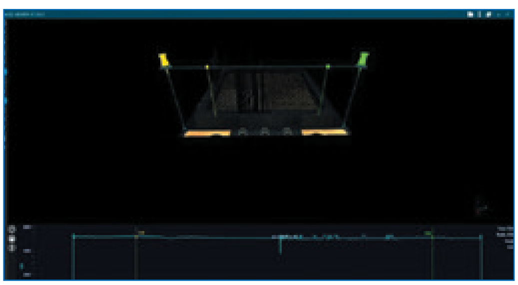

FIGURE 12. 3-D AOI rendered image of side D before rework. Calculations made by pins seen in image.

FIGURE 13. 3-D AOI rendered image of side D after rework. Calculations made by pins seen in image.

Conclusion

Using data collected during the rework of a defective BGA/LGA hybrid connector, we analyzed attributes of vapor phase soldering that benefit the manufacturing of PCBAs. The oxygen-free environment, low temperature process, and even heat distribution emulate an optimal reflow environment. This environment is extremely useful in tackling head-in-pillow defects both during the manufacturing and rework of PCBAs. The ability to rework and prevent these defects ensures the longevity of electrical devices and lessens constraints placed on PCB designers. Vapor phase reflow is a promising solution to the dreaded HiP defect. ▫

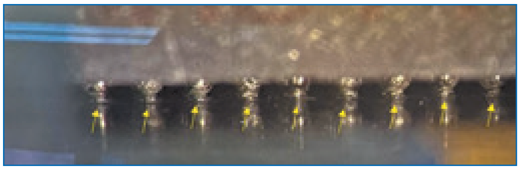

FIGURE 14. Side A solder balls before VPS rework.

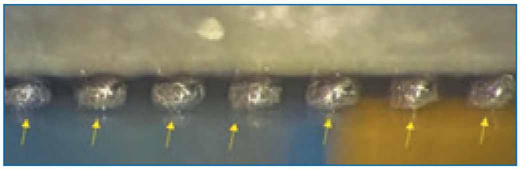

FIGURE 15. Side A solder balls after VPS rework.

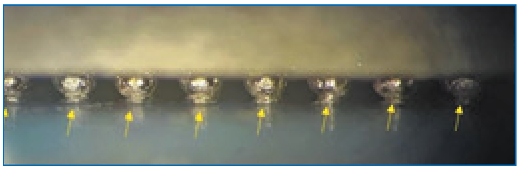

FIGURE 16. Side B solder balls before VPS rework.

FIGURE 17. Side B solder balls after VPS rework.

FIGURE 18. Side C solder balls before VPS rework.

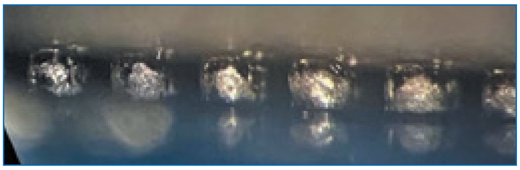

FIGURE 19. Side C solder balls after VPS rework.

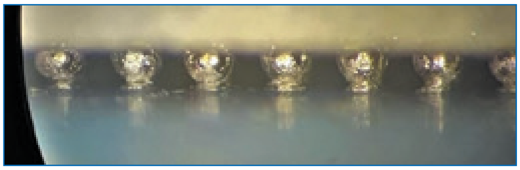

FIGURE 20. Side D solder balls before rework is done by vapor phase soldering

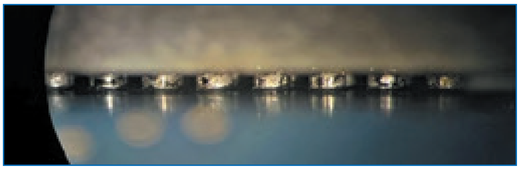

FIGURE 21. Side D solder balls after rework is done by vapor phase soldering

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M2M COMMUNICATION is Here. Do We Still Need Judgment Calls?

Data-driven processes require IP coordination among vendors – and that means humans. by CHELSEY DRYSDALE

We hear a lot these days about smart manufacturing, but is there a broad consensus on what it means, and more specifically, its application in electronics assembly?

Brian Morrison, vice president of engineering for Vexos, a mid-tier multinational EMS with manufacturing facilities in the US, Canada, China and Vietnam and more than 900 employees worldwide, explains his views on smart manufacturing to PCD&F/CIRCUITS ASSEMBLY in July.

Chelsey Drysdale: Let's get this out of the way first: How do you define "smart manufacturing?"


Brian Morrison

Brian Morrison: To me, smart manufacturing is essentially a methodology that leverages equipment software and integration protocols that allow continuous feedback to the process. Basically, it's the ability for us to use the equipment and data to have the owners act, react, execute and adjust non-value-added activities and optimized production. For me, in order for something to be smart, the process must be divided with targets. That means to monitor, report, detect nonconformities and be able to make adjustments based on those data.

CD: If one views smart manufacturing as "automation and computer systems to detect deviations from the norm," what are assemblers doing in this regard beyond what is available off the shelf?

