What is Copper Thickness? p. 18

UP Media Group

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September 2020

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Determining a Signal's Critical Length

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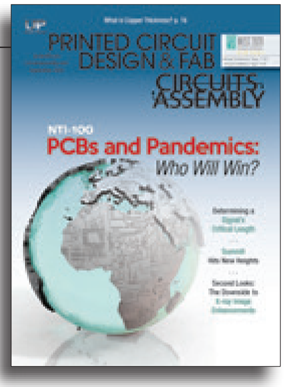
FEATURES



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MIKE BUETOW
EDITOR-IN-CHIEF

Will OSP Spec Finally Be Finished?

ORGANIC SOLDERABILITY PRESERVATIVES, or, if you prefer, organic surface protectants, or OSPs, have been with us for decades. Did you know more than 60% of the world's boards use OSPs? They are in everything from smartphones to tablets to medical devices, airbags, and engine controls.

Major OEMs like Intel, Apple, Cisco, Continental, Bosch, Denso, and Hitachi Automotive are known to use them. Yet when engineers discuss their preferred finishes, OSPs tend to be on the outside looking in.

A new IPC task group is trying to bring an added layer of credibility to OSPs for high-temperature soldering by developing a standard, along with a series of test methods.

At a glance, OSPs have ample potential. Compared to metallic finishes, they are low-cost and offer much-sought-after surface coplanarity on the coated copper pads. They emerged in the 1980s as a replacement for hot air solder leveling, which was an omnipresent but more expensive, higher maintenance process. Because of their ability to produce thin, even coatings, OSPs seemed superior for assemblers working with advanced packages, and in some cases OSPs cut the cost of the finish up to 50% over HASL and even more versus finishes containing gold or silver. Major OEMs like Lucent adopted OSPs for a large percentage of their boards.

But … back then metallic finishes offered better protection against oxidation, and the solderability of OSPs typically did not hold up following multiple lead-free reflow cycles. Those lingering issues of thermal resistance, copper diffusion suppression and solderability torpedoed consideration of OSPs for many higher rel products. The lack of ability to inspect real product without destructive testing was a limiter, too.

More than 20 years ago, several companies attempted to develop a standard for OSP under the auspices of IPC. In 1997, the Surface Mount Council – remember that? – assembled a white paper that offered a snapshot of the various offerings at the time, but little else. In 2008, the IPC Plating Subcommittee announced plans to release a standard. A key OEM disputed the results of the solderability data, however, and that effort was spiked. In a post-mortem, the subcommittee noted it couldn't reach consensus on the range of the coating thickness to meet the performance specification.

The latest effort appears to have put that old debate to rest. The committee, which includes members from Continental, Bosch, Sanmina and TTM, has agreed thickness is not a determinant in the performance of the coating. "That was a hang-up several years ago," recalls task group chairman Michael Carano. "We don't need one big range."

Moreover, today's OSPs are better than their ancestors. The pending spec defines high-temperature OSP as capable of withstanding two IR reflows at a peak temp of 245°-250°C and shows the same wetting balance results at zero reflows as at three, with a maximum 20% drop. And Carano believes the higher-performance OSPs are capable of five reflow cycles. Storage life has also improved, reaching 12 months. OSP is often used in mixed final finish products, such as with hard or soft gold. "It is common in chip packages. The packaging people will love (the standard)," Carano said.

The task group is currently finalizing the data that will support the process control recommendations and testing protocols. It plans to submit the draft of the new spec, known as IPC-4555, to the IPC membership for vote by spring.

This is not to suggest OSPs will broadly replace other finishes. They are reworkable, but electrical testing is generally not recommended, as the coating is hard and can bend the pin probe. Some manufacturers work around this by printing paste on test pads instead.

So why a standard now? Would it help elevate OSP into a greater array of products? Carano believes so. "If there were a workmanship standard, then yes. Right now, every fabricator uses a different protocol because each OEM has a different process."

Ultimately, I think this is a good way to go. Standards are often accused of constraining innovation, but the opposite is also true: Without standards, it's difficult for technologies to get implemented. Use of OSPs might not spread much wider – so to speak – in the bare board finish market. But it's past time for a standard.

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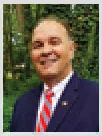
P.S. Last chance to sign up for the PCB West Virtual 2020 conference and exhibition. More than 125 hours of in-depth technical training! pcbwest.com

PCDF People

Cadence promoted **Dan Fernsebner** to R&D senior solutions architect. He joined Cadence in 2017 after 11 years with Altium and seven with Mentor.



Summit Interconnect named **John Vaughan** vice president of strategic markets. He been held senior management roles in the PCB industry (engineering, operations, business development) and the EMS sector (corporate VP sales and marketing, director of supply chain, and director of operational planning) over his near 40-year career in the electronics industry.

Taiyo America announced **Kate Han** as technical sales engineer for the Western Region of the US.

PCDF Briefs

AT&S signed a deal with **IMST** to develop radar, radio modules, communication systems, and other high-frequency technology products.

AT&S plans to invest up to €120 million in a technology upgrade during the next four years.

Bowman and **Raisa** will supply a comprehensive line of reference standards for benchtop and handheld XRF plating measurement systems.

Chasm Advanced Materials announced the formation of a business unit dedicated to printed electronics and appointed Daniel Skiba vice president.

Electronic Interconnect installed an **atg Luther & Maelzer** A7a flying probe tester.

Flexium Interconnect is building a $333 million mmWave LCP antenna module plant in Kaohsiung, Taiwan.

Kemmer Praezision named **Insulectro** distributor of its drill and routing tools in North America.

Mu-Del Electronics acquired RF product manufacturing company **Luff Research.**

As a result of a recent fire at a **Nittobo** plant in Fukushima, Japan, the supply of ABF substrates worldwide is expected to fall short of demand by at least 20% by the end of 2020.

Schmid Group is moving its main China factory to Zhongshan.

PCB fabricator **Sihui Fushi Electronic Technology** went public in July on the Shenzhen Stock Exchange.

Summit Interconnect Acquires ITL Circuits, Solidifies N. American Rank

ANAHEIM, CA – Summit Interconnect in July acquired ITL Circuits for an undisclosed sum. The deal solidifies Summit's hold on the no. 2 spot among the largest manufacturers of printed circuit boards in North America.

Summit has three facilities in Northern and Southern California, with a combined 810 employees. ITL Circuits has over 65,000 sq. ft. of factory space and approximately 130 employees.

Summit will retain ITL's same management team and staff, and ITL owners Adolf Czudnochowsky and Michael Campbell plan to retire.

"ITL's capabilities complement Summit's and will provide additional volume manufacturing capacity across a broad range of technology," said Shane Whiteside, president and CEO of Summit Interconnect. "The additional and meaningful scale will further strengthen our ability to serve our customers and broaden our relationships with key suppliers. This is very exciting news for both Summit and ITL, and we welcome our new Toronto employees to the Summit team."

Summit Interconnect acquired Streamline Circuits in 2018, and KCA Electronics and Marcel Electronics in 2016. Its revenue now tops $150 million, all in North America, based on the NTI-100 and PCD&F sources.

See the PRINTED CIRCUIT DESIGN & FAB/CIRCUITS ASSEMBLY interview with Whiteside in this issue. (CD)

TLB Set for IPO in Korea

DANWON-GU ANSAN, SOUTH KOREA – TLB Co. is set to go public on the secondary Kosdaq stock market sometime in 2020, according to reports.

The PCB fabricator plans to file a preliminary IPO review by September.

In 2019, the company had operating income of 10.5 billion won (US$9.5 million) on sales of 149.1 billion won (US$134.2 million).

TLB's primary focus is building printed circuit substrates for semiconductors. (CD)

IPC Calls on Congress to Pass Covid Recovery Bill with Pro-Industrial-Base Provisions

BANNOCKBURN, IL – IPC is calling on the US Congress to enact a Covid-19 recovery bill and include provisions of importance to everyone who depends on electronics.

In a letter to the top four leaders in Congress, IPC stresses electronics are at the heart of the modern economy and key sectors, including urgently needed medical equipment, critical infrastructure, and defense systems. "Yet, the crisis has exposed vulnerabilities in our manufacturing base," the letter adds.

The association urges Congress to support the nation's industrial resiliency by passing a recovery package with the following measures:

- Modified unemployment insurance benefit to continue essential support for laid-off workers, helping to maintain consumer demand, while reducing disincentives to return to work.
- Common-sense liability protections shielding businesses that have taken "reasonable steps" to comply with government workplace safety guidelines.
- Paycheck Protection Program extension and the Safe and Healthy Workplace tax credit.
- Supplementary funding to sustain and rebuild the defense industrial base.
- Aid to state and local governments to ensure essential services are maintained.

The timing and scope of the legislation are still being worked out, but a package is expected to be negotiated and voted on soon, IPC says. (CD)

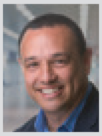
SnapEDA has created over 120,000 new **Samtec** connector models, including high-speed and micro-pitch board-to-board, edge card, and rugged connectors.

Unimicron Technology is slated to complete construction of a new plant in Yangmei, Taiwan, by the end of 2020, where it will build IC substrates for Intel, industry sources said.

Würth Elektronik is laying off up to 100 staff in Schopfheim, Germany, as orders slowed because of the Covid-19 pandemic.

CA People

Austin American Technology named **Justin Cody Worden** director of business development.

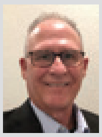


Emerald EMS hired **Joe Garcia** as vice president of sales and marketing. He has held executive sales, marketing and business development positions with Green Circuits, Creation Technologies and Viasystems.

Enics named **Mahmut Bertan** chief business officer and **Rami Aro** director, services.

Flex named **Murad Kurwa** VP – advanced manufacturing engineering and **Paul Lundstrom** CFO.

iRobot named **Hal Winslow** senior principal manufacturing engineer.



Southwest Systems Technology hired **Lynn Brock** as sales executive. Over a 30-year career, he has held roles as director of operations and director of sales at Benchmark Electronics, vice president of strategic projects at Plexus Corp., and most recently COO at Circuitronics.

Sanmina executive chairman and cofounder **Jure Sola** is taking over as CEO, replacing **Hartmut Liebel,** who spent just a year on the job.

Universal Instruments promoted **Todd Vick** to director of product management. He has been with UIC for 29 years in roles ranging from field service engineer to product marketing.

Zentech Manufacturing named **Michael Seltzer** chief commercial officer. He has over 35 years' experience providing customer solutions in the military/aerospace EMS sector, most recently serving as vice president of business development at Benchmark Electronics.

Cadence Acquires InspectAR

ST. JOHN'S, NEWFOUNDLAND, CANADA – Cadence Design Systems in August acquired InspectAR for an undisclosed sum.

InspectAR uses augmented reality to map electronics, labeling PCB schematics on-screen in real-time. Following the deal, InspectAR will continue to operate independently from its headquarters here.

The firm has a second office in the Autodesk Technology Center residency program in San Francisco.

"We've only gotten this far with the support of our families, friends, service providers, employees, and investors," the company said in a statement. "Today, Cadence joins this group, and we couldn't be more excited for this new chapter of growth and vision."

The startup raised $850,000 in January from Royal Circuit Solutions and Advanced Assembly.

Since launching, InspectAR claims it has garnered thousands of users and has partnered with companies such as CrowdSupply and Digi-Key.

"We now have far more resources to achieve our goals, and a far broader reach to get valuable insight from customers working in every part of the hardware sphere," InspectAR said, adding it plans to keep its platform vendor-agnostic, and plans to add additional support for EDA software and lab tools to its platform. (MB)

SEMI Forms FHE Standards Committee

HSINCHU, TAIWAN – SEMI formed a standards committee that aims to develop global standards for flexible hybrid electronics spanning design, materials, manufacturing, packaging and systems and to drive industry growth.

The first chapter is based in Taiwan.

Initial work of the committee will include establishing working groups to draft measurement standards; building industry consensus on the need for materials, equipment and manufacturing standards; and developing standards to accelerate the introduction of related FHE technologies into diverse consumer end markets.

"The SEMI Standards Flexible Hybrid Electronics Global Technical Committee sets out to clear development bottlenecks facing the industry and establish unified measurement standards for flexible smart textile, automotive, Internet of Things and related devices," said Terry Tsao, SEMI chief marketing officer and president of SEMI Taiwan.

"The Taiwan chapter looks forward to kicking off the development of international industry standards that help Taiwan's FHE sector promote industry growth by reducing costs and increasing competition." (CD)

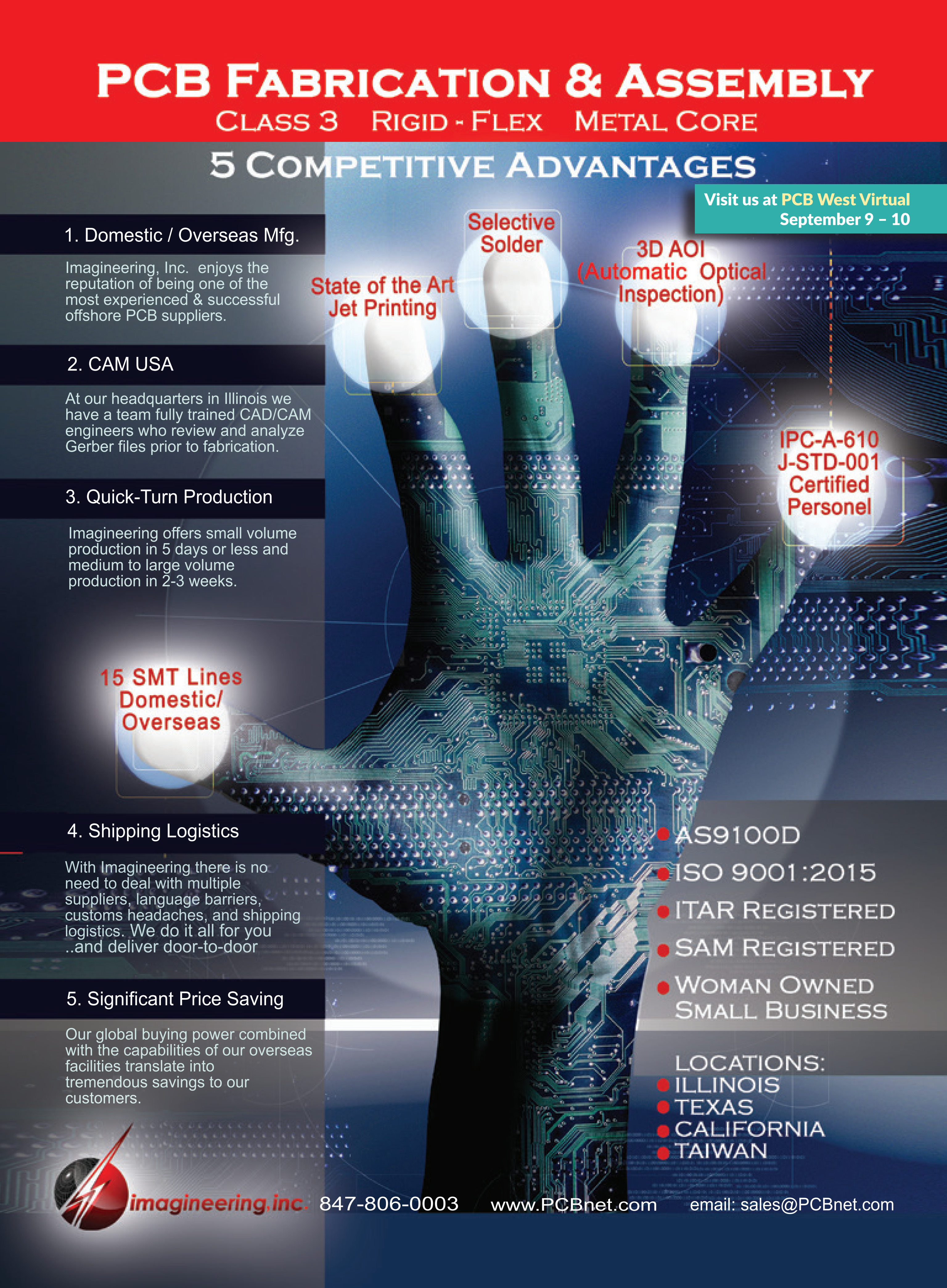
Digicom Expands Oakland EMS Facility

OAKLAND, CA – Digicom Electronics doubled the size of its facility here and added manufacturing equipment and additional personnel.

The facility has an ESD floor, cleaning equipment and process controls, and provides green manufacturing. Component placement, selective soldering, reflow ovens, and automated inspection and test equipment have been added.

"We moved into this new facility just three years ago, but business has grown, and we wanted to increase our capabilities and capacity, so we took over the entire building," said Mo Ohady, general manager, Digicom Electronics. "We are excited about the quality and services we can offer and invite everyone to visit, bring their designs or prototypes, and see for themselves."

Digicom specializes in complex PCBs and assemblies for medical device, military, aerospace, and industrial products. (MB)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Elexon Electronics Opens Industry 4.0 Factory

BRISBANE – Elexon Electronics opened an intelligent factory to enter new markets in defense and aerospace, according to reports. The Made in Queensland program provided $890,325 for the Industry 4.0 facility.

The firm invested in automated SMT equipment, an intelligent material handling system and x-ray inspection.

Elexon provides engineering support, procurement, tooling manufacture, PCB manufacture and assembly and final product testing and packaging.

The government's assistance helped create jobs within the company, and the program is helping other companies reshore electronics work. (CD)

iNEMI Publishes Best Practices for Protecting Electronics During Disinfection

MORRISVILLE, NC – An iNEMI team of experts has published new disinfection procedures for ensuring electronics product reliability. "Recommended Best Practices for Protecting the Reliability and Integrity of Electronic Products and Assemblies when Disinfecting for SARS-CoV-2 (COVID-19)" is the result of a broad iNEMI membership review of key industry, government and technical sources.

The team assessed chemicals included in the US EPA List N: Disinfectants for Use Against SARS-CoV-2 (Covid-19) and common application methods, identifying those substances that minimize the risk of negative impact on electronic equipment when applied in an appropriate manner.

"With the Covid-19 crisis, several of our members have contacted iNEMI for guidance on how to mitigate the possible detrimental impact of disinfecting procedures on electronic equipment and assemblies," said Marc Benowitz, CEO, iNEMI. "There are guidelines from groups such as the US EPA, CDC and the World Health Organization regarding cleaning and disinfecting for Covid-19, but none of these addresses the impact of disinfectants and their application methods on electronics equipment and assemblies.

"Many commonly recommended disinfection substances and/or application methods could potentially cause failures in electronic equipment if the internal electronics were inadvertently exposed to them. This is an obvious concern for electronics manufacturers who want to ensure the safety of their employees, supply chain partners and customers, while protecting the reliability and integrity of their products."

iNEMI's best practices are now available at inemi.org/disinfecting-best-practices-request. (CD)

CA Briefs

Absolute EMS said its new **Hanwha Techwin** SMT lines are up and running.

Apple plans to remove carbon emissions from its entire business, including its products and sprawling supply chain, over the next decade.

Austin Precision Machining and Manufacturing launched turnkey mechanical and assembly services in Austin, TX.

Benchmark Electronics announced completion of phase two of five phases toward the delivery of mobile video surveillance systems (MVSS) to the **Department of Homeland Security** for use along the US southern border.

Bharat Dynamics Ltd. (BDL), an enterprise under India's Ministry of Defense, has set up an SMT facility in Hyderabad.

Check Technology Solutions purchased a **MIRTEC** MV-6 Omni 3-D AOI.

Foxconn launched the **iAI Institute,** "an initiative focused on training the workforce of tomorrow and sharing Industrial AI knowledge across industries." It also broke ground on a ¥60 billion (US$8.6 billion) semiconductor assembly and test plant in Qingdao, China.

Britain's government set a deadline of 2027 for removing equipment made by **Huawei** from the country's 5G telecom networks.

IPC has updated the IPC-1752A standard for collecting supplier materials declarations to include the updated REACH Candidate List.

IPC and **iNEMI** signed a memorandum of understanding to collaborate and share information on developing technology roadmaps, organizing forums, establishing new programs, and identifying industry needs and projects.

ITW EAE named **EMEA Electro Solutions** to represent and distribute its complete equipment line in Spain and Portugal.

Lacroix Group acquired **eSoftThings,** consolidating its R&D center and strengthening its positioning around industrial IoT and artificial intelligence.

Luxshare Precision Industry will acquire a plant used to manufacture iPhones in China from **Wistron.**

MIT researchers argue that the computing demands of deep learning are so great that progress on tasks like translation and self-driving is likely to slow.

MIT and **University of Illinois** scientists are proposing a new method for training AI deep-learning systems to be more failproof and thus trustworthy in safety-critical scenarios.

Mycronic US integrated its operations into a new 102,000 sq. ft. facility outside Boston.

NeoTech announced a partnership with **Numerica** for defense products.

Nordson Select appointed **Neutec Electronics** distributor for its entire product line in Switzerland.

Parpro Technologies purchased a **ViTrox** V810i AXI.

Partnertec acquired the stencil manufacturing operations of **ASM Assembly Systems Benelux.**

Pegatron has registered a subsidiary in India, becoming Taiwan's third contract electronics manufacturer to produce iPhones in the South Asian country.

Rehm Thermal Systems has added a new building to its headquarters in Blaubeuren-Seissen, Germany, and many employees have already moved to the new site.

RelianceCM installed a **YesTech** FX-940 3D Ultra AOI at its contract manufacturing lab in Corvallis, OR.

Saki expanded its EMEA regional head office in Prague with the opening of a new solution center.

Schleuniger signed an agreement to acquire **Cirris Systems** in an asset deal.

