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March 2023

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PCB Outline Transfer

Fillet Starvation Fixes

Understanding Reflections

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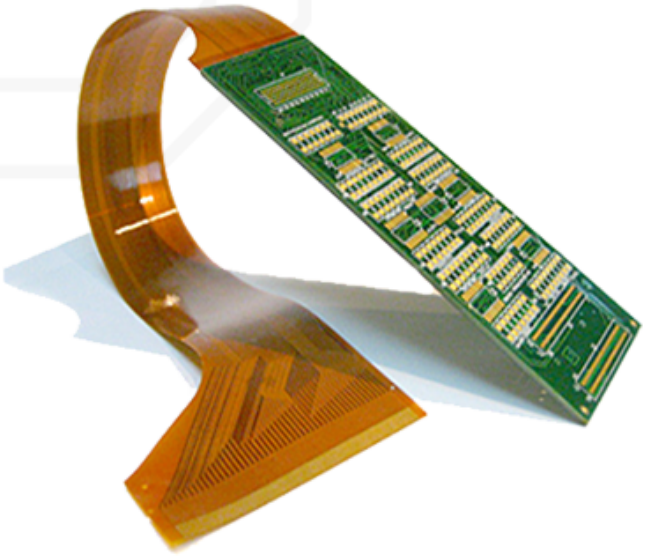

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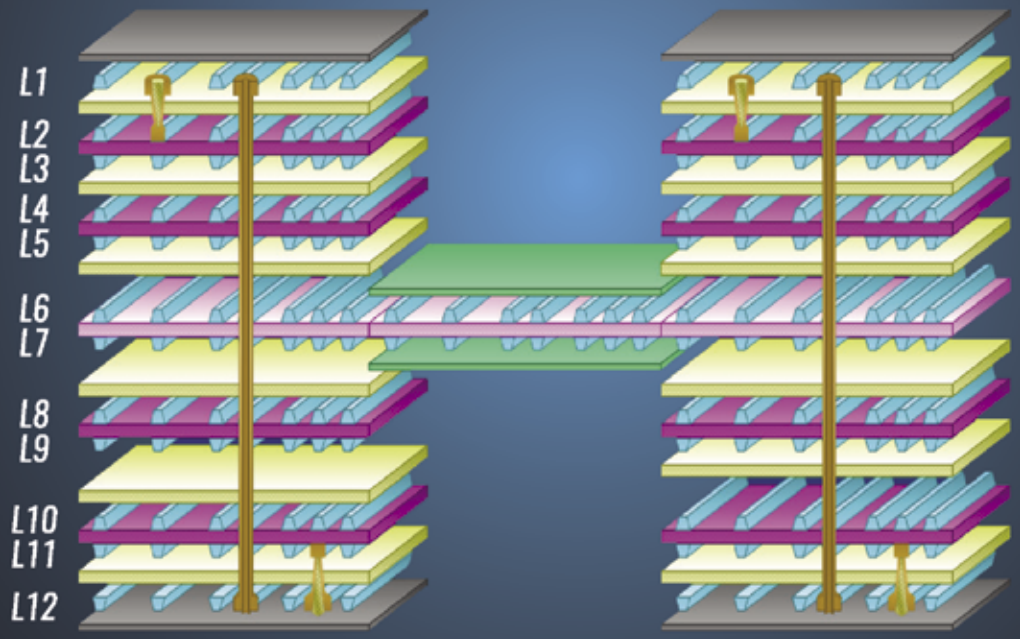


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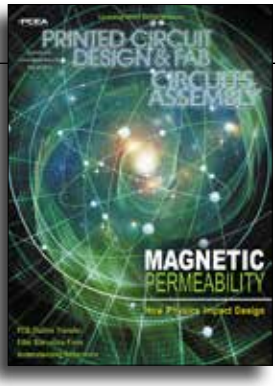


PHYSICS OF ELECTRONICS *cover story*

### Permittivity vs Permeability: What's the Difference?

PCB designers often have little to no experience with physics, but some areas of physics have a considerable impact on designs. The differences and relationships between permittivity and permeability in dielectrics are discussed.

BY DOUGLAS BROOKS, PH.D.

SIGNAL MODELING

### How Interconnects Work: Characteristic Impedance and Reflections

Reflections in an interconnect degrade the transmitted signal, which may cause link failure. How to solve for the reflections caused by transmission line characteristic impedance and termination impedance mismatch.

BY YURIY SHLEPNEV

VIA-IN-PAD

### A Quick Fix for Fillet Starvation

A typical problem for via-in-pad design is the creation of seemingly "starved" fillets when the via sucks up solder from pads at terminals during reflow. A simple solution to this problem is detailed.