BM: I think what you hear is a lot of AI. Everyone is coming out of the cloud, and they're saying "data management" – and there's more data. I think as we get more intelligent with the equipment we have, the more data are available. You'd be able to use that data to actually make a judgment based on what is actually critical.

With normalization of the data, I know the manufacturers are coming up with CAMX and IPC standards to be able to communicate between equipment and software to make that available. I think the real differentiations between what's considered a smart manufacturing facility and something else is the ability to use that data and make adjustments to your manufacturing, and I think that's what a lot of people are doing nowadays: integration; software; decision-making; upstream and downstream feedback.

Mike Buetow: Brian, to follow up on that, that really becomes part of your IP, right? The ability of an individual company to not just collect that data, which everyone's doing, but then how you process that data and put it into action would really become your IP.

BM: That's absolutely correct. With equipment and software becoming smarter, it's becoming a lot easier now. I think the more challenging part is that manufacturers nowadays have a mix of older and newer technology, so being able to use all those different inputs to basically go in – you're absolutely right – requires IP coordination with the manufacturers and software providers to do that. I've been in a number of calls where I've had competitors on the line to basically work together to create that IP and make a manufacturing solution that makes us competitive, and the results are outstanding to the point where we have equipment talking to each other, knowing what's going on and able to react whenever something's needed.

MB: Does that conversation tend to get initiated by the assembler, or does it tend to come from the equipment manufacturer or the software supplier that recognizes a similar problem across multiple or maybe several of their customers?

BM: I've never seen where an equipment manufacturer reached out to another one. Although it is rare, some manufacturers

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are moving toward adopting a standardized format to facilitate communication, but typically [these requests] come from the manufacturer: "I have a need. I need equipment A to talk to equipment B. They don't have an interface available. This one has output D that doesn't work with C. How do we make those things work?" I think a lot of it is collaboration, from the assembler bringing the parties together, coming to a mutual agreement, and a common place. What will happen is with the IP we generate, the manufacturer and software vendor will see the value in it because other assemblers had asked the same thing, and we'll work together to provide that level of smart integration, and they'll actually sell it to the next customer, and it just becomes a great working relationship.

CD: How do you balance the cost of implementation of additional software or machines with the cost of operators and the annual volume of product being built? For smaller run production, is smart manufacturing even feasible?

BM: It all starts with a value-stream mapping. You have to take a look at your current process: How are you doing it? Where are the areas of improvement and productivity as they relate to quality, cost, waste, etc.? Those are lean elements that drive the opportunities.

From there, what you need to do is take a look and say, "Okay, what are the solutions?" Usually that is software or equipment, which could be capital; it could be someone's time, or it could be operators. How do I eliminate high-cost operators in a high-cost region? Do I put robots in place to do that?

So, I think from a cost of implementation, it's a cost versus benefit, and what we typically do is we look at decisions like what's the cost? But in addition to that, what is the risk? What's the timeline? What are the resources, and what's our benefit?

Do you want on the smaller run versus larger? Whenever someone thinks automation, they think of automotive: single SKU, millions and millions of these things optimized all day. But actually, we are in a small manufacturer's world, high-mix, low-volume in some cases. We do a lot of prototypes. If you don't do automation and smart manufacturing, you're not competitive. You need to make sure you are leveraging all your changes, looking at your changeover [times], and being able to collect all the data where you may not run a product for six months to be able to find out what you did here and what the next one was six months ago to determine [whether] you [made] an improvement or not to make a decision for the next corrective action to go from there. Having that data and being able to look historically to make decisions in the future are really important. That could be low-cost. It could be simply software. It could be MES. It could be data collection. It could be connecting to equipment, so it doesn't have to be costly to get the benefits.

MB: We've heard a lot over the past few years of the so-called digital twin, which is basically a virtual model designed to accurately reflect the physical version of that same object. How much of smart manufacturing is tied to the use of the digital twin?

'I'M VERY ENCOURAGED WITH WHAT EQUIPMENT MANUFACTURERS AND SOFTWARE MANUFACTURERS ARE DOING TO BRIDGE THE GAP.'

BM: One of the things that we embrace from our perspective is what we call the essence of DFX, or what we used to call virtual prototyping or using models to make decisions, the ability to transform virtual data into a physical model that we can actually perform analysis on.

We usually look at it for assembly, test, fit; we use ECAD and MCAD to take a look at those models and find the opportunities as they relate to design rule checks and then make decisions on new product introductions. A key factor to using this digital twin is what helps us make good decisions [for our customers] of changes they should make before we even order a single part or release a single PCB or place a part on the board. It's really a differentiation. It costs no money, and it allows us to integrate at the time when they can make changes.

'Leveraging CFX-QPL to Integrate Equipment and Create a Smart Factory'

Leveraging IPC-CFX, companies can use AI-powered technology to help manufacturers realize a smart factory. These tools collect factory data on defects, optimization, traceability, and more to improve metrics, increase quality, and lower costs. Yet, successful CFX implementation on the shopfloor requires confidence that equipment has been qualified to IPC-CFX using the QPL certification platform.