METALS INDEX

STUCK AT HOME

Trends in the U.S. electronics equipment market (shipments only).	% CHANGE APR.	MAY	JUN.	YTD%
Computers and electronics products	0.5	0.3	-0.8	1.1
Computers	-0.2	2.1	-0.7	-11.9
Storage devices	-2.8	-2.1	-4.4	51.5
Other peripheral equipment	2.8	9.5	-14.4	4.5
Nondefense communications equipment	-0.2	0.2	-0.4	6.2
Defense communications equipment	3.5	7.2	1.4	-1.6
A/V equipment	5.3	4.0	10.1	-17.1
Components[1]	1.9	-0.3	-1.2	8.2
Nondefense search and navigation equipment	-1.3	-0.7	-0.4	-6.4
Defense search and navigation equipment	0.3	-0.2	-0.4	2.7
Medical, measurement and control	-1.1	0.0	0.1	-3.6

[r]Revised. *Preliminary. [1]Includes semiconductors. Seasonally adjusted.
Source: U.S. Department of Commerce Census Bureau, Aug. 4, 2020

US MANUFACTURING INDICES

	MAR.	APR.	MAY	JUN.	JUL.
PMI	49.1	41.5	43.1	52.6	54.2
New orders	42.2	27.1	31.8	56.4	61.5
Production	47.7	27.5	33.2	57.3	62.1
Inventories	46.9	49.7	50.4	50.5	47.0
Customer inventories	43.4	48.8	46.2	44.6	41.6
Backlogs	45.9	37.8	38.2	45.3	51.8

Source: Institute for Supply Management, Aug. 3, 2020

KEY COMPONENTS

	FEB.	MAR.	APR.	MAY	JUN.
Semiconductor equipment billings[1]	26.6%	20.1%	18.2%	12.9%[r]	14.4%[p]
Semiconductors[2]	5%	6.85%	6.13%	4.82%[r]	5.1%[p]
PCBs[3] (North America)	1.15	1.15	1.19	1.10	1.12
Computers/electronic products[4]	5.41	5.43	5.44	5.44[r]	5.47[p]

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

Hot Takes

- **The electronic skin market** is set to grow from its current value at over $6 billion in 2019 to $16 billion by 2026. (Global Market Insights)
- **Worldwide IT spending** is projected to total $3.5 trillion in 2020, a decline of 7.3% from 2019. (Gartner)
- **Electronic component suppliers** are slightly less concerned about the health of the supply chain, as passive and electromechanical components become more available. (ECIA)
- **PCB and MCM design software revenue** totaled $250.9 million in the March quarter, up 12% from a year ago. (ESDA)
- **The worldwide market for AI software** will expand to $98.8 billion by 2025, up from $16.4 billion in 2019. (Omdia)
- **Q2 worldwide PC shipments** totaled 64.8 million units, up 2.8% year-over-year. (Gartner)
- **Taiwan's PCB equipment suppliers** are poised to land more orders for automation equipment from PCB clients in China in the second half of 2020 as clients are expected to accelerate production automation.
- **Q2 worldwide tablet** growth rose 18.6% year-over-year after two sequential quarters of decline. (IDC)
- **Worldwide smartphone shipments** decreased 16% year-over-year in the June period. (IDC)
- **Global server shipments** are forecast to contract 5.6% sequentially in the third quarter due to slowing demand for cloud servers from datacenter operators and for enterprise servers. (Digitimes Research)
- **Global semiconductor manufacturing equipment sales by OEMs** are projected to increase 6% year-over-year to $63.2 billion in 2020 before logging record high revenue of $70 billion in 2021. (SEMI)
- **The worldwide IC market** is expected to show single-digit growth in 2020. (IC Insights)
- **Sales in the German electronics industry** fell 4.2% year-over-year in June, as the rate of decline fell. (ZVEI)

Let's Talk: The New Reality of Keeping in Touch

Just as Covid-19 jolted supply chains, it also disrupted how we communicate.

MAINTAINING EFFECTIVE, OPEN, timely communication can be one of the biggest challenges facing employees at every level. The executive team sets the vision, strategy and tactical goals. Managers and supervisors are tasked with communicating and converting that message into understandable, reasonable, attainable and ultimately successful initiatives and efforts. Employees, in turn, communicate *their* issues, problems and ideas to accomplish back to the higher-ups, who refine the goals, so the organization moves forward profitably, satisfying customers.

On normal days, good communications can be daunting and complex. And the past several months have been anything but normal.

In-person communication offers the advantage of body language to accentuate the spoken word. The parties involved can literally see eye-to-eye. A speaker can scan a room to see how their message is received and recalibrate as needed. Workers can lean back from their desk or stand over a cubicle wall to ask a colleague a question and receive a quick response. A team can huddle on demand to communicate a problem and brainstorm a solution. How does that work when you and your staff are forced to communicate virtually?

Technology affords business many exciting, user-friendly and adaptable communication options. With so many people forced to work from home, rather than at their usual desk or work station, tools such as Zoom, WebEx and GoToMeeting, to name a few, are being employed like never before to keep business communication moving during these historic and trying pandemic times. But as impressive, omnipresent and user-friendly as those options may be, how effective is technology for robust communication?

While not all employees are working from home, those who are must set up more of a "real" office than they might have had and establish an environment conducive to work, while possibly occupying that space with others. Conducting business in a nontraditional work environment is further complicated when that space is shared with a spouse who is attempting the same, or when children or pets are underfoot. All this creates distractions to juggle, manage or control in a way that enables focused, dedicated work concentration.

Technologies such as Zoom enable verbal communication but may not assure effective focused communication. Too many involved in a virtual meeting may be distracted by events in their home office and miss important details or a speaker's vocal nuances. To further complicate this, some may put up a still shot picture of themselves, or a favorite location, instead of risking having a rogue child or spouse enter the field of vision of the camera. In such a scenario, others present cannot see who is on-task and getting the message and who is only getting the basic outline and will need follow-up for the details. If effective communication is a challenge when people work together at the same location, the difficulties and potential for miscommunication increase exponentially when everyone works remotely.

Even communication with those still functioning from the home office can offer challenges and risks. When half the team is up to speed and the other half is getting only a portion of the story, problems arise. Unlike when a team assembled in one conference room virtually meets with a team likewise assembled in a similar conference room at a different location, when each person is in a unique site dealing with unique surroundings and unique distractions, collective comprehension suffers. The same is true even when a few members of a team are offsite, missing the banter that often provides the color commentary necessary to best deal with the task at hand.

What to do? Clearly the "new normal" will be around much longer than anyone originally thought. Tasks are being accomplished and business is churning along. But everyone from the CEO down to the newest entry-level employee must redouble their efforts to communicate with everyone, and not assume their message is heard as it once was. More one-on-one communications are certainly part of the solution. Confirm coworkers heard details that may have been missed during a group call, or to share thoughts about a given situation based on specific experiences.

Be patient. Some messages will need to be repeated, and often. After a call, reach out to participants to ask if, on reflection, they have questions or require additional information. Be creative: mix up the type and variety of communication methods to enable each group discussion to differentiate itself from the barrage of other Zoom or WebEx sessions. Determination is required. Be as clear a communicator as you can, regardless of the vehicle used. Be it by email, phone or virtual meeting, reaching out as often as possible will help avoid gaps.

Finally, use that sense of humor! Everyone is fatigued and frustrated dealing with these unprecedented times. Mistakes happen. Family will be overheard on some virtual calls. Life will interrupt. Don't get concerned. Show patience, creativity and determination to keep communicating as best as possible. □

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I'm a PCB Designer. What Must I Know about Drafting?

Why you should take the time to use the dimensioning tool.

ONE OF THE many hats worn by a board designer is that of draftsperson. Before settling into a position doing layout, I had a contract to create drawings on vellum – with a pencil! Before they turned me loose, the manager asked me to write my name and phone number on a piece of paper. That was all it took; get to work. Ever since seventh grade drafting class, my normal handwriting has been in all caps. We no longer need legible handwriting to land a job, but some of the things I learned at Cavro Scientific have stuck with me all these years.

Dimensions and tolerances. The electronic data alone are enough to fabricate a board most of the time. Whether it's an omnibus file like IPC-2581 or a collection of Gerber and drill data, the hole size and locations are provided with the circuit pattern. Why take the time to use the dimensioning tool? Here's why. Someone must inspect the PCB before it leaves the fabricator. Someone else inspects it on the way into the assembly factory. All the fab and assembly drawings are inspection documents.

The design intent can be lost without the effort made to establish a bolt pattern or other feature critical to the design. So-called "mid-mount" connectors are nested into a slot. That slot may have a very tight tolerance. The datasheet for the connector may even have a unilateral tolerance that permits the slot to grow but not shrink from the nominal value. Without the dimension and the tolerance, the "assumed tolerance" will take the nominal width of the slot and give plus or minus the usual allowance for deviation from the title block of the drawing. That may be fine for the rest of the board outline but could lead to issues if not properly controlled.

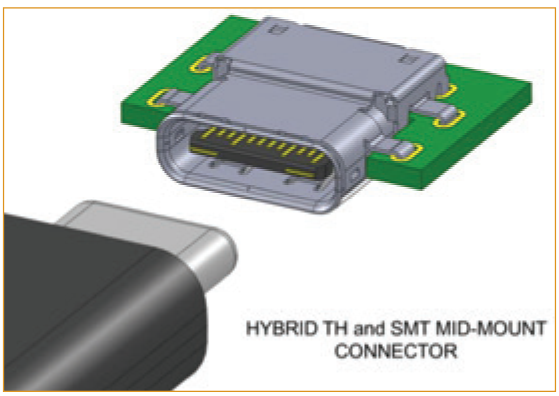

FIGURE 1. The PCB hugs the connector on three sides, all of which are critical dimensions. (Credit: Extreme Tech)

I draw some of these critical dimensions on the board dimension layer and the rest on the package dimension layer. Dimension the footprints to simplify checking and avoid mistakes. I've caught my own errors that way. Taking the time to dimension the features in much the same way as the drawing is a nice little insurance policy.

Details and the big picture. We use details whenever the feature is too small or oddly located for normal dimensions to cover the geometry. The bevel on an edge connector is one such feature. The "mouse bite" around the assembly sub-panel is another one. Since you're not reinventing the wheel every time, keep a scrapbook full of common design elements for reuse when appropriate.

We use details for many other things. Impedance is called out on a layer-by-layer basis and at the same time supports numerous impedance values for each signal layer. Reference planes for each are also noted. It's natural to set up a chart that allows interested parties to cross-reference the design against the design rules. We use another chart for the various drill sizes, tolerances, quantities and plating specifications. High-density interconnects (HDI) make use of several boxes of data broken out for each layer pair. The different stack-up regions of a flex or a rigid-flex could be depicted in this form or potentially broken out as separate details for modular reuse. Next, I'll discuss a less obvious way tables can come in handy.

Tabular drawings: a chance to save paper and time. Some types of drawings can cover more than one board. One instance is a flex circuit that mounts to a bespoke connector. Let's say there's a ZIF (zero-insertion force) connector on one end and a stacking connector at the other, with a pattern of lines and shapes running from end to end. It is possible the same connector pair can be used for different interconnects in a system of boards. You could have various lengths called out with a separate dash number for each length. Down the road, more examples could be added with little effort.

In this way, the same fabrication and assembly drawings can support numerous sets of artwork. You have two detailed images of the ends of the flex with a jagged pair of lines separating the two. A dimension from end to end refers to a table that indicates the overall length.

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Notes: Unless otherwise specified. This is a topic in its own right. The written instructions we give fabricators and assemblers can be insufficient and overkill at the same time. Process data do not belong on an inspection document. That is what we generate at the end of each cycle. Sampling plans, solder profiles, and other how-to items should go into separate documents to be referenced by the fabrication and/or assembly notes.

The inspector should be able to look at the product and the documentation and conclude whether they meet the requirements. Provided I'm not colorblind, I can see the color visually. I can measure the thickness of the solder mask with a cross-section. I cannot tell if it was cleaned with "ultra-pure" water prior to application of the mask. What I can do is determine if it passes the solder mask tape test according to IPC-TM-650 Test Method 2.4.28.1. That's what matters. That's what can be evaluated, and that's what you should be using for your notes.

If the product is to adhere to IPC-6012 Class 2 standards, write that in the notes. That performance specification covers a lot of ground, and there is no need to repeat what is conveyed by that one note. What you need to call out are exceptions to the rules set forth by the IPC classes. For instance, the via breakout of 90° may not be desirable. A follow-on note stating tangency is the minimum requirement makes sense.

> "A look at the product and documentation should reveal whether the requirements are met."

It is now up to the designer (you and me) to create padstack geometry and hole size/tolerance that support the kind of fabrication we require. If, for instance, the product requires a tight flatness spec, and you turn in artwork with unbalanced copper loads, the fabricator is unlikely to yield sufficient numbers to make it a viable product. Perhaps they can bake it in a press to get it flat. Guess what happens when the board subsequently goes through another heat cycle for assembly. It turns right back into a potato chip!

The point is don't let your notes write checks your layout can't cash. Use CAD tools to ensure the amount of copper on each layer is essentially a mirror image from the center core outward. Whether it comes to copper thieving on the signal layers or flooding every layer with ground, give vendors a chance to succeed, so your product can succeed. QED. That's what I came here to say. □

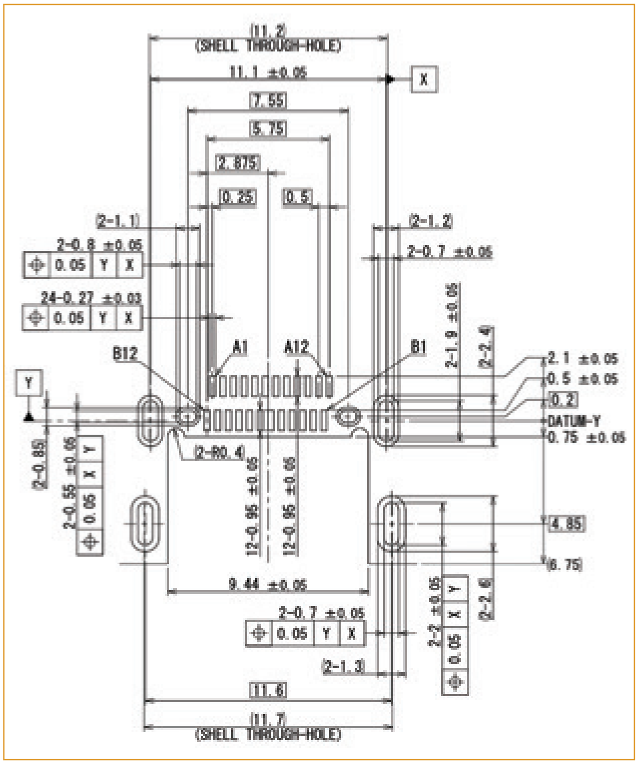

FIGURE 2. A typical mid-mount connector often used on phones and other slim form factors where the connector height above the PCB would be too much. (Credit: Mouser)

A Grand 'Grand Opening'

The PCEA's kickoff event was a massive success.

THIS MONTH I review the virtual PCEA grand opening, which took place in July and featured guest presenter and PCEA educational committee member Rick Hartley. Next, in our "Message from the Chairman," Steph Chavez writes of his satisfaction with our recent open house and talks about another event in which he and vice chairman Mike Creeden participated, hosted by our affiliate organization, the Surface Mount Technology Association (SMTA). Coming next month, I check in with the PCEA education committee and look at the PCEA's role in education. What do our education committee leaders have in store? I had an opportunity to hear from them and will highlight some of their ideas and plans for learning and curricula in the coming months.

PCEA updates. The PCEA virtual open house and webinar was held Jul. 14 and was moderated by PCEA director Mike Buetow. Mike welcomed the audience and introduced PCEA chairman Steph Chavez, who had grateful words to say about our sponsors and the publishing of our columns. He then took an opportunity to state the PCEA's mission statement: "At our core, our mission statement is to Collaborate, Inspire and Educate by promoting printed circuit engineering as a profession. Our goal is to encourage, facilitate, and promote the exchange of information and the integration of new design concepts through communications, seminars, webinars, workshops, and professional development through a network of local and regional PCEA-affiliated chapters."

Steph mentioned the association serves over 1,000 members worldwide. There are now eight regional chapters in the US and Mexico, and the PCEA is cultivating five new additional chapters to help serve our members. The organization has quite a few noble objectives by which to meet PCB engineering challenges. Steph laid them out: "The PCEA is about meeting today's industry challenges from concept, engineering development, standard implementation, and manufacturing, including fabrication, assembly, test, compliance, and field service. This knowledge includes details concerning printed circuit board materials, components, manufacturing processes, allowances and limitations. The final product should have high producibility, reliability and yield. This should all be confirmed by quality assurance and compliance. The Printed Circuit Engineering Association is structured for these challenges."

PCEA's objectives:

1. Stimulate communication among and between printed circuit designers and others in related engineering disciplines.
2. Disseminate information regarding current activities and new developments in design technology via newsletters.
3. Maintain a communications link between standards bodies related to printed circuit engineering and manufacture. Coordination includes, but is not limited to, the activities of government, industry, trade associations and special interest groups.
4. Coordinate the compilation of design standardization issues in printed circuit fabrication and assembly with related design technologies.
5. Encourage and coordinate the compilation of design information, including equipment, equipment capability (tools and technologies) and related information.
6. Promote the necessity of early collaboration between engineering, fabrication, assembly, test, and field service.
7. Assist in the participation of suppliers and OEMs in chapter programs.

I've been to many Rick Hartley presentations. I've attended presentations ranging from hours to days. Regardless of length or venue, I always enjoy the points Rick makes and the way he makes them. Hartley's emphasis on subject matter runs in a scale of magnitude from simple and personal to flat-out, in-your-face tangible.

The one-hour webinar on power distribution tips to control SI, EMI and noise did not disappoint. Rick is a master of making strikingly good points, while explaining anything related to electronic performance on PCBs. I hope all our readers had the time to tune in. In case you didn't, here are a few excerpts:

Regarding energy in PCBs: "Energy in a circuit is not in the voltage or the current. Energy is in the electric and magnetic fields!" Also, "Energy does not travel in the copper elements, such as traces and planes. Energy travels in the *space between* these copper elements."

Rick discussed many tips for SI and EMI control. He emphasized the importance of keeping inductance low and offered a few considerations for placement of vias in relationship to the positive and negative ends of a decoupling capacitor. When designing for high-speed signal integrity, Rick explained "mounted inductance" of capacitors. He showed how to lower inductance by adding a pair of vias to each end of the caps and explained the best arrangement of the vias. Rick moved on to a discussion of the importance of closely spaced power planes and the challenges to performance wrought by 2, 4, 6 and higher-layer-count stackups.

The excitement among viewers was obvious as

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Rick's presentation progressed. The more he presented, the more queries we received regarding variables within which to apply the concepts. Polling showed that 78% of the audience had 11 or more years in the industry and were hungry for answers as they posed questions to our host: "What about via-in-pad?" "Is it better to have lots of same-value caps or multiple-value caps?" "What is the best tool to simulate a power distribution network?" Although the presentation was set for an hour, presenter Rick stayed on long after to address many questions.

Many thanks to Rick Hartley and our audience of viewers for making this educational experience a success!

Message from the Chairman

by Stephen Chavez, MIT, CID+

Success! PCEA has truly hit the ground running with our Virtual Grand Opening that took place Jul. 14. We had a great turn with much positive engagement and attendee feedback. Rick's presentation was a small golden nugget of what PCEA has to offer to the industry. Our official website has been up and running now since Jun. 1, with a lot of activity and new members joining the PCEA collective. We also continue to gain industry sponsorship as well.

We have now had two outstanding global events. The first event was a great webinar opportunity PCEA had by teaming up with SMTA that took place on Jul. 9 regarding "Creating the Best Data Package." I want to personally thank SMTA for acknowledging PCEA and seeing the value PCEA brings to the industry as a legitimate professional industry association. SMTA's eagerness to collaborate with PCEA showed in how professional, seamless and positive the event turned out. We received awesome positive feedback from an international audience.

The second outstanding global event was PCEA's Virtual Grand Opening, as Kelly detailed above. A truly successful grand opening launch with a lot of knowledge-hungry attendees seeking advice and industry best practice information! It was another great event! The feedback from our grand opening to date is overwhelmingly positive. That's two awesome events now under our belt, with many more to follow. Stay tuned for more activities coming your way now that PCEA is official and extremely active.

Last, I'd like to give a very heartfelt and loud shout of "kudos" to the entire leadership team for successfully launching PCEA to the world. All the hard work and extra effort has truly paid off in bringing PCEA from concept to reality. If you have not yet joined the PCEA collective, I highly encourage you to do so by visiting our website (pce-a.org) and becoming a PCEA member.

I continue to wish everyone and their families health and safety.

Professional Development and Events

- Sept. 7-Oct. 7: PCB West Virtual 2020
- Sept. 28 - Oct. 23: SMTA International – Virtual
- Oct. 7-9: AltiumLive (San Diego, California) – Virtual
- Jan. 23-28: IPC Apex Expo (San Diego, California)
- Jan. 26-28: DesignCon (Santa Clara, California)
- May 5-6: Del Mar Electronics & Manufacturing Show (Del Mar, California)
- May 11-13: IPC High-Reliability Forum 2021 (Baltimore, Maryland

Spread the word. If you have a significant electronics industry event that you would like to announce, please send me the details at kelly.dack.pcea@gmail.com, and we will consider adding it to the list.

Conclusion

Next month we will have an interview with the PCEA educational committee. Recently, I had an opportunity to meet with our PCEA educational committee regarding its plans. The educational committee consists of PCEA executive staff members Mike Creeden, Tara Dunn, Gary Ferrari, Rick Hartley and Susy Webb. This team has a lot of power-packed ideas and curricula lined up for our members. Our new website is being salted with many informational links and resources as I write. I look forward to writing about my informative zoom meeting discussion with this dynamic group of printed circuit engineering veterans. Stay tuned!

No matter where you may find yourself in this worldwide network of PCB engineering professionals, your trajectories for success will vector about your ability to learn and apply knowledge. I encourage you to "lock on" to the PCEA as a valuable resource for your future missions. If your aim is to learn and engage, our aim is to serve and assist. See you next month or sooner! □

The Role of AR and VR in Longer, Better Lives

Even a small amount of virtual assistance can improve our quality of life.

IT MAY SEEM surprising that the automotive heads-up display (HUD), an aerospace-inspired innovation, was proposed by designers as far back as the 1960s. It took until the late 1980s to reach production. Interest among OEMs and electronics brands has surged recently. As an increasing quantity of information is pushed at drivers from autonomous functions, driver-assistance features and connected services, today's HUDs provide graphical and text overlays on top of the view through the windshield to aid concentration and improve safety.

Augmenting reality by overlaying computer-generated images and information on our view of the world can help us in many other important contexts as well. AR is increasing productivity in the workplace and is entering the medical arena. Surgeons are beginning to appreciate the benefits of AR, like a graphical overlay from a scan or x-ray image taken previously, which can show important information about the patient during an operation, alleviate distractions and improve outcomes.