BY AKBER ROY

RECOGNITION

### CIRCUITS ASSEMBLY NPI Awards Highlight Best New Products

A recap of the 16th annual New Product Introduction Awards, as selected by top engineers in recognition of the leading new products from the past year.

APEX RECAP

### Good Signs: IPC Apex Booth Traffic Suggests Busy Year Ahead

Brushing off warnings of a flagging economy, the assembly industry reported visions of a strong 2023.

## ON PCB CHAT (pcbchat.com)

PCB Chat

**COUNTERFEIT COMPONENT DETECTION**
WITH EYAL WEISS, PH.D.

**EMS BUSINESS CHALLENGES**
WITH DAVID RABY

**ELECTROLYTIC REFINING**
WITH DAVID BAO, PH.D., ERIC OZAN AND JEFF GILES

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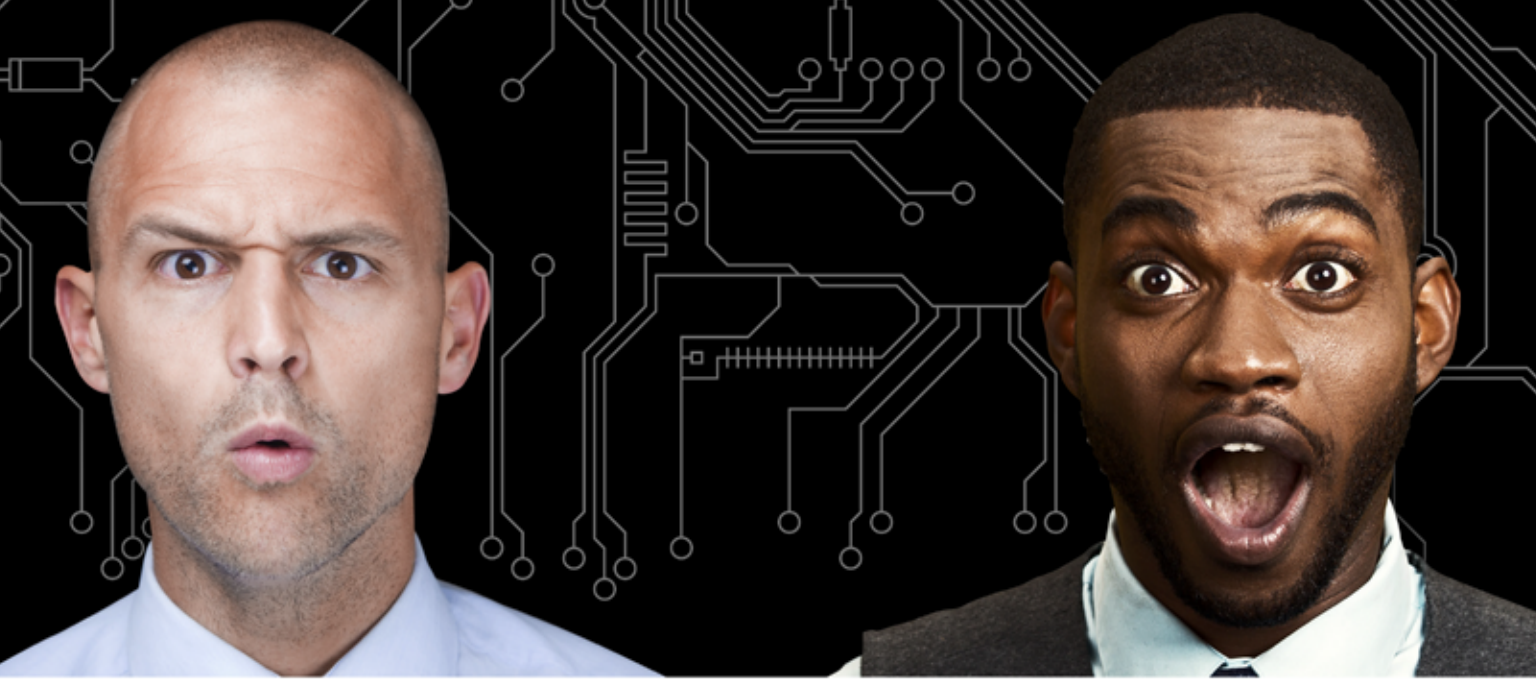

## APCT Acquires Advanced Circuits, Inc.

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# Cynical Forecasters Might Want to Lay Off

WE HEADED TO IPC Apex Expo in late January not certain of what to expect. The backdrop, of course, was one of job upheaval. Blue chip tech companies were announcing large-scale layoffs, and the "disengagement" counts were starting to accumulate in striking fashion. To wit:

- HP: 4,000 to 6,000
- Dell: 6,650
- Google: 12,000
- IBM: 3,900
- Meta: 11,000
- Microsoft: 10,000
- Twitter: Everyone except Elon Musk and a couple of engineers brought over from Tesla*

This wasn't wholly unexpected. Inflation, while trending down, remains stubbornly higher than pre-Covid levels. Fourth quarter sales slowed at many firms. The cost of money has ticked up for months. Companies have been hiring like mad for several years and what goes up – or in this case, out – eventually comes down, or in, at least somewhat.