At PCB West in October, Ivan Aduna of Koh Young will explore how the inspection equipment OEM successfully applies real-time data to improve the production process by converting data into process knowledge using CFX and other software tools. Combined with IPC communication standards, the gates to a smart factory are open to anyone.

Aduna's presentation is part of "Free Wednesday," a series of nine free technical presentations on Oct. 5 at the Santa Clara (CA) Convention Center. See pcbwest.com for details.

Smart manufacturing relies on data-driven machine-to-machine bidirectional feedback.

CD: It sounds like smart manufacturing and Lean manufacturing really intersect.

BM: I think the elements of Lean are what drive us to smart. I think a lot of people look to smart because the elements of waste within Lean drive that. You look at your process. You look at where your elements of waste are. You apply elements of smart to address that as an optimal solution, either through equipment or software. In my mind they're analogous in terms of one leads to the other.

CD: How do we use the tools available today to reduce defects that are inadvertently designed-in? For instance, tombstoning can be the result of surface tension imbalance due to unequal lands. Or perhaps it can be caused by mounting passive parts over a via, whereby the pad with the via heats faster due to the lower thermal mass. Are these issues best addressed in the DfM rules? Or does smart manufacturing have a role to play?

BM: One of the things we do is identify opportunities and risks in manufacturing. We talked a little bit about the digital twin, so being able to predict the risks of the product, identifying where potential problems may occur. DfM is an element, but also there's a supply chain risk: What are discontinued, end-of-life, not recommended? There are elements of the land pattern, as you've alluded to – vias and pads clearance, as well as the test access and other strategies open to improvement. By going through that risk and determining where we are and running it through manufacturing using the smart information to determine whether our predicted units will have a problem, and then validating that, making corrective actions, and integrating that, is part of our continuous improvement.

MB: If you think of smart manufacturing as something of a spectrum, where we are somewhere between the embryonic stage and fully mature, where is the electronics assembly industry on that spectrum right now?

BM: I'm pretty optimistic about where we're going. I'm very encouraged with what equipment manufacturers and software manufacturers are doing to bridge the gap, which wasn't there before. Equipment manufacturers didn't want to talk to one another. I think nowadays they realize talking to one another is the essence of us being competitive and moving the industry forward. I would say we are closer to sustainability, almost mature, on the upper echelon, at least from where we were from about 10 to 20 years ago. I think we're almost there. It's going to take a while because people are still a little bit hesitant to jump on board, but I think we're almost there. □

CHELSEY DRYSDALE is chief content officer of PCEA (pcea.net); chelsey@pcea.net.

How to Troubleshoot an Amber Printing Process

The top eight fixes in the fishbone diagram to get back in spec.

THE LAST COLUMN focused on making a "green light" stencil printing process more efficient, but for a not-so-green – maybe a bit more amber – print operation, some tried-and-true troubleshooting methodologies can get high-yield boards moving again. As I've noted before, myriad stencil printing inputs can affect outcomes. The famous fishbone diagram, noted in **FIGURE 1**, can seem daunting at first, but by taking a methodical approach to understanding the root cause of a problem, it's relatively straightforward to get printing back in spec.

The first question to ask is, "Has the process ever been good?" This is especially important for a legacy product. If the answer is "yes," then retracing steps using the fishbone diagram, along with some tacit knowledge, can point you toward what may have changed to move the results out of spec. Of course, this same checklist can work for a new product too. While many elements are in the fishbone diagram, the below represent my top eight most likely culprits and fixes:

1. Machine calibration. Check the date of the last machine calibration. In my experience, probably eight of 10 machines require calibration after they are released onto production floors. If the calibration is out of date, do it! And, if it has been calibrated, but you are seeing issues, check the onboard systems to ensure nothing has gone awry with the machine.
2. Product program. It's not that uncommon to see the wrong program loaded for a specific product, especially if the fiducials and board size are the same (and that's not the printer's fault, really), though other requirements may be different. To ensure you have the proper recipe, check that the parameters match the instructions, such as those for speed and pressure.
3. Squeegees. The proper squeegee length and angle are critical. Unless you are a printing specialist, the angles can look very similar when loaded on the machine. If the program calls for a 60°, 200mm-long blade, make sure you're not running a 45°, 300mm-long squeegee. This will result in a completely different process. In addition, check the condition of the squeegee to verify flatness and sharpness. The squeegee is doing all the work, so respect the squeegee.
4. Solder paste material. In the rare case a manufacturer uses only one solder paste vendor and one paste type/recipe variant, then half the battle is over because the correct material will always be on hand. This isn't likely, however, especially in an EMS environment. Check the barcodes, confirm metal loading of the material, expiry date and that the paste