The potential to improve our quality of life, particularly in later years, is also extremely exciting. The World Health Organization predicts that more than one in five people will be aged 60 years or older by 2050. Bringing the technology to an even wider audience is particularly important as we try to handle challenges presented by an aging population.

Where possible, people will need to keep working and living independently into later years. And as we age, many of us become somewhat forgetful, at best. However, with just a small amount of assistance from AR (and other technologies such as facial recognition), to discretely overlay the names of people we meet in our field of view, we can overcome some of the milder degenerative effects and interact in more natural ways without obvious assistance. There are also opportunities to help protect people against fraud perpetrated by strangers posing as acquaintances or relatives, for example.

AR's more immersive cousin, VR (virtual reality), could help us live more contentedly as we age. "VR bars" are an emerging phenomenon, currently aimed at younger socialites and the tech savvy to offer enticing other-worldly experiences. Only a pinch of imagination, however, is needed to contemplate recreating nostalgic environments, such as an '80s rock gig or '90s nightclub that could take older people back in time to interact with others in a familiar and comfortable environment. A scenic walk or slow-paced cycle ride, on the other hand, could encourage activity and mobility in elders. Groups could share the experience, enabling those otherwise at risk of isolation to feel engaged and connected, while enjoying the convenience and comfort afforded by participating from their own home. The technology to support this is ready now. The application development and marketing are critical ingredients of the mix that need to catch up.

Affordability is a part of the marketing mix to address. Innovations that involve cutting-edge technology typically need a successful high-volume application to generate sales revenue and create demand, both of which drive technical progress and enable the economies-of-scale needed for more niche applications – such as medical and healthcare equipment – to become economically viable. As far as AR and VR are concerned, the gaming market can provide that driver. Gamers' enthusiasm for high-performing PCs and consoles sustains a global hardware market worth about $50 billion. The AR and VR gaming markets, although younger and smaller, are growing quickly from a current base of about $3 billion in the US alone. More importantly, major computing pioneers, including Google, Facebook and Microsoft, seek a market edge by acquiring AR and VR startups. That expertise could give them an advantage in developing solutions across a variety of applications and markets, including retail and industrial, as well as health and aging-related applications.

Of course, the more tightly we weave connected technologies into the fabric of our daily lives, the more serious the consequences if they become compromised by cyberattack. This can range from "bricking" devices to prevent them from being used, to more sophisticated attacks that take over equipment and manipulate the responses. The results could be inconvenient, dangerous, or even potentially deadly if the attack involves an exploit like disrupting a surgical procedure.

As a technology ambassador, I believe in the power of science and innovation to help us deal with our challenges and goals as we seek to improve quality of life for as many people as possible. On the other hand, we must be discerning and realistic about the technologies we create. They will elicit both positive and negative human responses, which must be considered seriously to inspire better quality innovations. Some of the most challenging are the ethical issues that arise as we seek to make medicine, healthcare and elderly care more efficient and effective.

We can never expect every new technology simply to fulfill our needs and desires without raising questions and introducing challenges. Overcoming these is every bit as important as perfecting the underlying engineering. ❑

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Actual Copper Thicknesses (As Opposed to What You've Assumed)

Weight is still used as a determinant for copper thickness. Why?

SOMETIMES MY COLUMNS tie to issues or stackups that appear in my inbox each week. I'm occasionally asked why 0.6 mils (15µm) is often used for the thickness of 0.5-oz. copper, rather than 0.7 mils (18µm), and similarly why 1.2 mils (30µm) is often used for 1-oz. copper instead of 1.4 mils (36µm). If you're curious about the details, or if none of these numbers seems familiar, here's a quick primer. The thickness parameter "t" in **FIGURE 1** shows the thickness we're interested in here.

Let's start the discussion with why weights (ounces) are used to describe thickness. If someone asked your height and you told them 180 lbs., they would think you were crazy. However, in electronics, weight is still used as a determinant for copper thickness. Why is that?

The ounce rating has its roots in the gold-foil industry and, subsequently, for copper's use in the building industry. It's based on spreading an ounce of a given metal over one square foot of area. Today's copper foils for printed circuit boards are manufactured and sold by weight. The method has persisted for electronic circuits. There's a good reason for it.

Nominal thickness. Thickness determination of rolled and electro-deposited (ED) copper foil by weight provides far more accuracy than contact-thickness gauges. Since the topography of treated foil varies greatly, and since the density of copper is known, weighing a 1 x 1 ft. sheet is the best way to determine the average thickness of a sheet of copper. So formally, the unit that we refer to as "ounces" is actually *ounces per square foot*. For example, 1-oz. copper weighs one ounce per square foot and is 0.00135" or 34µm thick, nominally, as shown in **TABLE 1**. Some sources report the nominal thickness of 1-oz. copper at 35µm, but I'm using the IPC numbers rather than Wikipedia.

IPC-4562A. You may read other values for these nominal thicknesses from other sources, but manufacturers in the PCB industry are working from IPC-4562A, *Metal Foil for Printed Board Applications*.[1] If your laminate or copper vendor provides different thicknesses, you may want to use this standard – or this column – as a guide for double-checking the numbers they provide. To this day, in fact, I see electronic design (EDA) tools using nominal thicknesses in their stackup representations, rather than the as-fabricated thicknesses.

The subject of copper weight and thickness becomes even more interesting when you factor in the *tolerances* described in IPC-4562A, which specifies the *minimum thickness* shall not be more than 10% below the nominal value in Table 1. If you're a copper manufacturer pushing 2,000-5,000 tons of copper foil out per month, and you can keep your volume-production copper weights above 90% of the nominal values in Table 1, that's a great way to save some money, and that's in fact what happens in practice. The third column in Table 1 shows these 90% of nominal values, which are shown graphically for 1-oz. copper in **FIGURE 2**.

Post-fabrication. After fabrication, including etching and cleaning processes, the final thickness of

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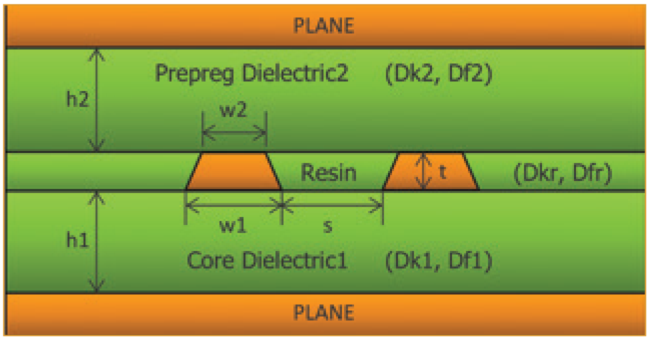

FIGURE 1. The parameter "t," shown in a stripline cross section, represents the thickness we're interested in here. (Image from Z-zero Z-solver)

these foils will average 0.2 mils (5µm) thinner than the "assumed" thickness (1.4 mils) for 1-oz. copper (Figure 2). Table 1 shows that 0.5-oz. copper will have a final thickness of about 0.6 mils (15µm). The fabricator may have an etching process that differs slightly from these values, but on 95% of the stackups I see from fabricators, these are the values used.

As a side note, the aluminum foil that most use for household cooking purposes is about 0.6 mils (15µm) thick, just like half-ounce copper.

Using inaccurate copper thicknesses. To calculate bulk resistivity from sheet resistance, sheet thickness is in the denominator, and whether you're getting the thickness from an assumed or estimated thickness, as opposed to the weight-based methodology noted above, you need to understand the real values in PCBs, rather than values you might find on Wikipedia, for example.

I often see engineers, designers and EDA tools rounding the above nominal values to 0.7 mils (18µm), 1.4 mils (36µm), and 2.8 mils (71µm). I'm not normally against rounding, but when you're rounding in the wrong direction, it needs to be questioned.

Board thickness, too, will be affected. On a four-layer design, the difference may not be significant, but on a 20-layer design using 1-oz. copper throughout and the wrong assumptions, the board thickness will be off by as much as 4 mils. I'm sure the mechanical engineers, if no one else, will appreciate if PCB designers worked with a sharper pencil.

FIGURE 3 shows impedance and skin effect loss at 10GHz for an 85Ω sample cross-section for 0.5-oz. copper using the post-fabrication number. Truth be told, the difference between a 0.7-mil thickness and the more-correct 0.6-mil thickness isn't huge, but if you're tracking millivolts and picoseconds, while signaling at multi-gigabit Serdes speeds and taking the time to simulate virtual prototypes using expensive signal-integrity software, it only makes sense to take every form of avoidable uncertainty off the table. Differential impedance will be affected. Signal integrity and crosstalk simulations will be affected. And losses from skin effect will be affected at some level. Why not feed that expensive SI simulator real numbers? □

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1. IPC-4562A, *Metal Foil for Printed Board Applications,* April 2008.

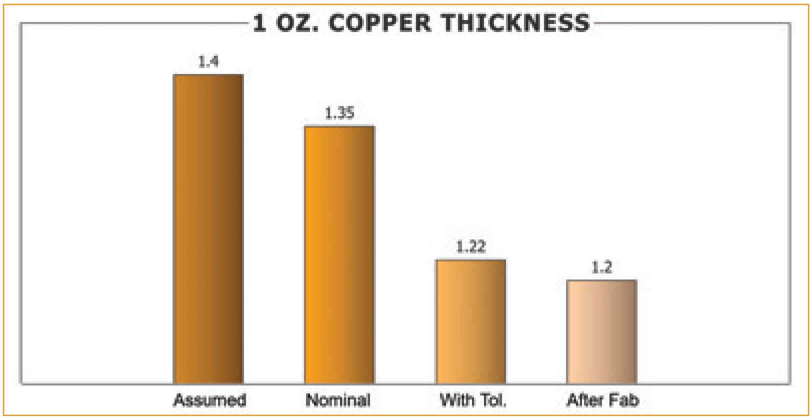

FIGURE 2. The variation in copper-foil thickness for 1-oz. copper, including the thickness that many designers assume, the IPC-4562A nominal thickness, the minimum IPC tolerance thickness, and a typical value after fabrication.

TABLE 1. Common Copper Foil Thicknesses, per IPC-4562A

Copper Weight (oz.)	Nominal Thickness	After Fabrication	90% of Nominal
½ oz.	0.68 mils (17.1µm)	0.6 mils (15µm)	0.61 mils (15.5µm)
1 oz.	1.35 mils (34.3µm)	1.2 mils (30µm)	1.22 mils (30.9µm)
2 oz.	2.7 mils (68.6µm)	2.4 mils (61µm)	2.43 mils (61.7µm)

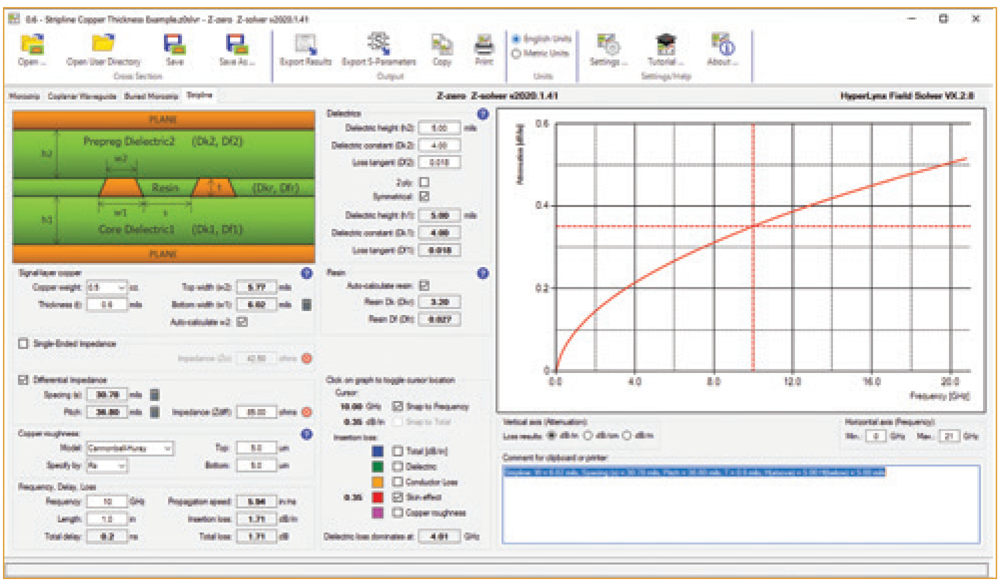

FIGURE 3. Impedance and skin effect loss at 10GHz for an 85Ω example stripline cross-section from Figure 1 using 0.5-oz. copper and the post-fabrication number. (Z-zero Z-solver)

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How to determine the critical length of a signal.

by **CHARLES PFEIL**

Ed.: The following is excerpted from the author's new book titled *High-Speed Constraint Values and PCB Layout Methods.* The book and accompanying calculator give effective constraint values based on signal edge rate and stackup information. The book and calculator are available as free downloads at https://pcdandf.com/pcdesign/index.php/constraints. This excerpt presents Chapter 3, which describes the best way to determine if a routed signal needs high-speed management. Other chapters in the book describe the layout methods and constraints to prevent signal degradation.

When a signal exceeds its critical length, it becomes a distributed length transmission line, and its effects must be managed properly, or it will become significantly degraded. The critical length is the primary filter for determining if a net requires high-speed management.

- If a signal can be routed to less than its critical length, it will most likely not have the high-speed concerns described in this book, which need to be mitigated.
- Critical length is exceeded when the time to propagate a conductor's length is greater than 1/4 of the signal rise or fall time, whichever is faster. This is when the problems begin.
- If the total interconnect of the net is greater than its critical length, it must be managed with the constraints and/or methods described in this book.
    - Total interconnect length includes pin-package, routing, and via-used lengths.
- Create max length constraints to flag nets exceeding their critical length.

FIGURES 2 and **3** present example critical length values for max length rules at which the signal "begins"[1,2] to have, or will "definitely"[3] have problems.

Use the High-Speed Constraint Calculator to determine the critical length values for specific edge rates and board materials.

Two charts are used, one for single-ended nets (Figure 2) and one for differential pairs (Figure 3). The propagation delay (Tpd) of differential pairs is about 9% faster than single-ended nets in the

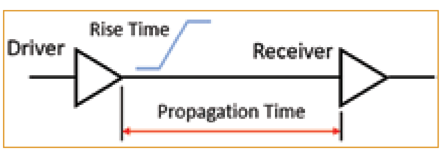

FIGURE 1. Propagation time vs. rise time[2].

Critical Length - Single-Ended Nets

	Edge Rate	English Units: Max Length Rule: Problems Begin (Tr/4)	English Units: Max Length Rule: Problems Definite (Tr/2)	Metric Units: Max Length Rule: Problems Begin (Tr/4)	Metric Units: Max Length Rule: Problems Definite (Tr/2)
MICROSTRIP Er = 2.98	2 ns	3.42 in	6.83 in	86.75 mm	174 mm
	1 ns	1.71 in	3.42 in	43.38 mm	86.75 mm
	700 ps	1.20 in	2.39 in	30.36 mm	60.73 mm
	500 ps	854 mil	1.71 in	21.69 mm	43.38 mm
	300 ps	512 mil	1.02 in	13.01 mm	26.03 mm
	100 ps	171 mil	342 mil	4.34 mm	8.68 mm
	50 ps	85 mil	171 mil	2.17 mm	4.34 mm
	25 ps	43 mil	85 mil	1.08 mm	2.17 mm
STRIPLINE Er = 4.10	2 ns	2.91 in	5.83 in	74.01 mm	148 mm
	1 ns	1.46 in	2.91 in	37.01 mm	74.01 mm
	700 ps	1.20 in	2.39 in	30.36 mm	60.73 mm
	500 ps	728 mil	1.46 in	18.50 mm	37.01 mm
	300 ps	437 mil	874 mil	11.10 mm	22.20 mm
	100 ps	146 mil	291 mil	3.70 mm	7.40 mm
	50 ps	73 mil	146 mil	1.85 mm	3.70 mm
	25 ps	36 mil	73 mil	0.93 mm	1.85 mm

FIGURE 2. Critical length values – single-ended nets.

Critical Length - Differential Pairs

	Edge Rate	English Units: Max Length Rule: Problems Begin (Tr/4)	English Units: Max Length Rule: Problems Definite (Tr/2)	Metric Units: Max Length Rule: Problems Begin (Tr/4)	Metric Units: Max Length Rule: Problems Definite (Tr/2)
MICROSTRIP Er = 2.98	2 ns	3.11 in	6.22 in	78.95 mm	158 mm
	1 ns	1.55 in	3.11 in	39.47 mm	78.95 mm
	700 ps	1.09 in	2.18 in	27.63 mm	55.26 mm
	500 ps	777 mil	1.55 in	19.74 mm	39.47 mm
	300 ps	466 mil	932 mil	11.84 mm	23.68 mm
	100 ps	155 mil	311 mil	3.95 mm	7.89 mm
	50 ps	78 mil	155 mil	1.97 mm	3.95 mm
	25 ps	39 mil	78 mil	0.99 mm	1.97 mm
STRIPLINE Er = 4.10	2 ns	2.65 in	5.30 in	67.35 mm	135 mm
	1 ns	1.33 in	2.65 in	33.67 mm	67.35 mm
	700 ps	928 mil	1.86 in	23.57 mm	47.14 mm
	500 ps	663 mil	1.33 in	16.84 mm	33.67 mm
	300 ps	398 mil	795 mil	10.10 mm	20.20 mm
	100 ps	133 mil	265 mil	3.37 mm	6.73 mm
	50 ps	66 mil	133 mil	1.68 mm	3.37 mm
	25 ps	33 mil	66 mil	0.84 mm	1.68 mm

FIGURE 3. Critical length values – differential pair nets.

same dielectric constant; therefore, the critical length for differential pairs is about 9% shorter.

Solution:

1. Max length constraints. Create constraints based on edge rates to identify critical length nets in the design by classes as described in Chapter 2.
2. Reference planes, termination, impedance. See the Introduction in Chapter 1 to properly address these issues, as they are essential for critical length nets.
3. Placement. Use the max length rule as a filter during placement to discover which nets have exceeded their critical length. Then move the components closer to possibly prevent the nets from exceeding their critical length.
4. Routing. During routing, some nets may exceed their critical length due to excessive meandering. A max length rule flags them.
5. Simulation. When working with high-speed signals, it is imperative to simulate to ensure timing, signal integrity (SI) and electromagnetic interference (EMI) problems are mitigated sufficiently to produce a layout that works as intended.

Equations.

$$\text{Critical Length [in]} = \frac{\text{Edge Rate x Light Speed}}{\sqrt{\text{Dielectric Constant}}} = \frac{\text{Tr x C}}{\sqrt{\text{Er}}} = \frac{\text{Tr x 11.8[in/ns]}}{\sqrt{\text{Er}}}$$

Example: Single-ended stripline, Tr = 0.1 ns, Er = 4.1

$$\frac{\text{0.1[ns] x 11.8 [in/ns]}}{\sqrt{4.1}} = \frac{\text{1.18 [in]}}{2.025} = \text{0.582[in]} = \text{582[mils]}$$

The single-ended critical length values in the chart are based on Tr/4 and Tr/2:

1. Problems begin @ Tr/4, for example, 582 mils /4 = 146 mils
2. Problems definite @ Tr/2, for example, 582 mils /2 = 291 mils

Example: Differential pair stripline, Tr = 0.1 ns, Ɛr = 4.1
(Tpd of differential pairs is about 9% faster than single-ended)

$$\frac{\text{0.91 x 0.1[ns] x 11.8 [in/ns]}}{\sqrt{4.1}} = \frac{\text{1.07 [in]}}{2.025} = \text{0.530[in]} = \text{530[mils]}$$

The differential pair critical length values in the chart are based on Tr/4 and Tr/2:

1. Problems begin @ Tr/4, for example, 530 mils /4 = 133 mils
2. Problems definite @ Tr/2, for example, 530 mils /2 = 265 mils

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SUMMIT INTERCONNECT Scales New Heights

Fresh off its latest acquisition, there's a sense of déjà vu. Is this the next big American fabricator? **by MIKE BUETOW**

When a pair of West Coast US fabricators called Pacific Circuits and Power Circuits merged more than 30 years ago, probably no one knew the new entity would someday become the largest PCB manufacturer in the world. The deal was financed by two private equity firms, one of which was Thayer Capital Partners. With it came a rebranding to TTM Technologies. The deal was the first in a long series of M&A activities that over the next 15 years eventually rolled up Details, the PCB units of Honeywell and Tyco, Hong Kong's Meadville PCB, and Viasystems, among others.

So, observers are forgiven then if the narrative developing with Summit Interconnect feels a little familiar.

It begins with the formation of the company in 2016 through the merger of two Southern California – where else? – board shops, KCA Electronics and Marcel Electronics. Separately, several Thayer partners had formed HCI Equity Partners, which funded the new entity, now renamed Summit. A follow-on acquisition took place in December 2018, when Santa Clara-based Streamline Circuits was added to the fold.

Then in July, Summit announced the acquisition of ITL Circuits, a Toronto-area fabricator with a 65,000 sq. ft. factory and approximately 130 employees. At a glance, the company resembles its new parent. It has historically served the high-rel market, holding certifications for AS9100, Nadcap, MIL-PRF-31032 and ITAR registration, and features an in-house custom metal shop capable of producing heat sinks and metal-backed boards.

That brings to four the number of facilities Summit operates, including the three in California. Moreover, the privately held Summit becomes the second-largest fabricator in North America, behind the aforementioned TTM, with estimated annualized revenues topping $160 million and a head count of about 810 employees, based on NT Information data and PCD&F sources.

Another coincidence? Summit chief executive and president Shane Whiteside was TTM's chief operating officer during its 1998 to 2015 run.

Whiteside discussed the rationale for Summit's latest acquisition and its broader goals in an interview with PCD&F in August.

Mike Buetow: ITL can do some pretty interesting things: high-layer count boards, up to 200 mils thick, and maybe more at this point rigid and flex boards. It's certified to AS9100. It looks like it has quite a bit of drilling capacity. These capabilities seem to line up with the capability you have in the California shops. What was it that you found attractive about ITL?

Shane Whiteside: We've been looking to expand for quite a while. The opportunity to expand with ITL was attractive because we are at or near capacity at our three locations in California. We have a fairly large and very effective sales force, and they were very clear to me and other senior executives that if you can do anything for us, get us more capacity. A shop with ITL's capability and capacity was attractive to us.

MB: What's Summit's basic strategy, and how does ITL fit into it?