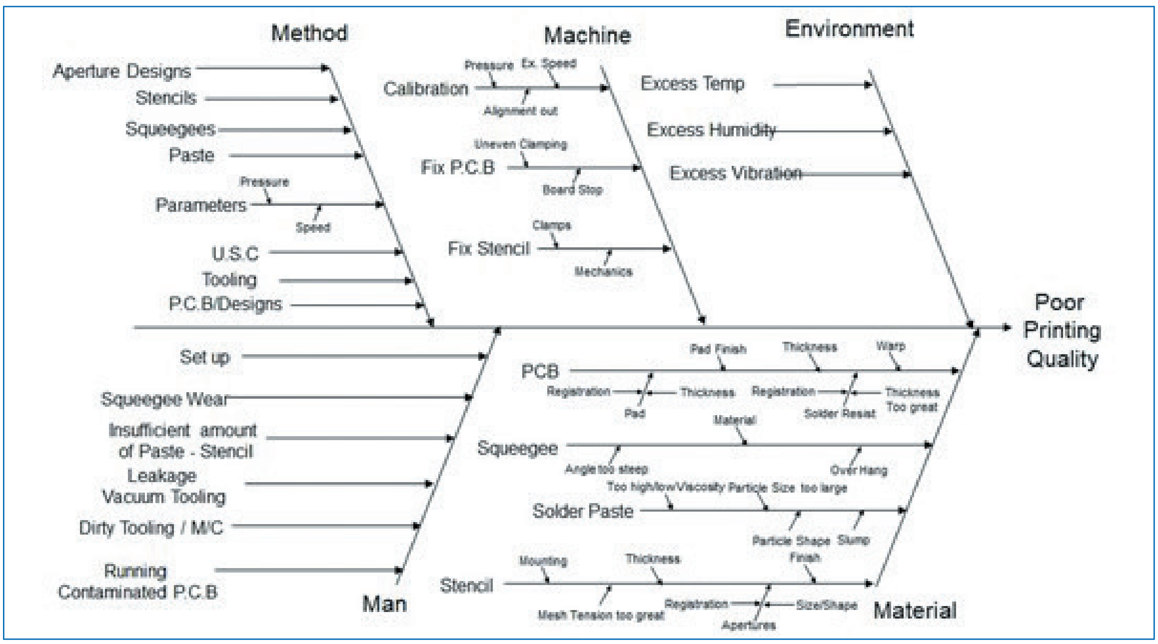

FIGURE 1. Fishbone diagram of factors that influence print quality.

CLIVE ASHMORE is global applied process engineering manager at ASM Assembly Systems, Printing Solutions Division (asmpt.com); clive.ashmore@asmpt.com. His column appears bimonthly.

has been stored properly.

5. Stencil quality. Stencil manufacturing is a variability. It's a manual process; someone has to select the right Gerber and the correct stencil foil blank. When an issue arises in the process and other quality checks have been made, look at the stencil. Measure it, make sure the certificate aligns, and if you have measurement equipment onsite (highly recommended), take a couple of aperture x, y measurements.
6. Tooling. A lot of tooling blocks can accept different products but may not be optimized for all of them. Check the serial number and align with the product identification. Verify the block's height, that it is clear of any debris, and if it's a double-sided assembly, verify that a small component isn't lodged in one of the cavities. With today's dimensions, even microscopic obstacles can affect deposit precision.
7. Understencil cleaner. If the process is running fine and then suddenly there are issues like bridging, the understencil cleaner may be the culprit. Check to see if anything's changed. Are you using different solvents? Different fabrics? Has the fabric been loaded properly for it to advance as needed? The cleaning is a process within a process. It must be optimized for the best results.
8. Printed circuit board (PCB)/substrate. Finally, my top-eight checklist includes the PCB/substrate. An assembly process engineer doesn't have a lot of influence on board quality, but you can verify it. Measure, measure, measure. Confirm proper board dimensions (width, length and thickness), as this can affect everything from clamping to alignment (the biggie!). Even solder mask and nomenclature can affect gasketing if not even or in the right place (in the case of nomenclature).

A systematic approach to resolving the root cause of an out-of-spec printing issue usually does the trick. Change one thing at a time and slowly work through the list. In our data- and stats-driven world, multifaceted analysis is achieved in seconds. Things are a little different on the shop floor, though, where you don't have the luxury of spending the day doing a controlled experiment. Going top down should lead you to the smoking gun and back to green lights. □

ROI, continued from pg. 15

Understand the critical skills that make your business competitive and make sure you are continually developing and cross-training those staff, so even when fraught times occur – and they will – you have a strategy in place to protect your most valuable resources and when business picks up, you are ready to satisfy your customers.

Economic cycles come and go. The electronics industry offers unique capabilities to demanding customers. That requires that managers ensure they are making the best staffing decisions for today and the future. Regardless of whether business is going well or problems are causing serious delays to delivery, investing in solid workers to provide the best customer service is essential. In addition, support both the skilled staff and dedicated customer service staff with accurate, timely communication, so they can be as successful as possible performing their jobs. In the end, your customers will be satisfied and happy. □

Focus on Business, continued from pg. 18

be a requirement for an employee to stay for a set period of time after completing their education. The employer that paid for my master's degree had a program that required employees work the same length of time as their educational benefits, following completion of the program, or pay back the tuition. For example, if the degree program took 18 months, the employee was obligated to stay another 18 months or return the reimbursement money.

Second, employees with the initiative to increase their education are more likely to be retained if they have a defined career path. It is important graduates of these programs understand how that added skills base will help them advance within your company.

Finally, work arrangements are another good retention tool. Three-day, 12-hour shifts are gaining in popularity with employees who like four days off. Four 10-hour days are another option for a compressed workweek. Hybrid remote and in-office administrative jobs are attractive, as are entirely remote jobs. There are challenges managing each of these options, but Covid has increased employee desire for more free time. Eliminating the commute or compressing the workweek achieves that goal. Eliminating the commute is also a form of pay raise with current gas prices. Employees with longer commutes have seen the cost of that commute nearly double over the last year.

None of these suggestions is a magic pill to solve labor challenges. Nevertheless, companies that create a well-rounded promotional strategy, combined with benefits appealing to their target workforce, do better than companies that don't. This is a cyclical problem that will eventually resolve, but until it does, companies need to take a multipronged approach to attracting and retaining good talent. □

AVISHTECH GAUSS STACK PRO SOFTWARE

Gauss Stack Pro software reportedly enhances PCB prototyping and reliability. Goes from stackup to layout in same environment to look at areas of concern from manufacturing, reliability, signal integrity and thermomechanical behavior standpoints. Can input layout files directly into software. Provides detailed, spatial simulation of factors such as glass stop, resin starvation and filler damming. Developers can simulate impact of imbalance of layouts on board level warpage. Stackups and layouts can be visualized and meshed.

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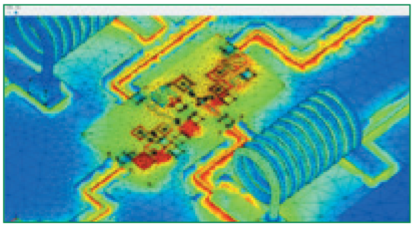

KEYSIGHT PATHWAVE ADVANCED DESIGN SYSTEM (ADS) 2023 RF/MICROWAVE SOFTWARE

PathWave Advanced Design System (ADS) 2023 integrated design and simulation software addresses increasing design complexity and higher frequencies for radio frequency (RF) and microwave designs. Includes enhancements to electromagnetic (EM) simulation for circuit designers. Streamlines integration of multi-technology circuit assembly and simulation into enterprise EDA design workflows. Addresses signal complexity, design densification, multi-technology integration and frequencies moving to 60GHz and beyond.

New features include: Automation of EM-circuit co-simulation setup which ensures that analysis is easily accessible by circuit designers without the help of an EM expert or the need for invasive layout editing. Advanced EM solvers and meshing technologies are accessible via a single unified environment with parallelized simulation acceleration through cloud-based, high-performance computing (HPC) that supports fast, high-capacity simulation. Seamless integration with Cadence Virtuoso, Synopsys Custom Compiler and Ansys HFSS facilitates enterprise electronic design automation signoff workflows.

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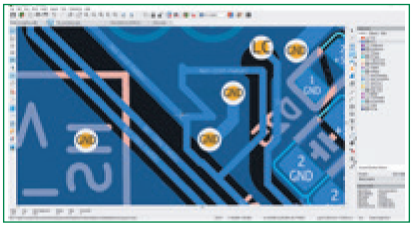

KICAD 6.0.6 PCB CAD

KiCad 6.0.6 EDA software contains bug fixes and other minor improvements, including the following: fix intermittent QA crash; fix stock templates path for flatpack; allow closing PCM progress windows after installation from ZIP file; enable and disable apply and discard buttons in PCM; fix net highlighting between schematic and board editors; fix "select previous symbol" toolbar state in footprint assignment tool; update selection filter title bar with language changes; implement cross-references for labels; resolve title variable when plotting; plot alternate pin definitions correctly; fix library symbol properties dialog tab selection bug; fix duplicate pin number test; fix duplicate messages when updating schematic from PCB; fix blind via visibility issue; fix reference and value variable expansion; change default symbol matching to use UUID instead of reference when back annotating schematic; use correct backside placement angle using experimental Gerber export option; import P-CAD footprints to correct layer; Import Eagle octagonal pads correctly; prevent length and skew tuning dialog values from becoming negative; fix router not on grid issue; maintain visibility state when changing layer count; many router fixes; export microvias correctly to Hyperlynx; and others.