SW: Our strategy is to provide leading-edge capabilities to our customer base, which is mostly defense and high-end commercial focused and to assemble operations with complementary capabilities and create something of value for our customers and shareholders. For our customers back in the 1990s, we used to be able to make the board and put it in a box and ship it. Now the value proposition customers expect is more specific: DfM on every job, stackup assistance, assistance with materials selection, a lot more statistical reporting, a lot more data, reliability testing. The value expectations these days are quite extensive. We believe it requires scale to deliver that value effectively and consistently.

MB: Do you currently build for any OEMs that are located outside North America?

SW: Yes.

MB: I know you have partnerships with offshore fabricators. Do you anticipate expanding to owning plants offshore?

SW: That's not in our front-sight focus at this time.

MB: Are there other time zones or geographies you find attractive?

SW: We don't really have a geographically based strategy. California is not a very business friendly place, or maybe I should say, other places are easier to do business in, so anything outside California is going be of interest.

MB: The IPC bare board numbers have been pretty good: 13 months of a B2B ratio above 1.0. Still, we are a long way from the peak 1999-2000 era. How would you characterize the state of the PCB market right now?

SW: We see a lot of strength, consistent with the IPC reporting. We see it very much driven by defense OEMs and, to a lesser extent, certain commercial OEMs. The demand outlook with some of our largest customers is very solid.

MB: Dr. Nakahara sent me his latest NTI-100, and he has Summit at $120 million in revenue for calendar 2019, double that of 2018. (Ed.: See the latest NTI-100 in this issue.) The acquisitions are paying off on the topline, it seems.

SW: We're seeing a very strong business environment, even with the Covid-19 impact. All three plants (in California) have grown significantly since we purchased them. ITL is relatively new, so I'm referring to the California plants.

MB: Summit is now the second-largest PCB fabricator in terms of North America revenue. That happened fast.

SW: We've been operating as Summit for four years now, and the company as it exists today is the result of four acquisitions to build the company to where it is now. We introduced a new brand name to the PCB industry, which we were cautious about doing, but I'm glad we did it. We are proving we are investing in our business and organizational depth, and we are seeing a great reception from customers.

FIGURE 1. In addition to the newly acquired ITL, Summit has three plants, including Anaheim ...

FIGURE 2. ... Orange ...

FIGURE 3. ... and Santa Clara.

MB: How would you characterize the private equity interest in the fabrication industry today? They kind of took a breather for a while there, but it seems like activity has picked up quite a bit in the past couple years.

SW: I think there's interest because there's an understanding the industry found bottom and has been growing. Since the middle of 2017, our industry has been growing pretty consistently from an overall vertical market perspective. There's now a strong and widely held expectation of PCB market growth going forward. That will attract investor interest.

MB: You went through a similar experience with TTM. Do you feel a sense of déjà vu?

SW: That's an interesting question. Yes and no. Yes, because I'm feeling the same excitement in building something. But no, because much of my time in TTM was navigating a declining American market and the plant closures and restructuring we had to do. I'm in a different place in my life now, but very excited because the industry is back in growth mode, like it was in the mid-1990s. I really enjoyed my time at TTM; it was a great experience, and I enjoyed great working relationships. I'm enjoying that again at Summit in this new chapter in my career.

MB: Looking 12 to 18 months out from now, how will you know you've been making progress? What metrics are you using to define success?

SW: We are measuring success metrics like our year-over-year growth, the ability to hit an ambitious budget, and customer metrics like on-time delivery and quality. We have external investors as well, so providing them return on investment is also a success metric. They have certain expectations, and if we can deliver on them down the road, that will be a success as well. ❑

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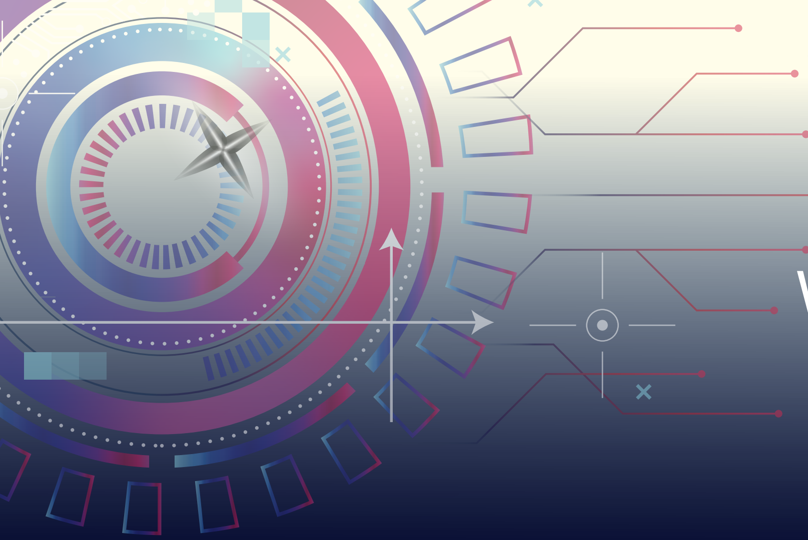
"The value expectations these days are quite extensive. It requires scale to deliver that value effectively and consistently."



A Not-So-Fabulous Year for FABRICATORS

How will the pandemic play out in the PCB world?

by DR. HAYAO NAKAHARA

Here we are, nine months into 2020, with little insight as to how the rest of the year will turn out for printed circuit fabricators. When was the last time that occurred? Perhaps more than a decade ago? The 5G implementation drove revenue gains at the best-performing PCB fabricators last year and are providing a foundation for 2020 as well. Automotive, on the other hand, is sputtering, as car sales have crashed with the onset of the Covid-19 pandemic. Who could have seen any of this when the book closed on 2019?

Six months of effort resulted in this latest NT-100 report, now in its 25th annual edition. As mentioned many times, each year it gets harder to compile the list, thanks to many new entries from growing Chinese fabricators, only one-quarter of which are publicly traded and publish annual reports (not always in time for the purpose of this report). The data from most unlisted Chinese fabricators are extracted from the "Top 100 Fabricators" published by CPCA. Unfortunately, valuable as it is, the CPCA list has some flaws in that it misses some important fabricators, and some entries are by factory, not company. Nevertheless, without the CPCA data, the NTI-100 would not be possible. TPCA data are valuable but include only stock-listed fabricators. Therefore, this author contacted those fabricators not publicly listed. They gracefully provided their sales revenues. Likewise, only AT&S and Schweizer Electronics publish annual reports. Other European entries, including KSG, Somacis and Würth Elektronik, provided the author their revenues. Southeast Asia fabricators were likewise cooperative. The author expresses gratitude to all who provided the valuable data.

Still, many entries are estimates, particularly those operations that are part of large corporations. Usually, they do not break out their PCB

TABLE 1. Average Exchange Rates vs. US$1

Currency	2014	2015	2016	2017	2018	2019
China yuan (RMB)	6.158	6.284	6.634	6.758	6.616	6.910
Japan yen	105.86	121.06	107.84	112.93	110.44	109.01
Taiwan NTD	31.855	31.777	32.25	30.44	30.16	30.93
Korea won	1,053.58	1,132.33	1,160.80	1,130.59	1100.8	1165.7
Thailand Baht	32.482	34.253	35.290	33.92	32.32	31.03
Singapore dollar	1.276	1.375	1.440	1.334	1.349	1.364
Malaysia ringgit	3.270	4.120	4.100	4.32	4.035	4.123
Vietnam dong	21,137.07	21,920.68	22,763.00	22,721.03	23,001.08	23.202.59
Philippine peso	44.399	44.520	47.300	50.44	52.7	50.82
Indonesia rupiah	12,671.31	13,749.27	13,320.00	13,440.00	14,236.00	13,798.61
Russian ruble	**1.104**	**1.279**	**0.997**	**1.297**	**1.296**	**1.327**
Indian rupee	61.007	64.235	67.800	64.87	68.43	70.39
Mexican Pesos	13.306	15.792	19.05	18.95	19.00	19.25
Russian ruble	38.512	61.195	57.4	58.31	62.78	64.69
Switzerland franc	0.915	0.962	0.997	0.98	1.022	0.994
UK pound	0.606	0.655	0.74031	0.81	0.75	0.784
Euro	0.754	0.902	0.904	0.886	0.844	0.894

NT Information summary from exchangerates.com

TABLE 2. Top Fabricators in 2000

Country	No. Entries	Country PCB Revenue	Share
China	6	916	3.2%
Taiwan	19	3,935	13.8%
Japan	51	11,957	42.0%
S. Korea	7	1,835	6.5%
US	20	7,509	26.4%
Europe	16	1,934	6.8%
SE Asia	3	378	1.3%

In US$ millions. Source: N.T. Information revenues. The author made educated guesses in these cases. Some errors, big or small, do exist. The author is solely responsible for any errors. He hopes PCB manufacturers can compare where they stand among competitors, and equipment and materials fabricators can see where to "attack." In summary, readers are cautioned the rankings are a reasonably accurate portrayal of the largest PCB fabricators, but do not assume total accuracy.

In recent years, more rigid board fabricators have engaged in assembly. For some time, major PCB fabricators engaged in EMS activities have been flex circuit (FPC) manufacturers for Apple products, but the situation is changing. A rough estimate of value-added assembly by "PCB fabricators" not by EMS specialists, flex or rigid PCBs, is about $6 billion. It is no longer possible to accurately separate the assembly value from the total output of PCB fabricators. Therefore, the aggregate total of the top 122 fabricators includes the PCBA value.

Of 122 fabricators with 2019 revenue equal to or greater than $100 million, some 52, or roughly 43%, saw sales fall. But their losses were compensated by gains made by the others.

In the past, the names of the fabricators in their native countries were provided. If readers want to know, let this author know. He will be happy to provide the "native names."

Exchange rates. Exchange rates of most of the major currencies in 2019 were about the same as in 2018, except for the Chinese RMB and South Korean won (TABLE 1). The average exchange rates are calculated by adding day-to-day exchange rates listed in exchangerates.com and divided by the number of days, approximately 260 days per year, excluding Saturdays and Sundays. To illuminate growth or decline by each fabricator in local currencies, 2018 revenues were converted to US dollars using 2019 exchange rates. Therefore, slight differences may be seen in the revenues listed in the 2018 NTI-100.

Comparison between 2000 and 2019. Before moving to the NTI-100 2019, let's compare 2019 against 2000. The author presented 200 fabricators in 2000, from which 122 fabricators are extracted to compare against the latest rankings. Interestingly, exchange rates in 2000 were not much different from those in 2019, except the RMB.

A comparison of TABLES 2, 3 and 4 reveals some interesting transformations.

TABLE 3. NTI-100 2019 Summary by Country

Country	No. Entries	2018 Top Revenue	2019 Top Revenue	2019/2018 Growth
Taiwan	27	20,470	21,152	3.3%
China	52	15,062	16,919	12.3%
Japan	18	11,680	11,229	-3.8%
S. Korea	12	7,271	7,125	-2.0%
US	4	3,257	3,109	-4.5%
Europe	5	1,811	1,725	-4.7%
SE Asia	4	1,096	1,058	-3.5%
Total	**122**	**60,647**	**62,317**	**2.8%**

In US$ millions. Source: N.T. Information

TABLE 4. NTI-100 2019 by Number of Entries

Country	No. Entries	Percentage	2019 Output	Output Share
China	52	42.6%	16,919	27.1%
Taiwan	27	22.1%	21,152	34.0%
Japan	18	14.8%	11,229	18.0%
S.Korea	12	9.8%	7,125	11.4%
Europe	5	3.3%	1,725	2.8%
USA	4	4.1%	3,109	5.0%
SEA	4	3.2%	1,058	1.7%
Total	**122**	**100%**	**62,317**	**100%**

In US$ millions. Source: N.T. Information

TABLE 5. NTI-100 Top 15 Fabricators, 2000

Rank	Company	Country	$million	2020 Remarks
1	Sanmina	US	1,550	2019: $280M
2	Viasystems	US	1,250	Absorbed into TTM
3	CMK Corp	Japan	1,112	75% automotive, which is hurting the firm now
4	Ibiden	Japan	1,083	IC substrate top maker (high-end)
5	Hitachi Group	Japan	973	Hitachi Ltd. closed PCB and Hitachi Chem. sold
6	Nippon Mektron*	Japan	905	The king of flex printed circuits
7	Compeq	Taiwan	802	Grown to $1.82B. Expansion in China
8	Multek	US	780	Sold to DSBJ, a part of M-Flex
9	Fujitsu	Japan	624	Shrank to half ($280M)
10	Tyco PCB	US	600	Now part of TTM
11	Shinko Denski	Japan	550	High-end IC substrate
12	Daeduck Group	S. Korea	480	Daeduck Elec & GDS merged and doubled
13	DDi	US	450	DDi→Viasystems→TTM
14	IBM	US	540	Only IBM Yasu survived, as a part of Kyocera
15	Matsushita MACO	Japan	445	ALIVH fame is completely closed
	Top 15 Total		**12,144**	**US (6), Japan (7), Taiwan (1), S. Korea (1)**

*FPC | Source: N.T. Information

TABLE 6. NTI-100 World Top PCB Fabricators, 2019

Rank	Company	Country	2018	2019	Growth	Comments
1	ZD Tech*	Taiwan	3,831	3,887	1.46%	Expanding and buying Boardtek (October 2020)
2	TTM Technologies	USA	2,847	2,689	-5.55%	Sold mobility-related business to AKMMeadville
3	Unimicron	Taiwan	2,450	2,668	8.9%	IC substrate expansion $800M?
4	Nippon Mektron	Japan	2,700	2,597	-3.81%	Heavy dependence on smartphone hurts
5	M-Flex (Dongshan Precison)	China	1,652	2,115	28.02%	M-Flex + Multek (Multek is expanding)
6	Compeq	Taiwan	1,634	1,816	11.14%	No. 2 plant in Chongqing will be operational at year end
7	Tripod	Taiwan	1,685	1,760	4.45%	Xiantao plant expanding
8	Shennan Circuit	China	1,129	1,523	34.9%	New IC substrate plants in Wuxi
9	HannStar	Taiwan	1,399	1,395	-0.29%	HannStar Board = GMB+Elan
10	Samsung E-M	S. Korea	1,273	1,386	8.88%	Shut down Kunshan HDI plant
11	KBC PCB Group	China	1,250	1,234	-1.28%	Several fabs under wing such as Elek & Eltek
12	Ibiden	Japan	1,064	1,213	14%	$1.2 billion IC substrate expansion (2020-2021)
13	Wus Group	Taiwan	971	1,193	22.86%	Is it a Taiwan maker or Chinese maker? Maybe Chinese
14	Young Poong Group	S. Korea	1,273	1,149	-9.74%	Interflex is recovering
15	AT&S	Austria	1,150	1,119	-2.7%	$1.3 billion investment over 5 years
16	Meiko	Japan	1,091	1,060	-2.84%	Trying to expand market horizon
17	Nanya PCB	Taiwan	932	1,005	7.83%	IC substrate for high-end servers doing well
18	Fujikura	Japan	1,120	956	-14.64%	More than 90% revenue comes from overseas
19	Daeduck Group	S. Korea	836	920	10.05%	Strong in IC substrate and high-end MLB
20	Kinwong	China	709	914	28.91%	New plant in Zhuhai
21	Simmtech	S. Korea	864	858	-0.69%	Includes Eastern in Japan and Xian plant
22	Flexium*	Taiwan	866	843	-2.66%	Apple, Apple, Apple
23	CMK	Japan	828	758	-8.45%	Heavy dependence on automotive
24	Shinko Denki	Japan	690	748	8.4%	High-end IC substrates like Ibiden
25	Unitech	Taiwan	632	725	14.72%	50%+ comes from rigid-flex PCB
26	Kinsus	Taiwan	767	722	-5.87%	IC substrate, contact lens
27	T.P.T.	Taiwan	746	702	-5.9%	PC motherboard and LCD driver circuit boards
28	Sumitomo Denko	Japan	831	671	-19.25%	What went wrong?
29	LG Innotek	S. Korea	661	616	-6.8%	Shutting down HDI and regular PCB plants
30	Gold Circuit	Taiwan	666	615	-7.66%	Currently strong with PC motherboards and tablets
31	Chin Poon	Taiwan	653	578	-11.48%	Automotive dependence is hurting
32	BH Flex	S. Korea	659	562	-14.72%	Three plants in Vietnam (north of Hanoi)
33	Victory Giant	China	477	561	17.61%	Added HDI plant
34	Career*	Taiwan	502	551	9.76%	24% of shares now owned by HannStar Board
35	Shenzhen Fast Print	China	501	549	9.58%	China, USA and UK
36	Shenzhen Suntak	China	527	515	-2.28%	New plant in Zhuhai
37	Kyocera PCB	Japan	550	500	-9.09%	A bit of a guess
38	SI Flex	S. Korea	472	462	-2.12%	Only in Vietnam; S. Korean plants are shut down
39	Murata	Japan	505	450	-10%	MetroCirc, LCP-based multilayer flex boards
40	DG Shengyi Electronics	China	294	447	52%	New plants in Ji'An and Dongguang (HDI)
41	Dynamic	Taiwan	421	443	5.26%	Taiwan plant was shut down
42	Isu-Petasys	S. Korea	481	439	-8.73%	Two groups and a US plant
43	Founder Tech	China	353	438	24.01%	Including ACCESS (new plant in Nantong)
44	Ellington	China	480	434	-9.58%	Automotive and motherboards
45	Nitto Denko	Japan	373	397	6.43%	HDD suspension specialist
46	Bomin	China	281	385	37.01%	What products drove 37% growth is not known
47	Kyoden	Japan	405	377	-6.22%	Japan and Thailand (collaboration with APEX)
48	KCE Electronics	Thailand	419	374	-10.74%	Heavy dependence on automotive, trying to diversify
49	CCTC	China	356	366	2.81%	Not much expansion
50	Wuzhu	China	368	357	-2.99%	Shenzhen, Meizhou, Dongguan and Gangzhou (new)
51	Xiamen Hongxin	China	325	355	9.23%	FPC specialist
52	Olympic	China	306	343	12.09%	Smart factory expanding
53	Hitachi Chemical	Japan	384	337	-12.24%	Bought by Showa Denko and removed from Tokyo Exchange
54	APEX	Taiwan	361	336	-6.93%	Thailand APEX 2 expanding with a new plant
55	Aoshikan	China	323	328	1.55%	Know to process large panels
56	Gul Technologies	Singapore	338	316	-6.51%	A small hiccup
57	Redboard	China	280	310	10.71%	HDI and rigid-flex
58	CEE PCB	China	251	303	20.72%	Absorbed
59	Guangdong Xinda	China	287	295	2.79%	CPCA data
60	Sun & Lynn	China	268	291	8.58%	Company report
61	Sanmina	USA	280	280	0%	Two plants in US, one each in Singapore and Wuxi
62	ASE	Taiwan	255	260	1.96%	IC substrate plants in Kaoshiung and Shanghai

TABLE 6. NTI-100 World Top PCB Fabricators, 2019 (cont.)

Rank	Maker	Country	2018	2019	Growth	Comments
63	APCB	Taiwan	289	256	-11.42%	Emphasis in Thailand
64	Fujitsu Interconnect	Japan	233	243	4.29%	Slight increase
65	Boardtek	Taiwan	246	241	-2.01%	Being purchased by Zhen Ding Technology (ZDT)
66	AbonMax (Palwonn)	Taiwan	234	240	2.56%	Not sure, very shadowy maker (Shenzhen and Suzhou)
67	MFS	Singapore	238	240	0.84%	New plant in Yiyang
68	DAP	S. Korea	261	232	-11.11%	Have not visited for many years. HDI board maker
69	STEMCO	S. Korea	199	231	16.08%	CoF specialist, JV between Samsung and Toray
70	Shirai Denshi	Japan	253	230	-9.09%	Visper AVI is slow (not included)
71	AKM	China	177	217	22.60%	Paid TTM $550 million for Mobility business
72	Guangzhou Jun Ya	China	162	212	30.84%	CPCA data
73	Ichia*	Taiwan	234	201	-14.1%	Not doing well in recent years
74	Kunshan Huaxing	China	195	199	2.05%	CPCA data
75	Delton	China	138	192	39.13%	Not sure about 2018 revenue
76	Guangzhou Kingshine	China	173	192	10.98%	CPCA data
77	Guangdong Chaohua	China	201	191	-4.98%	CPCA data. Makes laminates as well
78	Circuitronics	China	192	180	-6.25%	Wild guess
79	Somacis	Italy	177	180	1.69%	Dongguan plant expanding
80	Würth Elektronik	Germany	172	179	4.07%	Steady
81	Kyosha	Japan	193	174	-9.84%	A new plant near Hanoi, Vietnam
82	SZ Sandeguan Prec. Circuit	China	192	173	-9.9%	CPCA data
83	Liang Dar	Taiwan	176	171	-2.84%	Two plants in Kaoshiung and a plant in Dongguan
84	OKI PCB Group	Japan	166	167	0.6%	OKI Printed Circuits and OKI Circuits
85	Shenzhen Sunshine	China	163	166	1.84%	High-end products. Owns a small shop in Germany
86	BYD	China	156	163	4.49%	Wild guess based on 2018 data
87	Huading Group	China	154	162	5.19%	CPCA data
88	SZ Jove Enterprise	China	131	161	22.9%	CPCA data
89	Onpress	China	166	160	-3.61%	Gold plating and automtoive
90	Lead-Tech	China	173	159	8.09%	Four plants in China, one making CoF
91	Daisho Denshi	Japan	168	156	-7.14%	Never laid off employees, even during hard times
92	Ji'An Mankun	China	148	155	4.73%	From a friend
93	Tai Hong Ind	Taiwan	180	150	-16.67%	Wild guess. China plant shut down
94	Tigerbuilder	China	145	150	3.45%	Changing market direction
95	3Win Group	China	141	147	2.25%	Wild guess. Website does not work
96	Hyunwoo	S. Korea	127	145	14.17%	Don't know this company well
97	Mutual Tech	Taiwan	136	144	5.88%	TSE
98	Amphenol PCB Division	USA	130	140	7.69%	Nashua (NH), Guangzhou (FPC) and UK (Invotec)
99	Kunshan Wanzhen PCB	China	131	138	5.34%	CPCA data
100	Guangzhou GCI	China	126	138	9.52%	CPCA data
101	Schweizer	Germany	140	135	-3.57%	Annual report, automotive 70%
102	Brain Power	Taiwan	98	128	30.61%	Plant only in China
103	Jiangsu Suhan	China	135	128	-5.19%	CPCA data
104	QDOS	Malaysia	101	128	26.73%	From a friend, FPC and IC substrate
105	KSG	Germany	157	127	-19.11%	From a friend
106	Zhuhai Kingsun PCB	China	120	125	4.17%	CPCA data
107	Changzhou Haihong	China	138	122	-11.59%	CPCA data
108	Changzhou Aohong	China	138	122	-11.59%	CPCA data
109	Yihao Circuit Tech	China	112	120	7.14%	Data from Nepcon Japan 2020
110	Summit Interconnect	USA	60	120	100%	Mergers of KCA, Marcel and Streamline Circuits
111	New Flex	S. Korea	168	118	-29.76%	FPC specialist
112	Kunshan Hua Zhu	China	114	116	1.75%	CPCA data
113	SDG Precision Tech	China	109	114	4.59%	CPCA data
114	CHPT	Taiwan	106	109	2.83%	World's largest IC probe card maker
115	Jiangxi Liangyi Elec.	China	94	109	15.96%	CPCA data
116	Camelot Elecronic Tech	China	89	107	20.22%	CPCA data
117	StaRiver (Galaxy)	China	86	107	24.42%	Three plants
118	Dongguang Hongyuen	China	99	105	6.06%	High-end PCB
119	HT (HeTon) Electronics	China	99	103	4.04%	CPCA data
120	SZ Xinyu Tengyue Elec.	China	93	101	8.6%	CPCA data
121	Yamamoto Mfg	Japan	126	100	-20.63%	Wild guess
122	Deweibao(HK) Elect.	China	92	100	8.7%	CPCA data
Top 122 Total			**60,632**	**62,315**	**2.62%**	