KiCad
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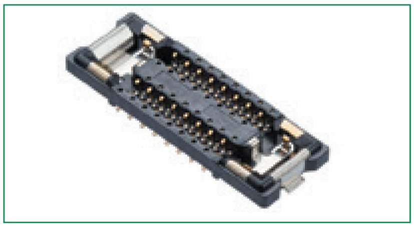
Quad-Row board-to-board connectors feature staggered-circuit layout. Support compact form factors, including smartphones, smartwatches, wearables, game consoles and AR/VR devices. Pins are



positioned across four rows at signal contact pitch of 0.175mm. Adhere to 3.0A current rating. Align with standard soldering pitch of 0.35mm to expedite volume manufacturing using typical SMT processes. Interior armor and insert-molded power nail safeguard pins from damage during volume manufacturing and assembly. Suited for applications requiring small PCBs and flex assembles. Come in 32- and 36-pin configurations with 20- and 64-pin configurations coming soon. Plans are underway to support up to 100-pin counts.

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BD9xxN1 series automotive LDO regulator ICs have stable operation at nanoscale output capacitance. BD950N1G-C, BD933N1G-C, BD900N1G-C, BD950N1WG-C, BD933N1WG-C and BD900N1WG-C are optimized for primary (direct connection to 12V) power supplies in applications including powertrain, body, ADAS and car infotainment. In addition to common µF-order MLCCs (multilayer ceramic capacitors) and large-capacitance electrolytic capacitors, regulators can handle output capacitances down to 1µF or less in 0603/0402 size. Meet basic requirements of automotive products, such as operation above 125°C, qualification under the AEC-Q100 automotive reliability standard, and input voltages greater than 40V for primary power supply. Support output capacitance of 100nF.

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SATURN PCB DESIGN TOOLKIT V. 8.20

Saturn PCB Design Toolkit v. 8.20 includes the following calculators: microstrip; stripline; differential pair; via current; PCB trace current; planar inductor; padstack; crosstalk; Ohm's law; XC XL reactance; BGA land; Er effective; wavelength; and PPM. Incorporates current capacity of

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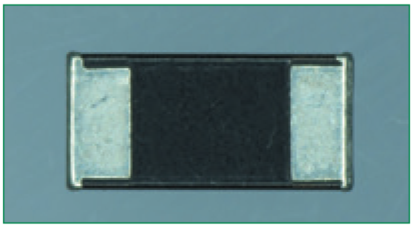

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UCAMCO REFERENCE GERBER VIEWER

Reference Gerber Viewer now includes formal syntax checker. Reports imperfections. Visualizer accepts almost anything following specification. Syntax checker reports syntax errors. Is accessible from any modern web browser.

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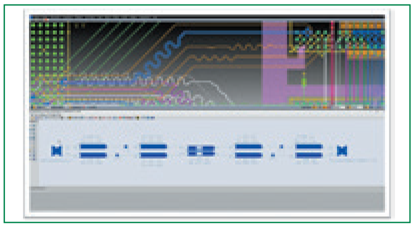

ZUKEN ECADSTAR 2022 ECAD

eCADStar 2022 PCB design software offers advanced capabilities for organization and reuse of designs, fine-tuning of high-speed circuitry, and layout and modification of densely populated PCB layouts through semiautomatic functionality. Organization of large circuit diagrams in schematic application has been simplified with additional support for multi-instanced hierarchy, making it possible to group circuit parts (e.g., multi-channels, like amplifiers) that are used several times in a design into hierarchical blocks. Blocks can be replicated in any number of instances. All instances are updated automatically whenever changes are made to block definition. Library management now has 3-D Model Manager that can import ProStep and other 3-D formats. Models can be organized into sub-folders. Overhaul of Configuration Editor makes it easier to define or edit physical track and layer stack cross-sections for analysis. Users can define etch factors to compensate for impedance variations introduced by inaccuracies in etching process, either for entire designs or for individual PCB tracks, enhancing accuracy of signal integrity analysis, especially for ultra-high-speed differential signals. Bi-directional cross-probe between Electrical Editor and Schematic and PCB has been introduced. Modification of existing layout patterns, such as moving placed components, now supports push-aside, automatically adjusting surrounding components and corresponding routing patterns in real-time. Routing of multi-pad footprint pads, in which single pins correspond to multiple IC pads, is now supported. Component positions can be exported to CSV file for either entire layout or part of it.

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SM-100 smart mixer provides solder paste mixing with real-time quality control and materials traceability. Automatically mixes solder paste jars to fit-for-use state. Monitors temperature, mixing time and fitness. Can mix solder paste directly from cold storage to bring to room temperature. Provides red, yellow and green light indicators of paste quality with reusable lid that attaches to solder paste jar. Reportedly eliminates hand mixing, reduces mix time and ensures repeatability. Mixing cycle provides statistical process control and documentation. Provides insight on paste quality before printing. Measurements correlate to J-STD-005 standards and IPC-TM-650 test methods.