In US$ million. 2018 data adjusted with 2019 exchange rates (N.T. Information Ltd)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1. In 2000, only six "Chinese fabricators" were among the world's top 122 fabricators, of which CCTC was the only "native Chinese" fabricator. The rest were Hong Kong-based (Elec & Eltek, OPC, etc.). CCTC's revenue in 2000 was $68 million (RMB8.3/USD), which would have been $82 million at the 2019 exchange rate. In 2019, 52 fabricators were from China! Hong Kong-based fabricators are included in this count.
2. Japanese entries numbered 51 among the top 122 in 2000. By 2019, they dropped to 18. However, the total revenue of Japanese fabricators in 2019 ($11.18 million) remained nearly the same as in 2000 ($11.98 billion). Growth came from overseas investments, while domestic production continued to decline. In 2000, Japan and the US were neck-and-neck in revenue. These two countries accounted for 63% of the world output in 2000. The output of the US's overseas PCB factories is smaller now that TTM sold its Mobility business to the Chinese firm AKMMeadville Electronics (Xiamen), which owns Chinese flex circuit fabricator AKM Electronics, for approximately $550 million. The US presence in China is getting smaller. The sale of M-Flex and Multek to Dongshan Precision and a part of TTM business to AMKMeadville means about a $2.7 billion gain for China.
3. The US had 20 entries in 2000, but in 2019 the number declined to four. Europe had 16, but likewise the count declined to five. The revenue of the top US fabricators fell to less than half, while European revenue slipped slightly. It is likely some amount of "trades" is inclusive in European fabricators' revenues.
4. The revenue of the Chinese top six PCB companies in 2000 was $961 million, the majority of which was from Elec & Eltek and OPC. As noted, the number of Chinese entries increased to 52 in 2019, with aggregate revenues of $16.74 billion. In the future, more Chinese fabricators are expected to enter the NTI-100, as a dozen "borderline" fabricators have revenues just below $100 million. Topsun fell off the list because it is now a part of CEE. Tigerbuilder was back in 2019, after being omitted in 2018, thanks to the author's mistake. Several other Chinese fabricators disappeared from the NTI-100 because revenues fell below $100 million. On the other hand, several new fabricators from China replaced them on the 2019 list.
5. South Korea has done well the past 20 years, thanks to Samsung Electronics and LG Electronics. Its FPC production is shifting toward Vietnam, in tandem with Samsung Electronics' cellphone manufacturing migration. Its cellphone manufacturing bases in China are all shut down. SEMCO shuttered its HDI plant in Kunshan (or perhaps it sold to a Chinese company). SI Flex no longer has a manufacturing base in South Korea. LG Innotek shut down its South Korean HDI and conventional PCB plants and concentrates only on IC substrates today. South Korean PCB fabricators are quietly shifting their production to overseas plants, mainly in northern Vietnam.
6. Southeast Asian fabricators have come a long way thanks to Gul Technology and MFS. However, these two are operating in China. MFS, which has a plant in Malaysia, just completed construction of a factory in China. QDOS in Malaysia came a long way, too. GUH is trying hard, but its revenue is still $70 million. Singapore lost its leadership in the PCB industry in Southeast Asia to Thailand and Vietnam in recent years. Only three PCB fabricators remain in Singapore today: Hitachi Chemical Singapore, Sanmina and Additive Circuits.
7. The top 15 fabricators are extracted from the original NTI-200 (yes, in 2000, the author was foolish to collect data from 200 fabricators; he was still young) and shown in **TABLE 5**. Of the 15, six were US-based and seven Japan-based. Only one American fabricator retained its original name (Sanmina). On the contrary, only one Japanese disappeared. That would be Matsushita (MACO) of ALIVH fame, whose parent, Panasonic, ceased PCB manufacturing activities altogether several years ago.
8. Hitachi Group consisted of Hitachi Ltd. and Hitachi Chemical. Hitachi Ltd. had a few PCB manufacturing plants but shut them down one after another. The last one was known as Hitachi Kanagawa, which provided high-layer-count multilayer boards to IBM, along with Endicott Interconnect Technologies. After the shutdown of Hitachi Kanagawa, Hitachi Group became one member "group": Hitachi Chemical. However, its parent Hitachi Ltd. decided to sell this subsidiary (annual revenue of about $6 billion) to Showa Denko. The sale was completed, and on June 19, Hitachi Chemical was removed from the Tokyo Exchange. It will take probably a few years before Hitachi Chemical becomes fully integrated into Showa Denko, but the future of its PCB operations is unclear at this time. Its largest PCB unit is in Singapore, which contributes about 40% of total PCB revenue of Hitachi Chemical's PCB operation.
9. Viasystems came into existence in 1996 when the Texas private equity firm Hicks, Muse, Tate and Furst purchased Circo Craft in Canada and bought Lucent's Richmond (VA) PCB plant, probably one of the largest PCB plants under one roof at that time. In rapid succession, it acquired ISL and Forward Group in the UK, Italy's Zincocelere, Netherland's Mommers Print Service, Termbary Group in China, and more. As American and European pricing could no longer compete against the Chinese, Viasystems eventually shut down all its plants except those in China. Then it acquired Merix, which acquired Wong Circuits before being bought by Viasystems. Viasystems then acquired DDi. Finally, Viasytems was acquired by TTM Technologies, which this year sold four plants in China. The story of acquisitions and closures is a melodrama! Multek is now a part of China's Dongshan Precision (DSBJ) except for the Minnesota FPC plant (Sheldahl), and it seems to fall under M-Flex, which was acquired by DSBJ, in 2016. Tyco PCB was acquired by TTM. DDi is also a part of TTM as a result of TTM's purchase of Viasystems.
10. IBM had two plants in the US: Endicott and Austin; one in Sindelfingen, Germany, which became STP, then shut down; and IBM Yasu (SLC developer) in Japan, now part of Kyocera. Endicott became Endicott Interconnect Tech-

nologies and later i3. Finally, TTM purchased some assets and technologies of i3 and moved them to Chippewa Falls, WI. IBM Austin became part of Multek, but Multek shut it down and moved some usable equipment to its B5 plant in China. Sadly, IBM's PCB business unit, one of the most valuable contributors to the development of PCB technologies, is now practically gone, with only the small operation remaining at Yasu. The author fondly remembers all these plants, which he visited many times.

11. The PCB plants of "captive" fabricators in the US – Hewlett-Packard, Digital Equipment, Data General, IBM, etc. – are all gone. In Europe, the situation is the same. Siemens, Ericsson, Alcatel, Italtel and other captive PCB factories no longer exist. In Japan, Hitachi, NEC, Panasonic, Sharp, Sony and a few other captive plants are gone. Only Fujitsu and Oki Electric retain PCB plants. Fujitsu Interconnect Technologies is no longer part of Fujitsu, however. It has plants in Japan and Vietnam.
12. Compeq of Taiwan lost a tremendous amount of revenue after technical problems encountered in dealing with Intel CPU package substrates. With relentless efforts, however, it not only came back from the disaster, but retained its position as one of the most valuable PCB fabricators in the world.
13. Daeduck Group consisted of Daeduck Electronics and Daeduck Industry, later changed to GDS. At the end of 2018, two organizations merged into a single unit: Daeduck Electronics. Starting as a single-sided PCB fabricator in 1972, Daeduck Electronics is now a high-tech PCB fabricator, with more than 50% of its revenue from IC substrates.

Taiwan is the world's largest PCB manufacturer, with total output topping $22 billion in 2019. Nevertheless, 65% of its revenue is derived from production in China, and Taiwanese PCB fabricators continue to expand there, despite the tense political relationship between the two countries. Taiwan is a province as far as China is concerned. Since the start of the US-China trade war and the Covid-19 pandemic, reshoring is a theme in Taiwan, but its PCB industry pays little attention to the reshoring voices.

Chinese PCB fabricators continue to invest huge sums to build new plants, calling them "smart factories." Many of them are mega-sized by any standard. Some complain this move creates overcapacity. What are you going to do? No matter how we view the situation, we are becoming more dependent on China as far as PCB sourcing is concerned.

Although the growth by top Chinese fabricators is fast, and the big get bigger, it is not possible for them to take away the top position from Zhen Ding Technology (ZDT). The firm is listed on the Taiwan Stock Exchange as ZDT (Chinese name is 臻鼎科技). It is listed separately on the Shenzhen Stock Exchange as Avary Holding (Chinese name is 鵬鼎股份). It announced the purchase of fellow Taiwan fabricator, Boardtek, a medium-sized company with strong microwave PCB technologies. The official purchase is scheduled to take place this October. Simple addition of the revenues of the two fabricators is $4.13 billion. As ZDT is increasing revenue at the time of this writing (end of June), its total revenue in 2020 could reach more than $4.2 billion in 2020. Unless some mega-mergers take place, no Chinese fabricators will overtake this monster easily, at least for the time being.

TABLE 7. World PCB Production* by Region (US$ Million)

Region	2018	2019	19/18	19 Share	2020F
America	3,160	3,220	1.9%	4.2%	3,200
Germany	940	841	-10.0%	1.1%	830
Other Europe + Russia	1,330	1,250	-6.0%	1.6%	1,200
Africa and Middle East	142	143	0.0%	0.2%	130
West total	**5,572**	**5,454**	**3.1%**	**7.2%**	**5,360**
China	40,400	42,250	4.6%	55.7%	43,000
Taiwan	7,780	7,850	0.9%	10.3%	7,800
S. Korea	7,415	7,220	-2.6%	9.5%	7,000
Japan	5,940	5,830	-1.9%	7.7%	5,700
Thailand	3,130	2,810	-10.2%	3.7%	2,650
Vietnam	2,700	2,890	7.0%	3.8%	2,900
Other Asia	1,670	1,590	-4.8%	2.1%	1,500
Asia total	**69,035**	**70,440**	**2.0%**	**92.8%**	**70,550**
World total	**74,607**	**75,894**	**1.7%**	**100%**	**75,910**

Source: N.T. Information, Europe by Michael Gasch
*Includes assembly by PCB fabricators, particuarly FPC

Many PCB forecasts are around. Since this author knows only publicly presented reports, he does not know the background for the forecasts, although the trends indicated are all in accord. Based on the NTI-100 2019 (**TABLE 6**), it may be easier to understand the tendency if readers are familiar with what the fabricators listed are doing. If you follow fabricators that showed significant gains from 2018 to 2019, such as Shennan Circuits, Wus Group (although listed as a Taiwan fabricator, the author has a hard time ascertaining its nationality), Dongguan Shengyi Electronics, etc., you may note all are engaged in 5G-related infrastructure PCBs such as base stations, servers, routers, switching networks, etc.

Another set of winners are fabricators of IC substrates for high-end servers, computers, storage, etc., also related somewhat to 5G wireless communication. Ibiden, Unimicron, SEMCO, Shinko Denki, Nanya PCB, etc., are major IC substrate fabricators. AT&S has been striving to be a major player in this field, investing €1.1 billion over five years to expand its Chongqing plant, but it seems it has not achieved the technological level of its competitors.

Generally, PCB fabricators that depend heavily on the automotive market did poorly in 2019 and are having a tough time in this Covid-19 year as automotive sales plunged, although the quantity of electronics in autos is increasing. As of late July, the automotive PCB market showing signs of activity, but the sector will be down 20% in 2020. CMK, Meiko, Chin Poon, KCE, Ellington, etc., for example, are large automotive PCB fabricators. To cope with the situation, they seem to be trying to diversify. It is not possible for this author to explain every fabricator on the list. Refer to the simple comments.

The author is almost blind to accounting theory, but looking at some of the annual reports, it seems when the cost of goods sold exceeds 90%, the company crosses into the red-ink zone. Fabricators that depend on a few large customers in a certain market tend to grow fast, but likewise could fall sharply.

Chinese fabricators play under different rules, it seems. For example, purchased equipment is depreciated over 10 years, while in most other countries the depreciation period is typically five years. This affects profits. Competitors mention jokingly that Chinese equipment fabricators "leave" their machines at their customers free of charge and don't receive payment for quite a while. How do equipment fabricators survive without payment? Probably with government financial assistance. The author is too bashful to ask keen and penetrating questions regarding such matters. Good or bad, however, PCB production in China, including foreign fabricators, will continue to grow.

Luckily, PCB fabricators outside China will survive in their respective countries if engaged in prototyping and quickturn business, building small quantities with large numbers of parts, in protected and specific technology-oriented markets. Mass production under one roof is unthinkable. TTM's Chippewa Falls plant is perhaps one of the few exceptions.

Equipment and material fabricators' survival and growth depend on Asia, particularly China. Large portions of PCB chemicals suppliers' sales are derived from Asia. Mechanical and laser drilling machine revenues come mostly from there as well. DI systems sell relatively well in the US, Japan and Europe, but the numbers compared to Taiwan and China are fairly small. All these major changes took place in the past 20 years. What will the trends be in the next 20 years?

continued on pg. 43


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Enabling Technologies for MEDICAL ELECTRONICS

Despite competing goals of price and reliability, the technology requirements for most products are similar.

by INEMI MEDICAL PRODUCT EMULATOR GROUP (PEG)

Ed.: This is the eighth of an occasional series by the authors of the *2019 iNEMI Roadmap.* This information is excerpted from the roadmap, available from iNEMI (inemi.org/2019-roadmap-overview).

Medical electronics have historically been associated with high-cost diagnostic and imaging systems such as computed tomography scanners, magnetic resonance imaging, and ultrasound imaging, among other applications. Additionally, medical therapy devices like defibrillators, pacemakers and hearing aids have been marketed using value-based pricing. Neither of these medical electronics families were subject to aggressive cost reduction, and they all required high reliability.

Today, the focus in medical electronics is shifting out of the medical facilities to consumer access-based products, requiring technologies centered on portable diagnostics, remote patient monitoring and patient wellness therapy. This change in focus requires medical device manufacturers not only to meet aggressive reliability and performance requirements, but to also drive down cost for a broader, high-volume consumer market.

Two prominent differentiated medical electronics technology tiers are:

1. Diagnostic and imaging systems: High cost, high reliability and low volume.
2. Consumer-access portable diagnostics: Low cost, acceptable reliability and high volume.

Based on these two tiers, two opposing sets of goals bring products to market and manage the cost of ownership. The diagnostic and imaging systems business is well established. Companies like GE, Siemens and Philips have developed a methodology to design, qualify and manufacture these types of high-end systems, which are proven over many years for these types of products.

In the areas of consumer access portable diagnostics, cost challenges will dominate the approach to design, qualify and manufacture these types of products. Startup companies and major healthcare players must skillfully manage new platforms that empower customers to manage self-directed digital health and wellness.

The technology requirements for both tiers are similar. Many solutions are underway or in development, with a focus on the cost sensitivity for medical electronics' mix of low, medium and high-volume products. Once these components and processes are developed and stabilized, they can be leveraged across medical electronics to meet industry needs and consumer demand. Several key enabling technologies are described briefly below.

Flexible carriers. Medical devices used for implantable, percutaneous, *in-vivo* or wearable applications often must accommodate size constraints and atypical form factors. Advanced flexible hybrid electronic (FHE) substrates, coupled with ultra-fine assembly, meet the challenge of miniaturization and unique form factor requirements. Ultra-thin flexible base polymer films, on the order of 12.5µm thick, have been fabricated for assemblies that can be rolled or folded into small volumes. Examples include highly miniaturized assemblies for use in a single-sided flexible module for an intravascular ultrasound catheter, and a double-sided flexible device used as an *in-vivo* diagnostic device.

Reduced lines and spaces. Semi-additive plating can produce fine-line circuit features that are key building blocks for miniaturization. This process (or pattern plating) provides the surface mount and interconnection pathways for passive and active electronic devices on a substrate. For double-sided flexible modules, electrical interconnection between the two sides of a base polymer flexible film is achieved using laser-drilled and copper-plated through-holes. Electroplating may be preceded by sputter deposition of a chromium tie layer (to promote adhesion between the metal and the polymer surface) and a copper seed layer. A smooth copper-polymer interface is ideal for this fine-line circuitry. Semi-additive plating provides a uniform cross-section that is scalable to line widths thinner than 10µm. Other advantages of the semi-additive process include higher metal trace aspect ratios than can typically be achieved using subtractive metal patterning.

Flexible circuit materials. Appropriate materials and surface preparation are vital to ensure good circuit metal adhesion. Polyimide films are traditionally a good choice as a base polymer material for these applications. The material offers excellent thermal durability at temperatures as high as 400°C. This mitigates issues of degradation in polymer properties, for example, induced by sintering of ink-jet printed circuit features or during solder reflow for component assembly.

One major caveat for medical device manufacturers is some polyimide manufacturers may be reluctant to permit their products to be used in certain medical applications. Those meant for permanent implantation in the human body or permanent contact with human body fluids or tissues are subject to supplier review. Risk management strategies may be in place to control which applications use the material. Medical applications that present only transient or minimal contact with human body fluids or tissues are more likely to meet supplier risk management conditions.

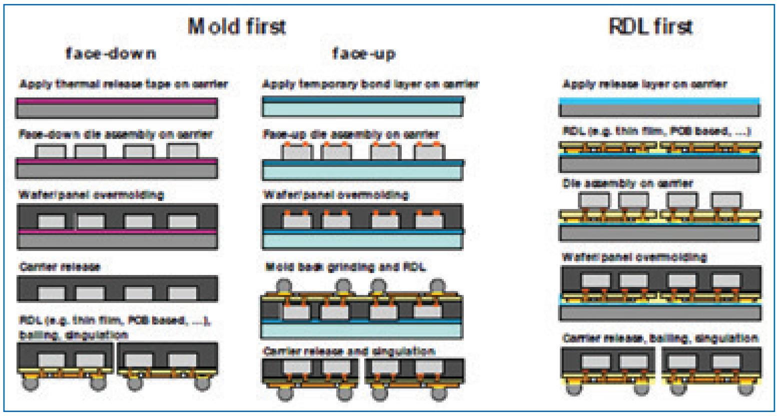

FIGURE 1. Multiple-die FOWLP package process flow options. (Source: Fraunhofer Institute[1])

Liquid crystal polymer (LCP) is another high-performance, flexible circuit material with excellent thermomechanical properties. It can be thermoformed (even as a complex multilayer flex with embedded thin film traces) to any desired shape. Challenges regarding metal adhesion to LCP have been largely overcome. It is possible to manufacture high-performance flexible circuits using LCP.

High-density interposers. An interposer is an electrical interface often used to route a connection to a wider pitch. Two basic types of interposers (or substrates) are common. The first is a standard laminate multilayer substrate made using conventional PCB technology. The dielectric material may be a standard FR4 type using subtractive etching of the copper to form the circuitry. These substrates typically have plated through-holes that have been drilled using standard mechanical drilling methods. These substrates have as few as two layers or more to meet functionality needs in higher-performance devices.

Another type of interposer (often used for flip-chip attach) is the buildup substrate. In this design, a standard laminate core is used, most often two or four copper layers with PTHs. Buildup layers are added to both sides of the substrate to create up to 12 layers on each side. Buildup substrates enable the fine-line circuitry to fan out the high-density area array I/Os on the flip-chip die to a coarser pitch.

3-D chip stacking. Three-dimensional chip stacking can be accomplished using different techniques. A common technique utilizes stacked die with conventional wire bonding. Another approach uses silicon die having through silicon vias (TSVs) attached using solder cap copper pillars. This is commonly used to stack memory die on a laminate substrate. A newer stacked die methodology uses TSVs in the silicon substrate to be able to stack die directly on top of each other. This is accomplished using a TSV that is Cu-plated and allows communication directly through the Si substrate. The TSV eliminates the need for wire bonding, and the distance is much smaller than a wire bond, reducing the time for the signal to travel, therefore improving overall performance.

Fan-out wafer-level packaging (FOWLP). FOWLP produces very low-profile packages at a low cost. For instance, attaching a processor die directly to the redistribution layer (RDL) creates a very thin low-profile package. The entire first-level solder attach and underfill process steps are eliminated. Copper-filled TSVs connect the solder ball to the top memory module in a package-on-package configuration.

FOWLP may also be used to package multiple die. FIGURE 1 shows a system-in-package made by integrating different die types and interconnecting them with an RDL. In the mold example, die are placed on a carrier with a tape that has a thermal release layer. The die are then overmolded and the carrier removed. An RDL is applied on the surface of the die and solder balls attached. This is the most common approach used today. However, another RDL first approach is possible. The main difference here is the die are solder-attached to the carrier, which requires additional steps of solder attach and underfill.

The industry is pushing developments in all these areas, with a view to cost-effective miniaturization of medical electronics and enabling increased functionality in future products across all segments. ❑

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This article was excerpted from the Medical Product Emulator Group (PEG) chapter of the *2019 iNEMI Roadmap,* chaired by Don Banks (Abbott, retired).

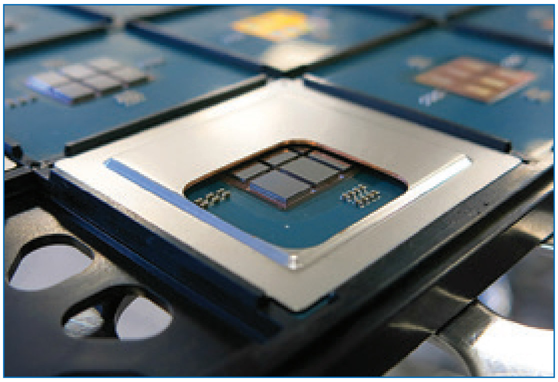
State-of-the-Art Technology Flashes

Updates in silicon and electronics technology.

Ed.: This is a special feature courtesy of Binghamton University.

Generating electricity out of thin air. University of Massachusetts researchers have developed a device that uses natural protein to create electricity directly from moisture in the air, a technology that could have significant implications for the future of renewable energy, climate change, and medicine. The device is called an "Air-gen," or air-powered generator, with electrically conductive protein nanowires produced by the Geobacter microbe. The Air-gen connects electrodes to the protein nanowires where the electrical current is generated from the water vapor naturally present in the atmosphere, literally making electricity out of thin air. The Air-gen generates clean energy 24/7 and is an exciting application of protein nano. *(IEEC file #11678, UMass Amherst, 3/17/20)*

Three ways chiplets are remaking processors. AMD and Intel researchers are leaning on chiplets to boost performance, and CEA-Leti shows just how far the approach can go. The combined squeeze of rising costs and ever-larger chip sizes is leading to a solution in which processors are made of collections of smaller, ¬less-expensive-to-produce chiplets bound together by high-bandwidth connections within a single package. The CEA-Leti processor stacks six 16-core chiplets on top of an "active interposer" made of a thin sliver of silicon to create a 96-core processor. The interposer houses voltage-regulation systems usually found on the processor. It features a network-on-chip that uses three different communication circuits to link the cores' on-chip SRAM memories. Developers imagine a system-on-chip industry using chiplets from multiple vendors could all be integrated with standardized interfaces. *(IEEC file #11715, IEEE Spectrum, 4/29/20)*



Development of attachable sticker-type rechargeable batteries. Researchers at the Korea Institute of Energy Research have developed re-attachable micro-supercapacitors (MSCs) by using highly swollen laser-induced-graphene electrodes. As demands increase for smaller wearable devices and high functional IoT gadgets, there is a growing need for new technologies for power collection, storage and management. The research team successfully developed sticker-type flexible MSCs that have a flexible structure and can be attached everywhere on surfaces by using ultra-short-pulse-lasers. By impregnating adhesive polymer composites to the inside of highly swollen graphene, researchers were able to develop sticker-type MSCs with excellent electrode performance and durability, while maintaining adhesiveness. *(IEEC file #11676, Printed Electronics World, 4/15/20)*

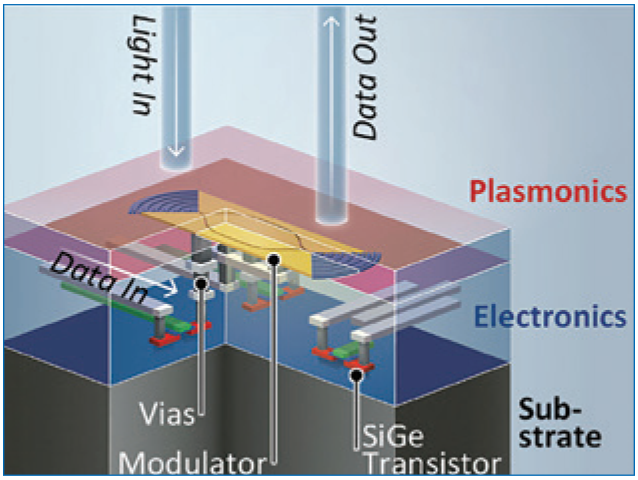
Using the shadow effect to generate electricity. National University of Singapore researchers are giving shadows a positive spin by demonstrating a way to harness this optical effect to generate electricity. This novel concept opens new approaches to generate green energy under indoor lighting conditions to power electronics. The team created a device called a shadow-effect energy generator (SEG), which makes use of the contrast in illumination between lit and shadowed areas to generate electricity. The SEG comprises a set of SEG cells arranged on a flexible and transparent plastic film. Each SEG cell is a thin film of gold deposited on a silicon wafer. With careful design, the SEG can be fabricated at a lower cost compared to commercial silicon solar cells. *(IEEC file #11696, Printed Electronics World, 6/4/20)*

Six-junction solar cell sets two world records for efficiency. National Renewable Energy Laboratory researchers have fabricated a solar cell with an efficiency of nearly 47.1%. The six-junction solar cell now holds the world record for the highest solar conversion efficiency. This device demonstrates the extraordinary potential of multijunction solar cells. To construct the device, researchers relied on III-V materials that have a wide range of light absorption properties. Each of the cell's six junctions are specially designed to capture light from a specific part of the solar spectrum. The device contains about 140 total layers of various III-V materials. Due to their highly efficient nature and the cost associated with making them, III-V solar cells are most often used to power satellites. *(IEEC file #11677, Science Daily, 4/14/20)*

BINGHAMTON UNIVERSITY currently has research thrusts in healthcare/medical electronics; 2.5-D/3-D packaging; power electronics; cyber-secure hardware/software systems; photonics; MEMS; and next-generation networks, computers and communications. The S3IP Center of Excellence is an umbrella organization at Binghamton University comprising six constituent research centers including the Integrated Electronics Engineering Center (IEEC).

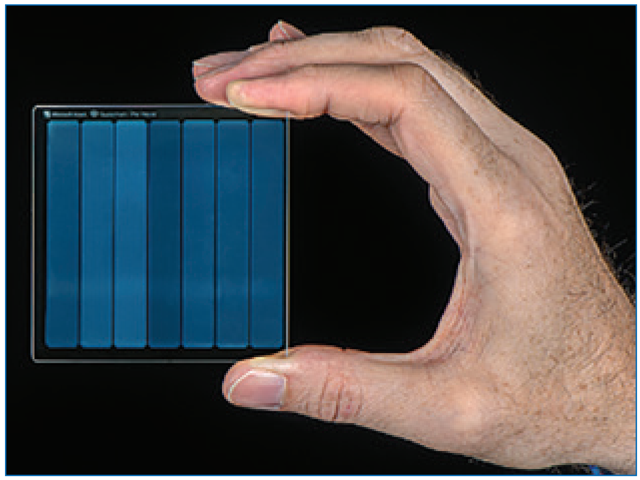
INTEGRATED ELECTRONICS ENGINEERING CENTER (IEEC) is a New York Center of Advanced Technology (CAT) responsible for the advancement of electronics packaging. Its mission is to provide research into electronics packaging to enhance partners' products, improve reliability and understand why parts fail. More information is available at binghamton.edu/ieec.

Photonics and electronics on one chip. Researchers from ETH Zurich have integrated photonics and electronics on one chip. Converting electronic signals into light signals using separate chips loses a significant amount of signal quality and limits the speed of data transmission. The integration was achieved by placing the electronic and photonic components on top of one another and connecting them through vias. This layering of the electronics and photonics shortens transmission paths and reduces losses in signal quality. As demand for bandwidth pushes datacomms above 100Gbs transmission speeds, this chip configuration provides a way forward. As plasmonic IC features are smaller than electronic ones, it now becomes possible to manufacture much more compact, monolithic chips that incorporate both a photonic and an electronic layer. *(IEEC file #11799, Electronics Weekly, 7/6/20)*



Scientists take steps to create a "racetrack memory," potentially enhancing data storage. Researchers from New York University have taken steps to create a new form of digital data storage, a "racetrack memory," which opens the possibility to both bolster computer power and lead to the creation of a smaller, faster, and more energy-efficient computer. Racetrack memory, which reconfigures magnetic fields in innovative ways, could supplant current methods of mass data storage, such as flash memory and disk drives, due to its improved density of information storage, faster operation, and lower energy use. While additional development is necessary for deployment in consumer electronics, this pioneering type of memory may soon become the next wave of mass data storage. *(IEEC file #11714, Science Daily, 5/5/20)*

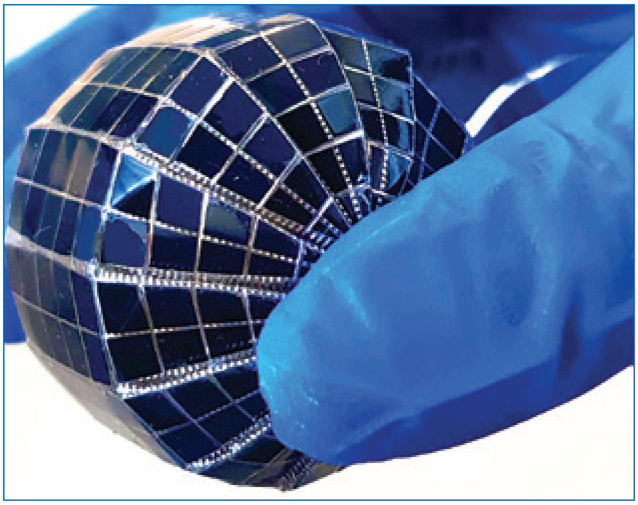
Lasers write data into glass. Magnetic tape and hard disk drives hold much of the world's archival data. But archivists have another option: using an extremely fast laser to write data into a 2mm-thick glass where that information can remain essentially forever. Microsoft Research, in an effort called Project Silica, completed its first proof of concept by writing the 1978 film *Superman* on a single small piece of glass and retrieving it. Writing data to glass involves focusing a femtosecond laser on a point within the glass. The laser's pulse deforms the glass at its focal point, forming a tiny 3-D structure called a voxel. Researchers could theoretically store up to 360Tb of data on a disc the size of a DVD. Microsoft's work is part of a broader company initiative to improve cloud storage through optics. *(IEEC file #11761, IEEE Spectrum, 5/29/20)*



Crystalline "nanobrush" clears way to advanced energy and information. Oak Ridge Laboratory synthesized a tiny structure with high surface area and discovered how its unique architecture drives ions across interfaces to transport energy. Their "nanobrush" contains bristles made of alternating crystal sheets with vertically aligned interfaces and pores. The bristles of their "supercrystal," are grown freestanding on a substrate. They synthesized the supercrystals using pulsed laser epitaxy to deposit and build up alternating layers of CeO_2 and Y_2O_3. The achievement is proof of concept that it is possible to create vertically aligned interfaces through which electrons or ions can be transported out of the substrate's plane. Architectures like the nanobrush could be combined with other nanoscale architectures to create devices for quantum technologies and sensing, as well as energy storage. *(IEEC file #11741, Science Daily, 6/8/20)*

Waveguides can be laser-written into silicon carbide for photonic circuits. Optical waveguides can be fabricated in glass and other optical materials by focusing light from an ultrafast laser into the material, so a threshold peak optical power beneath the surface is reached, above which a change in refractive index occurs. In this way, the focused spot can be moved around within the optical material to create waveguides of various geometries. Shandong University researchers using a femtosecond laser have written waveguides into the bulk of silicon carbide with modal properties tailored by altering the writing parameters. The laser produced a train of 400fs polarized pulses at a repetition rate of 25Hz to write waveguides at a depth of 175µm. *(IEEC file #11737, Laser Focus World, 4/19/20)*

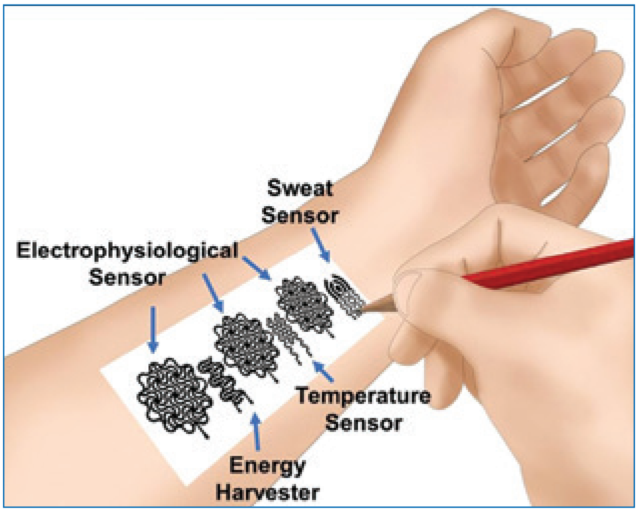
Spherical solar cells soak up scattered sunlight. Silicon solar cells folded into spheres hint at solar power's flexibility in even small devices. A new spherical solar cell design aims to boost solar power harvesting potential from nearly every angle, without requiring expensive moving parts to keep tracking the sun's apparent movement across the sky. The spherical solar cell prototype designed by KAUST researchers is a tiny blue sphere that a person can easily hold in one hand like a ping pong ball. Indoor experiments with a solar simulator lamp have already shown it can achieve between 15% and 100% more power output compared with a flat solar cell with the same ground area, depending on the background materials reflecting sunlight into the spherical solar cell. *(IEEC file #11763, IEEE Spectrum, 6/9/20)*



Market Trends

Chiplets promise to help reinstate Moore's Law and generate $5.8 billion by 2024. A new approach to semiconductor design and integration called the "chiplet" promises to help restore the microchip industry to its historic rate of advancement. The global market for processor microchips that utilize chiplets in their manufacturing is set to expand to $5.8 billion in 2024, rising by a factor of nine from $645 million in 2018. Chiplets effectively bypass Moore's Law by replacing a single silicon die with multiple smaller die that work together in a unified packaged solution. This approach provides much more silicon to add transistors compared to a monolithic microchip. Chiplets will return to the two-year doubling cycle that has underpinned the economics of the semiconductor business. *(IEEC file #11708, Semiconductor Digest, 4/28/20)*

The new tattoo: Drawing electronics on skin. University of Missouri researchers demonstrated the simple combination of pencils and paper could be used to create bioelectronic devices on skin to monitor personal health. Existing commercial on-skin biomedical devices contain a biomedical tracking component and a surrounding flexible material to provide a supportive. They found pencils with 93% graphite were the best for creating a variety of on-skin bioelectronic devices drawn on commercial office copy paper. The researchers said their discovery could have broad future applications in home-based, personalized health care, education, and remote scientific research such as during the Covid-19 pandemic. *(IEEC file #11827, Science Daily, 5/13/20)*



Smart-labeling using battery-on-circuit technology. CPI has announced a new project to demonstrate a novel technology for printing smart "battery-on-circuit" labels that are used to track shared objects in workspaces. This low-cost power source will eliminate the need for expensive and bulky external batteries for printed electronics, overcoming a key barrier to their widening application, mass production and industry growth. The smart label can be easily attached to objects and tracked automatically through a phone app. It incorporates a key innovation that allows a battery to be inserted directly alongside the wireless tracking circuit on a thin plastic film. The low-cost battery is formed by electrochemically coating and laminating two plastic films together. *(IEEC file #11728, Printed Electronics World, 5/13/20)*

Biometrics market estimated to exceed $37.2 billion globally by 2024. The global biometrics market size reached $16.7 billion in 2018. Biometrics refers to a technological authentication method utilized in information assurance for secure entry, data, or access. It primarily relies on scanning physical or biological characteristics, such as the face, DNA, fingerprint, iris, retina and palm veins, which are difficult to forge or duplicate. It provides more accurate identification and lowers the risk of unwanted intrusion. As a result, biometric technologies are widely used in schools, colleges, banks, public libraries, corporate and government offices, and consumer electronics. The market value is projected to exceed $37.2 billion by 2024, expanding at a CAGR of 14%. *(IEEC file #11706, Global SMT & Packaging, 4/27/20)*

Recent Patents

Semiconductor device with phase-change material for thermal performance (assignee: Deere & Company), patent no. 16/167,528. A semiconductor device comprises a generally planar semiconductor chip. The semiconductor chip comprises a first side and second side opposite the first side. The first side is associated with a source conductive pad. The second side is associated with a drain conductive pad. A gate pad overlies a portion of the first side. A source terminal comprises a metallic strip assembly with a series of pocket chambers spaced apart from each other and partially filled with a phase-change material filling. A drain terminal is spaced apart from the source terminal by a dielectric layer.

Intra-semiconductor die communication via waveguide in a multi-die package (assignee: Intel Corp.), patent no. 16/643554. An interposer layer includes an integral waveguide to facilitate high-speed (e.g., greater than 80GHz) communication between semiconductor dies in a semiconductor package. An interposer layer may include a waveguide member and a dielectric layer disposed adjacent to at least a portion of an exterior perimeter of the waveguide member. The waveguide member includes a material having a first relative permittivity. The dielectric member includes a material having a second relative permittivity that is less than the first relative permittivity. The waveguide member and the dielectric member form an interposer layer having an upper and lower surface.

Printed circuit board using two-via geometry (assignee: Intel Corp.), patent no. 16/662717. To reduce the effect of undesirable electrical resonances in via stubs, a multilayer printed circuit board can electrically connect traces in different layers using two vias electrically connected to each other. For example, a first electrical trace can electrically connect to a first via at a first layer; the first via can electrically connect to a second via at the topmost layer (or the bottommost layer); and the second via can electrically connect to a second electrical trace at a second layer. Compared to a typical single-via connection scheme, the two-via connection scheme can produce stubs that are shorter in length and therefore have an increased resonant frequency that may avoid interference with electrical signals sent through the electrical traces.

Nanofluidic channel fabrication by controlled spontaneous fracturing (assignee: IBM Corp.), pub. no- US10622220. A combined nanofluidic and integrated circuit device includes a semiconductor wafer, which includes a substrate with active circuitry formed in the substrate; an oxide layer deposited adjacent the active circuitry; a stressor film deposited onto or into the oxide layer in sections, wherein the stressor film has a higher coefficient of thermal expansion than the oxide layer has, and a nanochannel formed in the oxide layer between the sections of the stressor film. ❑

Lean *Poka-Yoke* and IT

Leveraging the IT department to reduce operation-caused variation.

ONE CONTINUING TREND in electronics manufacturing services is the increasing role IT-related solutions have in supporting a Lean manufacturing-driven organizational culture. This is particularly true of proprietary solutions that automate processes in ways that minimize normally occurring variation or help eliminate non-value-added activity.

One example of this is SigmaTron International's proprietary Manufacturing Execution System (MES) system known as Tango, whose Phase III system went live at the EMS company's Elk Grove Village (IL) facility in June. The overarching goal of Tango is to centralize tools used throughout the company for production management, while adding enough flexibility via customization to address facility-specific or customer-specific situations.

The EMS company uses a combination of proprietary and internally developed systems for enterprise and shop-floor management. All facilities utilize a common ERP system, plus third-party product lifecycle management (PLM) tools. Tango is now deployed as an app accessible through computers and handheld devices. It interfaces with the company's ERP system, and the goal is to have it be the frontend interface for production personnel for all production-related data collection and tracking activity.

Its Phase III iteration strengthens its ability to support data collection and traceability functions in production and eliminate processing defect opportunities in production activities.

Tango acts as a partner with production operators, tracking each assembly through all processes. On assemblies where serialization needs to be added in different formats at different parts of the process, Tango ensures the right serial number is associated with that assembly. Additionally, if any process steps are skipped, or if an operator attempts to add the wrong serial number, the system notifies the operator of the error. The enforced routing warning feature is a *poka-yoke* that prevents production operators from making routing errors, while the system collects data on each step of the production process. The data collected support traceability requirements, quality trends tracking and real-time visibility into production status.

The IT department has also created specific standalone applications that help *poka-yoke* unique requirements. For example, some SMT pick-and-place machines come with software that includes feeder verification, while other placement machines lack this feature. IT wrote a program that verifies component and feeder location against machine programming for machines, which don't include this feature in their proprietary software. This ensures the same verification process is in place throughout the SMT area. However, because it is only applicable to a subset of the company's SMT equipment, it isn't integrated into Tango for company-wide deployment.

As this specialized programming has deployed, lessons have been learned. For example, originally the enforced routing feature wasn't operator-controllable. When a product was removed from the routing at one step and reintegrated, the system automatically jumped into the next step in the routing. In some returned material authorization (RMA) loop cases, there was a need to repeat a prior step and the system wouldn't allow the part to be scanned. The enforced routing feature has been modified to enable an override in those cases.

Operator training also has a new approach. When a system is introduced, some employees get nervous about learning to use it. On most production floors, some employees are highly computer-literate, while others don't use computers often. Regular computer users can usually intuitively figure out next steps if they forget part of the training information, but less frequent users don't have that advantage. During the Phase III implementation, a full week for training was scheduled, and training was divided into multiple sessions to ensure everyone had time to get comfortable with the system. A strong focus was on explaining "why" the system works as it does, so employees understand how their use of the system helps others in the factory. Training materials are highly visual and make it easy for new users to "walk" through a labeled version of the app that helps them see how each screen relates to the activity they are performing.

Meanwhile, IT staff members provided mentoring during the first week of use. "Superusers" took over the role of mentors for the rest of the team when IT wasn't available. The result has been that IT support calls have gone down substantially in the month following implementation, and IT resources have been freed up to work on additional programming activities.

Minimizing operation-caused variation via IT-designed *poka-yokes* will continue to gain in popularity. In this example, the process for designing these *poka-yokes* has multiple steps. Production personnel

continued on pg. 43

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X-ray Inspection Image Enhancements – To Paint the Lily?

Humans love modifications, but over time they can add up to false comparisons.

"TO GILD REFINED GOLD, TO PAINT THE LILY … *is wasteful and ridiculous excess."* – William Shakespeare, *"The Life and Death of King John"*

WE ARE USED to editing, cropping and modifying cellphone photos to improve and enhance the original images. This is often achieved by adjusting their contrast and brightness, and applying software filters that could, for example, sharpen or otherwise change the look and details. Why should images taken for x-ray inspection be any different? They are not, of course. The images you see in my columns, as well as in probably every other piece of technical literature, together with virtually every other image seen in today's media, are likely modified on some level. While we may accept this situation intellectually, I would suggest we often too implicitly trust what our eyes see, and therefore any inherent image manipulation is often taken as fact. This can cause the details we see and accept to possibly mislead us as to the reality of the original. As we use such images to make value judgments on the quality and possible faults in electronics manufacture, is this an issue we should be concerned with, or is it a manipulation we need, but also need to understand why we do it, so we can make the best analysis?