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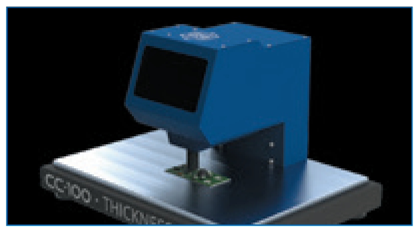


INSITUWARE CC-100 THICKNESS TESTER

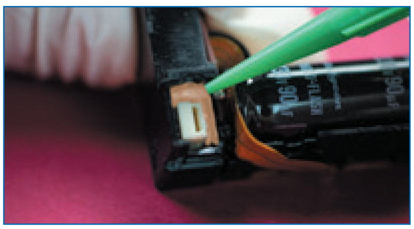
CC-100 thickness tester provides nondestructive and contactless conformal coating thickness measurements. Measures dry thickness of conformal coatings to verify against IPC-A-610 requirements. Measures wet thickness of conformal coatings to provide insight for process adjustments. No ground plane is required. No measurements of uncoated boards required. Multi-coating support: acrylic, polyurethane, silicone, epoxy and UV. Less than 5 sec. measurement time. Reportedly eliminates need for coating test coupons. Local and cloud data storage for traceability and process control.

Insituware
insituware.com

INSPEKTO S70 AUTONOMOUS MACHINE VISION SYSTEM SOFTWARE

Inspekto S70 autonomous machine vision software features recommendations center that guides users to create and maintain inspection profiles and improve process integration and accuracy of inspection. Incorporates profile center, including tools that guide users when adjusting profile. Can compare previous and new profiles for same item. Serves as long-term QA solution. Includes AI-based active recommendations to adapt profile to production changes, either process- or environment-related. Can increase or decrease sensitivity to specific types of defects, while sensitivity to other defects remains unaltered; this can be done by selectively adding defected samples to profile parameters. Can add to profile both good (OK) and defected (NOK) samples for performance finetuning. Can define unlimited regions of interest within part and adjust size and sensitivity thresholds independently for each one. Inspects highly reflective objects regardless of whether inspected item is stationary or moving. Incorporates antireflection technology that can be applied to moving objects as well as stationary ones.

Inspekto
inspekto.com



MASTER BOND EP17TF EPOXY

EP17TF one-part epoxy has paste consistency and can be dispensed evenly and uniformly. Has glass transition temp. of 150°-155°C and service temp. range from -150° to +550°F. Is designed to compensate for thermal mismatches. Resists impact, vibration, shock and rigorous thermal cycling. Is reliable electrical insulator, possessing volume resistivity greater than 10^{15} ohm-cm and dielectric constant of 4.5 at 60Hz at room temp. Maintains electrical insulation properties. Has good toughness with elongation of 5-10%. Exhibits superior strength properties, bonding well to similar and dissimilar substrates such as metal, ceramics, plastics and composites. Offers lap shear strength of 3,200-3,400psi, tensile strength of 8,000-9,000psi and tensile modulus of 350,000-400,000psi at 75°F. Requires elevated temp. cure of 300°F for 5-6 hr., followed by post-cure at 350°F for 4-5 hr. Additional post cure is recommended. Withstands acids, bases, fuels, oils and many solvents. Is available in standard packaging from ½ pint containers up to 5-gal. pails.

Master Bond
masterbond.com

KYOCERA AVX INTERACTIVE COMPONENT SEARCH TOOL

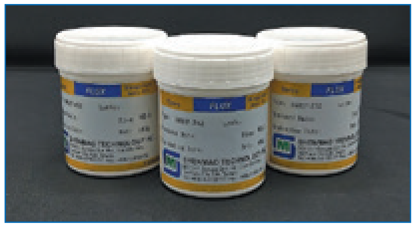
This interactive component search tool is available as a fixed navigation menu option on the Kyocera AVX website and accessible via computer, tablet or smartphone. Explores extensive selection of company's antennas, capacitors, circuit protection devices, filters, couplers and inductors, as well as view and purchase available stock from authorized distributor network. Groups products by technologies and common features. Interface features filtering menus that allow customers to narrow down list of suitable components and clickable product selections represented by component pictures. Once users narrow search to specific product line, they receive list of active part numbers. Clicking one of the part numbers reveals detailed product data, including parameters, descriptive information, downloads such as spec sheets, datasheets, product catalogs and available product stock at authorized distributors.

Kyocera AVX
kyocera-avx.com

PROMATION PANDA 500 CE ROBOTIC SOLDERING SYSTEM

Panda 500 CE robotic soldering system is capable of processing 500mm x 500mm PCB or pallet and deploying vision for fine alignment. Has multiple witness cameras for up-close viewing, dual-touch screen monitors and PCB visual import for programming.

Promation USA
promationusa.com



SHENMAO SMEF-Z52 FLUX

SMEF-Z52 enhanced solder joint encapsulation material flux combines abilities of conventional flux and underfill. Epoxy cures after reflow and provides excellent bonding strength and joint protection. Is active epoxy flux designed for SMT assembly (SAC paste) and BGA ball mount (SAC ball) processes. Activator helps eliminate solder balls and form smooth solder joints. Epoxy flux residue is cured and provides mechanical support to joint after reflow. Reportedly doesn't require cleaning and is compatible with molded underfill and capillary underfill. Is suitable for system-in-package (SiP), wafer-level-package (WLP) and flip chip. Is halogen-free and complies with RoHS, RoHS 2.0 and REACH. Is designed for use in stencil printing, dispensing, jetting, dipping and pin-transfer processes.