In my view, for image analysis by the human eye, image enhancement is necessary. By using the appropriate image modifications, we can assist the eye's inherent limitations in viewing the grayscale images produced by x-ray systems. However, do these modifications introduce false artefacts into what we see? In the case of adjusting the contrast (often called contrast stretch) and brightness of the image, then no. With other enhancements? Possibly.

The image produced by an x-ray system contains a number of gray levels that graduate the difference from black to white. The available levels for a particular x-ray system are shown in the technical literature by the number of bits the system detector provides. For example, an 8-bit detector will provide 256 gray levels and a 10-bit detector 1,024. However, and depending on which literature source you check, the typical human eye can only discriminate ~30 to 60 gray levels (perhaps not even 50 shades of gray!), far fewer than the detectors provide. In comparison, with the same caveat as above, we can see ~1 million different colors (shades of color). Therefore, a method that improves our limited ability to perceive differences in gray levels in an image is helpful. This is achieved by applying a contrast stretch. Using an 8-bit detector as an example, where black is level 0 and white is level 255, most images we produce will not have all 256 gray levels present. Usually it is far fewer.

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For example, the minimum black level could be level 10, rather than level 0, and the maximum white level 160, not 255. Applying a contrast stretch to such an image takes the actual gray levels seen (150 in this case) and redivides and presents them across the full 8-bits. In other words, the boundary between where one gray level ends and the next starts is widened in the contrast shown, hopefully allowing the eye a better chance of discriminating differences and observing more detail in that image (FIGURE 1). As the range of available levels in an image reduces, the greater the effect on the stretched image, allowing what might originally might have been a dark, almost monochrome, image to now appear to have a much larger contrast variation (FIGURE 2). Most x-ray systems permit the contrast stretch function to be applied and allow manual changing of the start, end and midpoint of the levels used, which can enable further contrast adjustment. Changing the midpoint means that gray level 128 can be moved closer to either the black or white end of the spectrum. Moving it closer to black, for example, will narrow the 128 levels in the

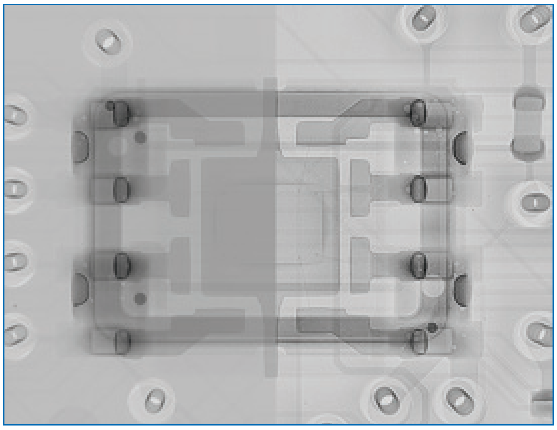

FIGURE 1. X-ray image showing "before and after" application of a contrast stretch and edge enhancement.

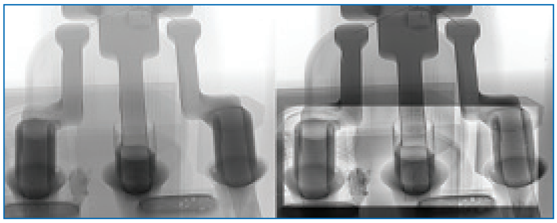

FIGURE 2. X-ray images showing "before and after" application of a contrast stretch to the whole image and an edge enhancement to the central portion.

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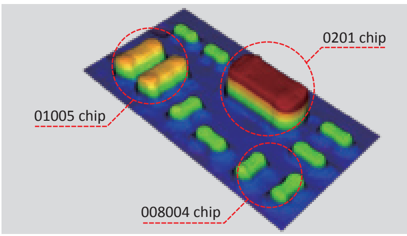
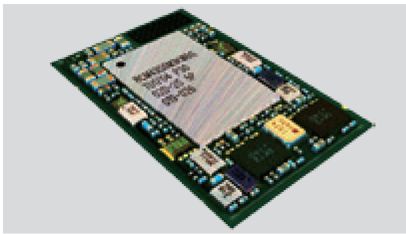
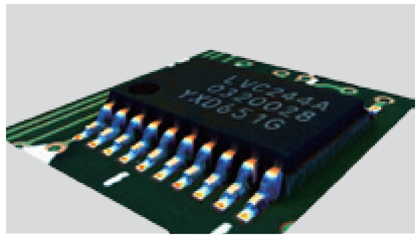


008004 Chip


Specular Die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black end of the spectrum but further broaden the 128 levels at the white end, which may pull out yet more information to the eye. Using a contrast stretch does not alter the underlying original image; it just pulls out subtlety what it already contains for the eye to see. When looking for variations in images that will help identify failures, applying a contrast stretch usually helps.

The other type of image manipulation often used for electronics inspection applications is edge enhancement. There are many types of such filters, and, as the name suggests, they can help to specifically sharpen and delineate edges between light and dark features (Figures 1 and 2). For example, they can provide better definition to BGA solder balls and the clarity of traces on and within the board (**FIGURE 3**). These filters help the eye better discern the difference between specific features. This is particularly necessary, as the resolution of an x-ray image is on the order of microns compared with that of nanometers for optical images. Therefore, all x-ray images appear blurred compared to an optical image. Applying edge filters makes the x-ray image appear clearer. However, these filters modify the original image, so what you see is not a true representation of what was originally captured. The changes may be minor in nature, but may also bring in the possibility for, and presence of, artefacts into the "corrected image." The creation of "artificial" features by the enhancement process may lead to false interpretation or analysis. Other more complex filters are also available from many x-ray system suppliers. Try them. Do they help you see what you need to?

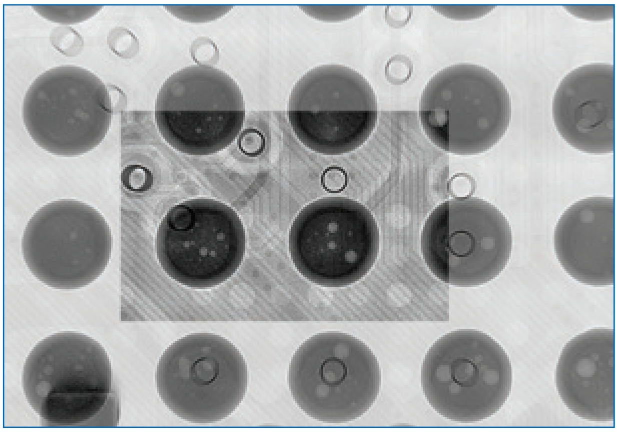

FIGURE 3. X-ray image of BGA showing "before and after" application of a contrast stretch and an edge enhancement.

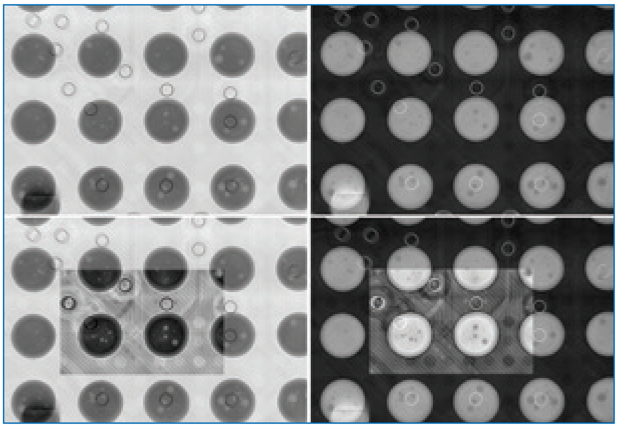

FIGURE 4. Comparison of inverse x-ray images with and without enhancements applied.

The images presented in my columns for this magazine have been predominantly white on black. This is the reverse of the image convention typically used for hospital x-rays. I do not believe that for analytical purposes one convention is better over the other, but I think an experiential bias causes any preference. Most x-ray systems allow the conversion of one format into the other, if required. I find a brighter image, like Figures 1 to 3, is more pleasing and easier to see. However, I believe hospital radiologists, with over a century of film-based x-ray history behind them, where a darker image is the norm, would argue the reverse. See **FIGURE 4** and decide for yourself!

Making appropriate image enhancements allows us to create the best or "golden" image. This is certainly helpful when explaining to one's clients and superiors the issues that have been captured, particularly if knowledge and expertise of x-ray may not be their primary concern. However, what presents best to a customer, like editing your own photos, might take some time to achieve and, in reality, may not be needed for the experienced operator, who may be able to correctly analyze from an unenhanced image during production. But the capability is there if required.

The application of image filters is really beneficial for human operation and analysis. When it comes to automated machine analysis, however, filters are more likely to be a disbenefit. This is because enhancements are applied to each captured image prior to analysis. Unless you have similar, and consistently exposed, original images, the resulting "modified" image will not necessarily be the same time after time. Unlike the human eye, the computer can differentiate and analyze over the whole grayscale range. Therefore, potentially small changes in grayscale levels for key features in enhanced images, created by small differences in the original image, could result in erroneous, or missed, analysis. Automated x-ray inspection equipment suppliers have to consider system performance drift over time and make great efforts to achieve consistency of image quality, and permit a range of grayscales as the pass/fail threshold, such that similar images of the same product are consistent whenever testing is required over time. However, these necessary adjustments can impact throughput, as "system optimization" must be completed without product being present. Thus, unenhanced images are, in principle, easier to maintain for consistency and, as such, typically used for automated analysis. To the human eye the images for automated analysis look poor, but because the computer can effectively use all the grayscale levels in the image, good analysis can still be achieved.

A good image from x-ray inspection tells us what we need to know, but be cautious that this good image, however modified, has not hidden rather than enhanced what we need to see. ❑

Au.: Images courtesy Peter Koch, Yxlon International.


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The PCB Podcast

The Anthill's Revenge

If only defects were in as short supply as logic and wisdom.

THIS IS WHAT happens when the pyramid inverts and falls on little old unsuspecting you. Just what you deserve for minding your own business.

"We need to audit your quality system. You're a new vendor with contingent qualification. We can't make it permanent without an audit."

What do you mean we're a new vendor? We've been doing business with you for 11 years.

"Doesn't matter. New regime in place. Since you're a great big unknown to us, who are new, consider yourself, as we do, a new vendor. Clean slate. Get used to it. Plus, you had a recent test escape, and we need to determine the root cause. Might as well do the full workup."

So much for any shred of gratitude and recognition for 11 years of hard work. But it's true: He needs to allow for the possibility we may have been engaged in a conspiracy so immense that only he could whisk the wool from his employer's eyes after 11 befuddling years. Fiendishly clever of him to smoke us out. Thus are reputations built.

Guess I don't have much choice.

"Nope. And we're working with flight hardware. Whole new level of scrutiny, traceability, and accountability. Best you get used to that, too."

Ah yes, I forgot about the Whole New Level of Scrutiny Button embedded in the x-ray inspection software. Silly me. That's why he's the Quality Guy. No piddling corner office suite for him. He's a Man of Action.

We've been scrutinized, traced and accounted for every day of our 11-year relationship with your company. Otherwise, we wouldn't be talking today in the 12th year.

Tales from the anthill. It's not an ethnic group. It's a state of mind.

And a state of power. Small man, big influence. Up from the ranks and off the anthill. His one chance in life to assert himself and spread misery. Score points with the higher-ups. Prior history be damned. Procedures offer cover.

"You know we can shut you down in a minute for lack of written qualifications."

Yes.

You know I can shut you down in a femtosecond for lack of common sense. I still have your urgent work on my floor, and I believe your engineers are still awaiting results detailing why it didn't work. So, were you born lacking common sense or was that skill surgically excised in graduate school?

"We need to come in and audit your facility."

May I remind you we have a pandemic afoot, and of our local and state shelter-in-place orders that continue in full force and effect until further notice?

"That does pose a few challenges. But I know: Been confined to barracks myself these past few months because I have a health history and am in one of the most vulnerable age groups."

Yet it's okay for you to demand an onsite inspection and potentially die in the attempt? I'm not exactly in lockstep with your logic.

"Priorities. We do what we need to do, and qualifying you to our new procedures is one of the things we need to do, and quickly. Otherwise, critical projects get delayed."

Okay. So, save the trip, remove the health risk, check a box and make us qualified. Flick of the wrist, and no annoying TSA lines.

"Can't do that. Got a checklist that needs to be completed."

Guess you're going to have to complete that checklist online. Fire away.

"Can't do that either. Gotta go through channels."

Meaning?

"You'll get a list shortly."

He went away for a while. Ran a bunch of jobs for his colleagues. Successfully. None questioned our qualifications.

Like Halley's Comet, without the dazzling visuals, he returned a month later in written form.

To wit:

"Please complete the attached Supplier QMS (quality management system) form at your earliest convenience. Include copies of relevant certifications or qualifications."

Filled out all the boxes. The survey was merciless. No exemptions or skip-overs for preexisting certifications. Sent, accompanied by ITAR letter and AS9100D certification.

Another month elapses. The Comet returns.

"Please supply personnel qualifications for all NDT (nondestructive testing) personnel."

There's more.

"Are they certified to ASNT, NAS 410, or SNT-TC-1A?"

And more.

"Are any of the certifications to Level II or Level III? Do you perform validations of your equipment? Does your equipment manufacturer perform them or do you? What are your process controls? Do you use

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a reference standard to check systems? What is the scan rate? What is the field-of-view? What magnification is used? What is the maximum resolution? What is the pixel/voxel size?"

More still.

"Does your work reference adhere to the following standards: IPC 7095D-WAM1 (Design and Assembly Process Implementation for Ball Grid Arrays); ASTM E 1000 (Standard Guide for Radioscopy); IPC TA-723 (Technology Assessment of Surface Mounting); AIA/NAS 410 (Certification and Qualification of NDT Personnel); ASTM E2736 (Standard Guide for Digital Detector Radiography)?"

We answer in writing:

No. No. Yes. Yes. See equipment data supplied. Ditto. Ditto. Ditto. Ditto. Depends on the system. (We have four x-ray systems.) See equipment data supplied. With respect to applicable standards, our pass/fail calls derive, as they always have, from IPC-A-610.

All done.

Not so fast.

Another month goes by. Behold, a corrective action request. Under the guise of addressing a single AXI test escape, our friend maneuvers all the questions previously asked the month before into the body of the CAR. No doubt as a helpful reminder. Just making sure we're paying attention.

"There were no quality indicators used for x-ray inspection, per ASTM E100."

We're paying attention.

Answer: Correct. ASTM E100 was not stipulated as the basis for quality indicators, either in our quotation or by you in the language of the PO received. Our quote clearly states that acceptability decisions default to IPC-A-610, current revision, classes II or III, as applicable. Additional requirements must be listed in the purchase order. They were not.

We are in the business of x-raying boards. Should we also x-ray heads?

"System should have a clearly defined field-of-view (FOV), and that field-of-view must be repeatable as part of a written process."

Answer: System has a clearly defined field-of-view, which varies with the board, component location, board topography, and algorithm employed to detect solder joint anomalies. In 11 years of providing AXI services, this is the first time a customer has attempted to micromanage AXI process details like field-of-view. Most customers just want conclusive images of the relevant defect. If specific parameters are required, list categorically in your Statement of Work (SOW) and purchase documentation what they are, and we will quote accordingly.

Anything is possible. For money.

"Validation or verification documentation was not provided and should be available upon request."

Answer: The AXI system has its own self-diagnostic routine, which is run regularly. Beyond that, the system is calibrated regularly. If a specific validation protocol above and beyond what is already being done is needed, please specify what it is, and we will endeavor to comply, while also accounting for the additional cost.

"AXI technicians are not certified to NAS 410 or equivalent NDT certifications."

Answer: That's true. Nobody asked us before. Now you have. We will acquire the requisite certifications; meanwhile, the equipment manufacturer has a responsible NAS 410 certified Level III technician who can sign off on manual x-ray projects if needed. One small, lingering problem: This does not apply to automated x-ray inspection (AXI). I am not aware of any AXI operation with NAS 410 personnel certifications (although it is possible they exist in some high-reliability captive mil/aero operations). Certainly not in the commercial world. We will train our people to reach this goal by the end of the year, and our quotes henceforth will reflect the cost of the training.

And off the answers went.

I can hear the comeback now.

"Not good enough. Ignorance of these requirements is not an excuse for inaction."

Your predecessors seemed quite comfortable with our "inaction" for 11 years. And, as for ignorance, if you don't stipulate these things upfront as requirements in your written documentation, then who precisely is the ignorant party?

(Sound of grumbling and inaudible language.)

Rather than engaging in a fruitless mind-reading exercise, tell us what you want; we'll return to you with the cost to do it; you'll know where it stands, and you can show management what it costs. (I'm sure they'll be thrilled at all the new, unbudgeted costs.) Can we go back to inspecting your boards now?

"Yes, but under the condition you fulfill the requirements listed on the CAR."

Consider it done. You'll get a timeline and a bill within the next two weeks.

And with that the anthill returned to its natural state (status quo ante). There were no unwanted or irrelevant incursions. All were happy ever after, and tranquility reigned upon the land. ❑

What is Impedance, and How Does It Work?

To increase signal quality, match the impedance, capacitance and inductance of all areas of the signal path.

IN PCB DESIGN and fabrication, possibly the most frequently used, yet least understood, term is impedance.

Most of us have seen the buzzwords that accompany it: impedance Z_o, 50Ω, 10%, balanced lines, microstrip, stripline ground plane, dielectric loss, dielectric constant, and others. What do they mean?

In this first of a two-part column, we'll start by defining them in common terms for the novice. By the end, a few more people might make better sense of what is happening inside the circuit board. The second half will take a more thorough look at impedance.

First, why do we need impedance specifications? When a fast rise time signal (i.e., a 100MHz to 10GHz or higher pulse) travels down a PCB trace without impedance matching, not much of any use comes out the other end of the trace. What does come out is only a percentage of the original signal, with rounded-off edges and ringing on the trailing edge.

Impedance is stated in ohms, typically 50, plus or minus 5 or 10%. It can be thought of as a fast rise time voltage/current energy level running through the traces. These traces sit on a dielectric core, typically FR-4, which affects these energy levels in quite a few ways. The signal at the start of the PCB trace comes out in various ways and places, including many undesired ones. Some of the signal will be lost in magnetic radiation; some will reflect back from changes in the impedance along the trace; e.g., glass fiber bundles or nearby crossing traces. The dielectric material will absorb some of the original signal. What's left after all the losses is a possibly unusable signal that arrives at the other end of the trace out of phase.

The term "dielectric" means a material (FR-4 or PTFE) that is basically an insulator in that it does not directly conduct electricity. That does not, however, mean the dielectric absorbs a small amount of electricity passing through the trace. The dielectric constant, or Dk for short, is a number that relates to the ability of the laminate to hold a capacitive charge of electricity, like a battery. The typical FR-4 laminate we use has a dielectric constant of about 4.2 to 4.4. This compares to PTFE laminate used for RF signals that has a lower Dk, in the range of 2.3. The higher the Dk number, the more capacitance it has and the more it stores, absorbs and discharges electricity out of phase, which is the worst time for maintaining signal integrity. The lower dielectric constant of PTFE means a smaller battery or capacitor for the signal energy to charge and discharge. When less energy is absorbed along the trace, a larger signal with less reflection and less noise will reach the end of the trace.

Along with Dk is dielectric loss, also called dissipation factor, or Df. Dielectric loss is simply the amount of signal absorbed or lost within the dielectric material itself. It is expressed as a very small number; typically, the Df of FR-4 is 0.01, whereas that of PTFE is many times less, at 0.002. The lower the Df number, the less it absorbs or affects the signal energy level in the trace and the more signal that comes out at the other end of the trace. To add to the confusion, both Dk and Df can have large changes in the same material with different frequencies of the signal.

Frequency expresses the number of times per second the signal changes from positive to negative. Alternating signals switch from relative negative to positive. A 1MHz switches back and forth a million times a second. We now work in Ghz, which is an astounding 1 billion cycles per second. As frequency goes up, strange things start to happen in the impedance world. The matching of dielectric and impedance needs to be close to perfect. Also, as frequency goes up, electricity no longer travels inside the copper traces but instead starts to travel more along the outer skin. This is called skin effect.

The effect trace impedance has on signal strength and integrity has a lot to do with the signal electrical energy put in. If the electrical energy traveling down the trace hits a spot where another trace is close under it, creating a higher impedance, and thus inductance, this causes a mismatch that will bounce back part of the signal, causing signal degradation. For example, a 0.031" trace over 0.031"-thick FR-4 with a ground plane has 10nh inductance and 2.0pf per inch of trace.

The same occurs with mismatched impedance

FIGURE 1. As frequency goes up, electricity starts to travel more along the outer skin, a phenomenon known as skin effect.

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between frequency and PCB design. The trace has a certain amount of parasitic capacitance all along the trace; the higher the impedance, the lower the capacitance and the less energy can be stored. Parasitic capacitance can only be charged and discharged so quickly and with only so much signal energy. If we send an electronic signal into a higher impedance trace with its lower capacitance, we will not be able to absorb and charge the capacitors. The extra energy will bounce around and end up as reflections and interfering signals, which we do not want. Just like throwing a rock into a small pond, the waves will flow outward, hitting the shore and reflecting back and forth many times, crossing over each other, causing distortion of the wave shape. The less signal energy the trace will accept, the less comes out the other end. Without impedance matching and careful trace design of, say, a 6GHz computer signal, only about 15% of the original signal makes it to the end of the trace. Could we just feed the signals into a low impedance that would increase how much signal we can carry? Chips are designed for mostly 50Ω impedance. Therefore, to optimize integrity, we need to match the 50Ω all along the trace. Signal levels and quality are the reason we control impedance on a trace-by-trace basis. For balanced dual traces over a ground plane, splitting send and return signals independently, the two signal lines need to be the same length and run over the same type of background traces such as a ground plane. Each trace must have the same impedance overall and at any point along the trace.

For balance, dual trace inductance is created by two conductors crossing or running parallel with each other or bumps and wiggles in the trace line that cause the magnetically coupled fields to distort. In this case, the number of copper traces and their proximity, or the number of turns they make, create more inductance. Inductance changes along the traces affect the quality and end signal speed and cause voltage to be out of phase with the signal. Both capacitance and inductance can store and release signal energy, but they are out of phase with each other and therefore interfere with each other. The signal can disappear if coming from a low-energy signal (i.e., high impedance = low energy) to a high energy signal (i.e., low impedance = high energy). To increase signal quality, match the impedance, capacitance and inductance of all areas of the signal path. Many software programs carefully design and lay out the traces to ensure desired impedance is achieved. □

NT-100, continued from pg. 32

It is impossible to make a decent forecast for PCB production in 2020. **TABLE 7** is the best this author can do, based on the NTI-100 2019 and the latest market production data. It may be too optimistic and totally wrong.

Taiwan PCB manufacturers gained momentum in mid-July as Apple released new orders, and automotive electronics are now on a (slight) upswing, which keeps automotive PCB fabricators' above water, although still gasping for air.

With so much work and study now done at home, demand for PCs and tablets has created a mini-boom for PCBs for these applications. Higher data traffic has led to expanded data centers, which in turn increased demand for high-end servers and chips. Shennan Circuits, Wus, Shengyi Electronics, Gold Circuit, etc., are benefiting from this. At the same time, Unimicron, Nanya PCB and Kinsus of Taiwan, Samsung Electro-Mechanics, Daeduck, Korea Circuit and LG Innotek of South Korea, and Ibiden, Shinko and Kyocera of Japan are growing revenues as if there were no pandemic. Currently, PCB makers are facing a dichotomy. Some doing very well, others very poorly.

By examining the major PCB fabricators in fair detail, I believe we will experience small but positive growth in revenue in 2020 despite the pandemic. This conclusion is strictly based on the performance and forecasts of the world's top PCB companies, none of which hail from the US except TTM. □

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Getting Lean, continued from pg. 37

identify the need, and a central production representative (normally in facility or production management) is charged with communicating the requirements to IT. An initial requirements definition meeting is held with a corporate IT resource, the production representative and the facility-specific IT resource. A flowchart of the process requiring IT support is provided, and a wireframe of the proposed program solution is developed. Once approved, the programming team creates a beta version for test with the production team. Following the beta test period, improvements are made, and the program is released.

Partnering IT and production teams in creating system-resident *poka-yokes* reduces operator-driven variation and common process defects. Effectively deploying this strategy requires a well-structured development and testing process, and a training methodology designed to ensure users with different computer competency levels have the support they need to learn the new system. □


Celebrate
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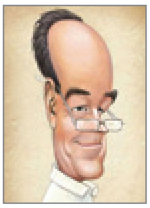
High-Temperature Soldering of Through-Hole Connectors

Be sure to optimize the preheat to improve wetting.

BOB WILLIS is a process engineering consultant; bob@bobwillis.co.uk. His column appears monthly.



THIS MONTH WE we illustrate high-temperature soldering of through-hole connectors. In this case both the PCB nickel/gold surface and the tin surface of the pin were perfectly solderable. The time to preheat the board and connector before soldering was not optimized for robotic soldering, however. To obtain the correct process setting, balance all settings, but to increase throughput in an inline process using a robot, many applications require preheating. Robots are flexible, but an operator can see and judge the time required.

Nitrogen used on robotic point soldering can improve wetting but more importantly increase preheat to the joint area. Soldering trials have shown it can increase throughput with small increases of flow rate. Another option is to have the waiting boards on the conveyor first pass over a preheater or through a heated tunnel.

We have presented live process defect clinics at exhibitions all over the world. Many of our Defect of the Month videos are available online at youtube.com/user/mrbobwillis. ❑

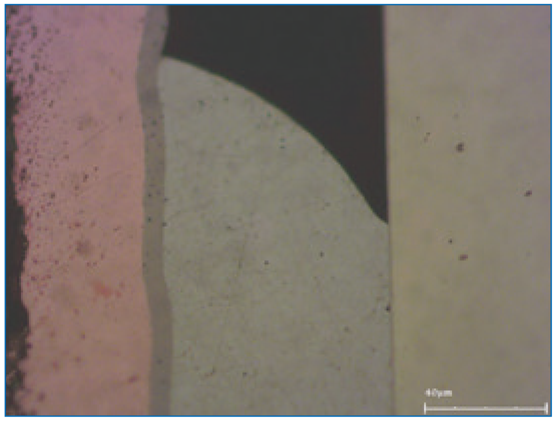
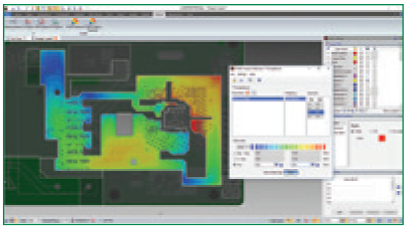


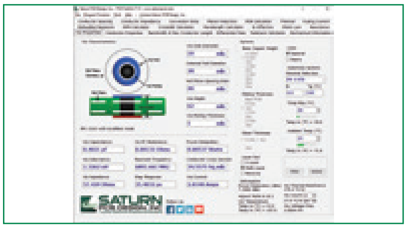
FIGURE 1. A mounted PTH connector.



SI/PI ECAD

eCADStar 2020.0 comes with new modules for signal integrity, power integrity and IBIS-AMI simulation. Analysis tools are tightly integrated with PCB constraint management and optimization functionality. Displays results in a common viewer within the eCADStar design environment. Displays heatmaps directly within PCB editor. Enables SI planning and checking throughout schematic and PCB layout process. Offers TDR and S-parameter analysis.

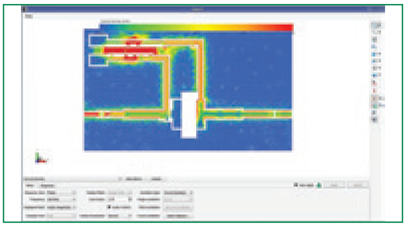
Zuken
ecadstar.com



PCB DESIGN FREEWARE

PCB Toolkit version 7.12 calculates current capacity of a PCB trace, via current and differential pairs. Calculates DC resistance with temperature compensation; bandwidth of a digital signal and maximum trace length using IPC-2251 or frequency domain methods, for transmission line effects and more.

Saturn PCB
saturnpcb.com/pcb_toolkit



5G AND MMWAVE TOOL

PathWave Design 2021 has new capabilities across all design phases, including simulation to validation, test and manufacturing. For RF/microwave workflows, can increase speed and reduce complexity of chip-level analysis and verification with integrated EM simulation; predicts performance at circuit and system levels using common modulated signals and accurate RF system models; accelerates verification by running simulations in parallel.

Keysight Technologies
keysight.com

OTHERS OF NOTE

WET PROCESS NEUTRALIZER

Magnum N-499 neutralizer is based on hydrogen peroxide. Removes residues of manganese dioxide from drilled holes after permanganate desmear in preparation for metallization of multilayer PCBs. Is effective on resin materials, including epoxy resins and polyimide. Can be replenished and does not require PCBs be dried prior to processing. Can be used in conjunction with Magnum K-401 oxidizer or Magnum N-501 oxidizer.

RBP Chemical Technology
rbpchemical.com

HIGH-CURRENT TERMINAL SHUNT RESISTORS

HCSK4026 series now includes 0.7mΩ and 3 mΩ resistance values. Can be used in wider range of precision power control applications where efficient sensing is critical. Applications include power management, power modules, battery charging, frequency converters, hybrid power current sensing, engine and motor controls, and PC graphics and motherboards.

Stackpole Electronics
seielect.com

WIRE HARNESS DESIGN TOOL

E3.series 2020 electrical and fluid engineering tool suite features expanded functionality from schematics and cable planning through to 2-D and 3-D cabinet and wire harness design and documentation. Designs electrical cabling, control cabinet, and wire harnesses. Features enhancements in tabular editing, embedding of office documents, 3-D cabinet layout, and 3-D PDF support. Can search, modify, and update large schematic and wiring plans without navigating numerous sheets.

Zuken
zuken.com

CURRENT SENSE RESISTOR

CSM2512 offers a metal element with TCR now improved to 50ppm. Reportedly ensures high-accuracy measurement at 3W for resistance values from 0.001 to 0.1mΩ. Is AEC-Q200 and RoHS compliant. Has molded package and is capable of full power operation for terminal temp. up to 120°C. Is good for power supplies for currents up to 54.8A, industrial power control, consumer electronics, telecom, computer, measurement equipment, battery management, and LED drivers.

Stackpole Electronics
seielect.com

FLEX CIRCUIT FILM

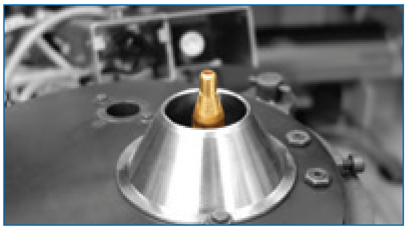
Hyaline bio-manufactured film for electronics applications can be used in flexible circuits, display touch sensors and printable electronics. Is completely transparent. For high-temperature printed electronics – including flexible PCBs – that eliminate epoxy/acrylic adhesive layers to create an optimized system that is 30% thinner and more flexible. Is solderable using standard reflow soldering. Enables durable full-screen touch sensors in flexible/foldable devices and permits higher ITO annealing temperatures.

Zymergen
zymergen.com

HIGH-VOLTAGE SMT CAPACITOR

Tantalum Stack Polymer O 7360-43 is suited and sized for use in high-voltage power management applications such as buck boost converters, filtering, holdup capacitors, and other high ripple current applications that require a small form factor, stable performance, and long operational lifespan. Also comes in 82µF/75V-rated voltage extension in polymer hermetically sealed.

Kemet
kemet.com



SELECTIVE SOLDER NOZZLE

LongLife mini-wave solder nozzle improves selective soldering process. Gold alloy coated. Lifetime is reportedly more than three times conventional solder nozzles under same conditions. Reduces maintenance. Does not need to be cleaned or reactivated throughout production shift. No activation needed prior to production start; insert nozzle, turn on pump and start production. Ready to solder within seconds.

Seho Systems

seho.de/en/

NETWORK ANALYZERS

PNA and PNA-X contain low-spurious direct digital synthesis source, enabling accurate measurements with less phase noise interference. With clean source signals, customers can perform two-tone IMD measurements with close tone spacing. DDS sources enhance performance of software applications, including modulation distortion, SMC with phase, and I/Q converter measurements to provide speed in mixer/frequency converter characterization. Offering a third radio frequency source up to 13.5GHz on PNA-X simplifies measurement setup by taking place of external signal generator to drive local oscillators.

Keysight Technologies

keysight.com

CONNECTOR ICT

BSI (Boundary Scan Interconnect) Plus in-circuit tester is for DDR4, USB, PCIe and M.2 SATA connectors. Hardware is reportedly easy to integrate into fixture and set up for new test programs. Performs an OPS test and battery test before powering on DuT to ensure correctness of board.

Test Research Inc.

tri.com.tw/en

OTHERS OF NOTE

MED DEVICE EPOXY

EP42HT-4AOMed Black two-part epoxy for medical device products is biocompatible and non-cytotoxic, passing USP Class VI and ISO 10993-5 certifications. Withstands aggressive chemical sterilants, radiation and repeated cycles of autoclaving. Service temp. range from 4K to 400°F. Thermal conductivity measures 9-10 BTU•in/(ft^2•hr•°F); volume resistivity is greater than 10^{14} ohm-cm.

Master Bond

masterbond.com

DRYBOX WITH MSD TRACKING

McDry electronic drying storage cabinets now include MSD control tracking software and data loggers, including wireless, intranet and cloud-based systems with alert capabilities. Upgraded features include energy-saving eco-mode; drying unit, including dehumidifier; door open/close frequency once every 10-20 min.; digital RH meter; lockable door seal. Compliant to ESD-IEC61340-5-1. Desiccant doesn't need replacement. Shelves are adjustable and can hold 220lbs.

McDry | Seika Machinery

mcdry.us | seikausa.com

ROOM TEMP. SOLDER PASTE

PF606-RT35 room-temperature no-clean solder paste is designed for SMT processes. Reportedly provides consistent printing performance, low voiding, stable viscosity life, and excellent testability. Has wide reflow window. Is Pb-free and has low melting point. Solders with low peak reflow profiles in air or nitrogen atmospheres. ICT testable and high-speed printable. Suitable for pin-in-paste.

Shenmao

shenmao.com

'HEAVY PCB' AOI

V510i 3-D optical inspection system inspects PCBs weighing up to 25kg. Can inspect PCBs up to 1.3m x 1.3m. Includes high-speed inspection and artificial intelligence programming. Is integrated with internal developed light source and projectors. Includes 3-D phase shift profilometry and adaptive concurrent lighting. Software captures real-time analytics data with industrial digital twin in networked manufacturing process through customizable open platform.

ViTrox Technologies

vitrox.com

CONTAMINATION TEST SOFTWARE

Zero Ion software now includes Windows 10 compatibility and update to operator interface. Has original Zero Ion g3 cleanliness algorithm. Upgrades include updated screen layouts; reporting features; database search capabilities; rolling graphs; improved calibration accuracy; integrated test results graph; programmable board area (pass/fail, timeout slider bars); enhanced screen continuity; current status box updates; other features and bug fixes to enhance user experience and maintain compatibility with current Microsoft requirements.

Aqueous Technologies

aqueoustech.com

IRREGULAR SMD TEST FIXTURE

IM9202 test fixture achieves reliable high-frequency measurements of surface-mount and leaded components. Can handle SMDs of irregular shape, including axial and radial leaded components, film capacitors and RFID and NFC tags. SMDs from 1.6mm to 23mm long can be tested, as well as radial components with lead spacings up to 26mm. Applications include components for high-power, high-frequency PCBs, as well as components and antennas for RFID and NFC circuits.

Hioki

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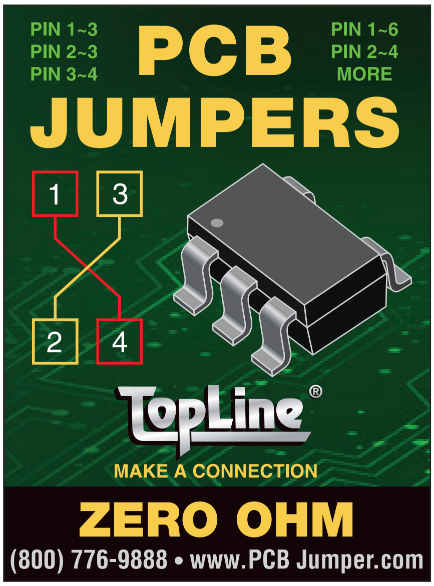
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"Fan-Out Wafer and Panel-Level Packaging as Packaging Platform for Heterogeneous Integration"

Authors: Tanja Braun, Karl-Friedrich Becker, Ole Hoelck, Steve Voges, Ruben Kahle, Marc Dreissigacker and Martin Schneider-Ramelow; tanja.braun@izm.fraunhofer.de.

Abstract: Fan-out wafer-level packaging (FOWLP) is one of the latest packaging trends in microelectronics. Besides technology developments toward heterogeneous integration, including multiple die packaging, passive component integration in packages and redistribution layers or package-on-package approaches, larger substrate formats are also targeted. Manufacturing is currently done on a wafer level of up to 12"/300mm and 330mm, respectively. For a higher productivity and, consequently, lower costs, larger form factors are introduced. Instead of following the wafer-level roadmaps to 450mm, panel-level packaging (PLP) might be the next big step. Both technology approaches offer many opportunities as high miniaturization and are well-suited for heterogeneous integration. Hence, FOWLP and PLP are well-suited for packaging a highly miniaturized energy harvester system consisting of a piezo-based harvester, a power management unit and a supercapacitor for energy storage. In this study, the FOWLP and PLP approaches were chosen for an ASIC package development with integrated SMD capacitors. The process developments and successful overall proof-of-concept for the packaging approach have been done on a 200mm wafer size. In a second step, the technology was scaled up to a 457 x 305mm^2 panel size using the same materials, equipment and process flow, demonstrating the low cost and large area capabilities of the approach. (*Micromachines,* May 2019; www.ncbi.nlm.nih.gov/pmc/articles/PMC6562530)

AI Routing

"Effective PCB Decoupling Optimization by Combining an Iterative Genetic Algorithm and Machine Learning"

Author: Riccardo Cecchetti, Francesco de Paulis, Carlo Olivieri, Antonio Orlandi and Markus Buecker

Abstract: An iterative optimization for decoupling capacitor placement on a power delivery network (PDN) is presented based on genetic algorithm (GA) and artificial neural network (ANN). The ANN is first trained by an appropriate set of results obtained by a commercial simulator. Once the ANN is ready, it is used within an iterative GA process to place a minimum number of decoupling capacitors for minimizing the differences between the input impedance at one or more location, and the required target impedance. The combined GA-ANN process is shown to effectively provide results consistent with those obtained by a longer optimization based on commercial simulators. With the new approach, the accuracy of the results remains at the same level, but the computational time is reduced by at least 30 times. Two test cases have been considered for validating the proposed approach, with the second one also being compared by experimental measurements. (*Electronics,* Aug. 2, 2020, www.mdpi.com/2079-9292/9/8/1243)

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.

Sustainable Electronics

"*Geobacter* Protein Nanowires"

Authors: Derek R. Lovely, Ph.D., and David J.F. Walker, Ph.D.

Abstract: The study of electrically conductive protein nanowires in *Geobacter sulfurreducens* has led to new concepts for long-range extracellular electron transport, as well as the development of sustainable conductive materials and electronic devices with novel functions. Until recently, electrically conductive pili (e-pili), assembled from the PilA pilin monomer, were the only known *Geobacter* protein nanowires. However, filaments comprised of the multi-heme *c*-type cytochrome, OmcS, are present in some preparations of *G. sulfurreducens* outer-surface proteins. This review evaluates available evidence on the *in vivo* expression of e-pili and OmcS filaments and their biological function. Abundant literature demonstrates that *G. sulfurreducens* expresses e-pili, which are required for long-range electron transport to Fe (III) oxides and through conductive biofilms. In contrast, there is no definitive evidence yet that wild-type *G. sulfurreducens* express long filaments of OmcS extending from the cells, and deleting the gene for OmcS actually *increases* biofilm conductivity. The literature does not support the concern that many previous studies on e-pili were mistakenly studying OmcS filaments. For example, heterologous expression of the aromatic-rich pilin monomer of *Geobacter metallireducens* in *G. sulfurreducens* increases the conductivity of individual nanowires more than 5,000-fold, whereas expression of an aromatic-poor pilin reduced conductivity more than 1,000-fold. This more than million-fold range in nanowire conductivity was achieved, while maintaining the 3nm diameter characteristic of e-pili. Purification methods that eliminate all traces of OmcS yield highly conductive e-pili, as does heterologous expression of the e-pilin monomer in microbes that do not produce OmcS or any other outer-surface cytochromes. Both e-pili and OmcS filaments offer design options for the synthesis of protein-based "green" electronics, which may be the primary driving force for the study of these structures in the near future. (*Frontiers in Microbiology,* Sept. 24, 2019, https://doi.org/10.3389/fmicb.2019.02078)

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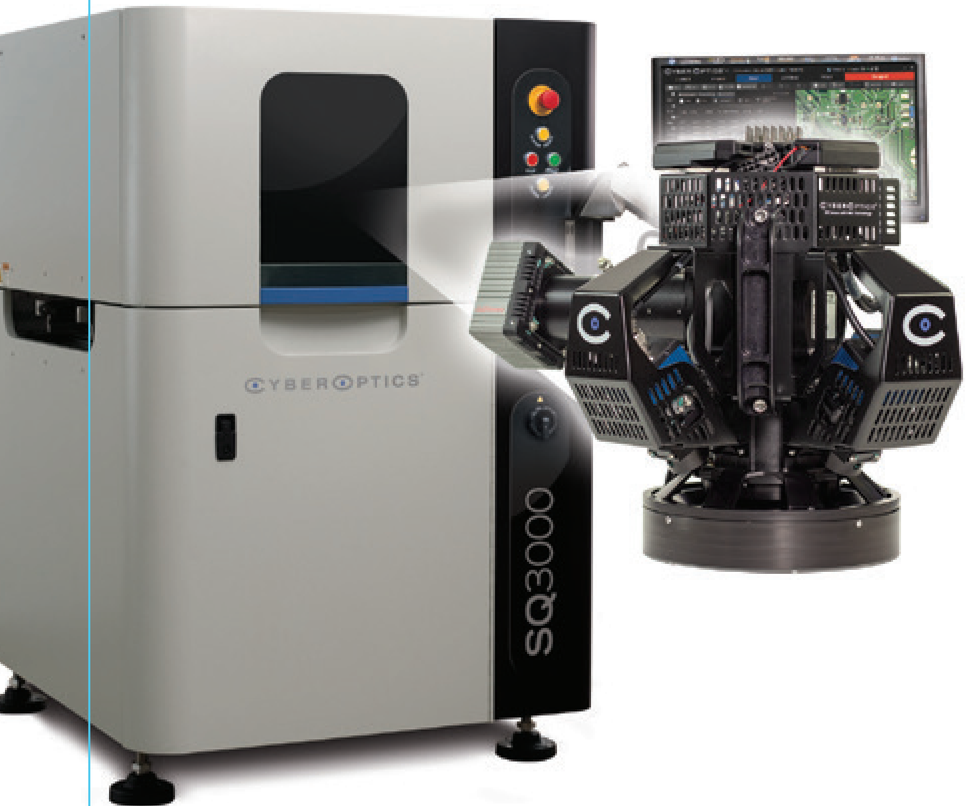

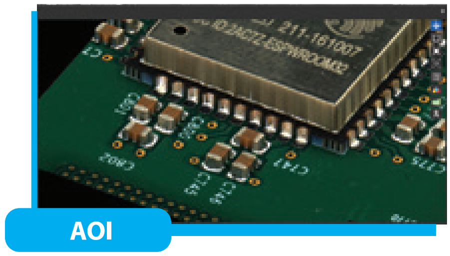

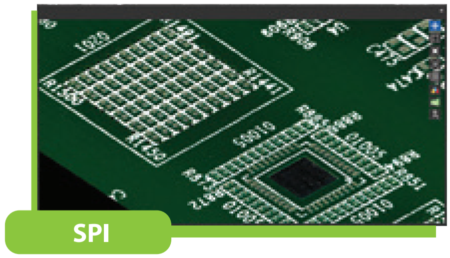

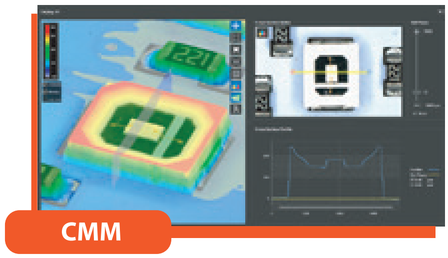

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