Shenmao
shenmao.com

In Case You Missed It

Components

"FlexiCores: Low Footprint, High Yield, Field-Reprogrammable Flexible Microprocessors"

Authors: Nathaniel Bleier, *et al.*

Abstract: Flexible electronics is a promising approach to target applications whose computational needs are not met by traditional silicon-based electronics due to their conformality, thinness, or cost requirements. A microprocessor is a critical component for many such applications; however, it is unclear whether it is feasible to build flexible processors at scale (i.e., at high yield), since very few flexible microprocessors have been reported and no yield data or data from multiple chips has been reported. Also, prior manufactured flexible systems were not field-reprogrammable and were evaluated either on a simple set of test vectors or a single program. A working flexible microprocessor chip supporting complex or multiple applications has not been demonstrated. Finally, no prior work performs a design space of flexible microprocessors to optimize area, code size, and energy of such microprocessors.

In this work, the authors fabricate and test hundreds of FlexiCores – flexible 0.8µm IGZO TFT-based field-reprogrammable 4- and 8-bit microprocessor chips optimized for low footprint and yield. They show that these gate count-optimized processors can have high yield (4-bit FlexiCores have 81% yield – sufficient to enable sub-cent cost if produced at volume). We evaluate these chips over a suite of representative kernels – the kernels take 4.28ms to 12.9ms and 21.0µJ to 61.4µJ for execution (at 360nJ per instruction). The authors also present the first characterization of process variation for a flexible processor – the authors observe significant process variation (relative standard deviation of 15.3% and 21.5% in terms of current draw of 4-bit and 8-bit FlexiCore chips respectively). Finally, the authors perform a design space exploration and identify design points much better than FlexiCores: the new cores consume 45-56% the energy of the base design, and have code size less than 30% of the base design, with an area overhead of nine to 37%. (International Symposium on Computer Architecture, June 2022, https://dl.acm.org/doi/10.1145/3470496.3527410)

Materials

"Rapid Photolithographic Fabrication of High Density Optical Interconnects Using Refractive Index Contrast Polymers"

Authors: Julie I. Frish, *et al.*

Abstract: New polymer optical interconnect materials that the authors term refractive index contrast (RIC) polymers are ideally suited to a wide variety of photonic interconnect applications as the refractive index can be tuned over the range of n = 1.42 to 1.56, while index contrast Δn can be precisely tuned through composition and ultraviolet exposure; the waveguides can be directly patterned in dry films with no wet or dry etching processes required. RIC polymer interconnects thus have the ability to access numerous photonic platforms, including silicon photonic chips, ion-exchange (IOX) glass optical substrates, and optical fiber arrays. The authors demonstrate for the first time efficient single-mode polymer interconnect fabrication via a maskless lithography approach that exhibits low loss adiabatic coupling (~1.5dB at 1550nm) to IOX waveguides through the formation of grayscale tapers. *(Optical Materials Express,* vol. 12, no. 5, 2022, https://opg.optica.org/DirectPDFAccess/F2850C64-9BF0-449E-9E03207E48AB4EC4_471361/ome-12-5-1932.pdf)

SPC

"Time to Failure Prediction on a Printed Circuit Board Surface Under Humidity Using Probabilistic Analysis"

Authors: Sajjad Bahrebar and Rajan Ambat

Abstract: This paper presents the probabilistic study of time to failure (TTF), which is caused by combinations of various important controllable factors on a printed circuit board (PCB) surface under humidity. The study investigated the impact of four changeable factors including pitch distance, temperature, contamination, and voltage, each at three levels upon the surface insulation resistance test boards. Constant 98% relative humidity with adipic acid as contamination related to flux residue was used for a 20-h parametric experiment. Two main states were considered on the whole output current measurements: the stable part before the short transition phase and the unstable part after due to electrochemical migration (ECM) on the PCB surface. Leakage current (LC) in the first state and TTF at the beginning of the second stage was measured with five replications for each condition as the predictive indicator in all models. The trend of LC and TTF was also investigated on three levels of each factor. In addition, probabilistic distribution analysis using fitted Weibull distribution, multivariate regression analysis, and the classification and regression tree (CART) analysis were used to predict the probability of TTF and failure risk prediction on the PCB surface. All the prediction models had an acceptable prediction of TTF at diverse accuracy levels, according to changing factors/levels. Nevertheless, the multivariate regression analysis had the best prediction, highest R2, and lowest error compared to the other models. *(Journal of Electronic Materials,* May 18, 2022, https://link.springer.com/article/10.1007/s11664-022-09668-7)

This column provides abstracts from recent industry conferences and company white papers. Our goal is to provide an added opportunity for readers to keep abreast of technology and business trends.

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The PCB Podcast