Nevertheless, some of this seemed proactive, a rebalancing coupled with expectations that

growth would abate in the coming year.

Then we hit the ground in San Diego and what we heard blew that thinking all up.

Exhibitor after exhibitor told us that coming off double-digit gains in 2022, they expected growth this year to slow. But their customers, they added, hadn't received the message. Every equipment supplier we spoke with – and we spoke with almost all of them – said their order books are ahead of forecast, in some cases tremendously so. And every equipment supplier said they now expect 2023 to be a strong growth year.

Now, that doesn't mean some won't feel slowdowns. Some in the bare board industry are paring their operations and staffing, and a few larger EMS companies are trimming here and there. As noted in Market Watch this month, TPCA expects a 4% drop in printed circuit board output this year, and IPC's latest book-to-bills for the PCB and EMS sectors both note falling orders in the December period. (Some of the latter can be explained by changes in OEM buying patterns, which were extended from a typical six-month forecast to as many as 18 months during Covid, and are now retreating to more traditional levels.)

Still, I don't expect a repeat of 2001-05, when the dot-com crash precipitated the big tech version of the Cretaceous-Tertiary extinction, where 25% of the workforce was sent packing. And I believe the issue this time resides more with an overload of software engineers and non-product related staff, versus hardware and manufacturing personnel.

The cost of durables, especially autos, will subside, and after a painful year for smartphone and PC device manufacturers, discounts for consumers may be ahead, spurring demand – and supply chain orders.

I think the glass is more than half-full.

mike@pcea.net

*This is, of course, exaggeration. But give it time.

P.S. Looking for some first-hand input on the industry? Register now for PCB East, the electronics industry technical conference and exhibition for the East Coast. Coming May 9-12 (exhibition is May 10) to the Boston suburbs (pcbeast.com). 

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

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CAM350

DownStream's CAM350 and BluePrint-PCB support importation and visualization of PCB designs containing Flex, Rigid Flex or Embedded components. Visualize designs in both 2D and 3D, and easily document complex Flex or Rigid- Flex Stack-Ups for submission to PCB Fabricators.

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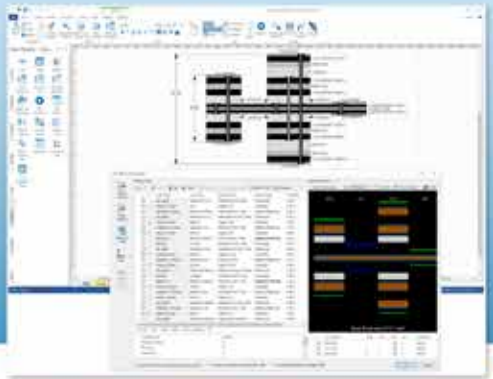
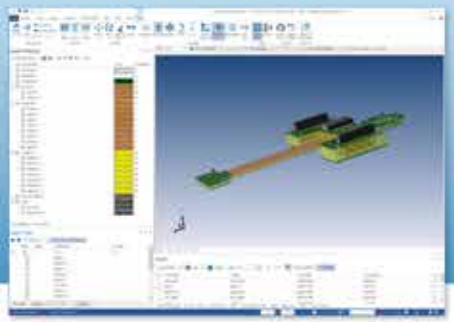


Use Stack Up Visualizer and Blueprint's Rigid-Flex Stackup template to easily manage and document rigid-flex stackups.



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

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

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AROUND **THE WORLD**

# CIRCUITS ASSEMBLY Opens Registration for 2023 Service Excellence Awards

PEACHTREE CITY, GA – CIRCUITS ASSEMBLY has opened registration for its annual Service Excellence Awards (SEAs) for EMS providers and electronics assembly equipment, material, service, and software suppliers.

Now in its 31st year, the SEAs honor companies for excelling in the critical area of customer service, permitting participants to benchmark customer service against their peers. It is the only industry awards program that uses direct customer feedback to determine best-in-class.

The deadline to enter is Mar. 15.

Customers are surveyed to determine their satisfaction with a participating company in various categories, including dependability/timely delivery; manufacturing quality; responsiveness to requests and changes; technology; value for the price; and flexibility/ease of doing business. For each EMS category, the overall best-in-show winner is selected. All customer responses and ratings are tabulated and provided in a confidential report to the participating company. The SEAs recognize four categories of EMS providers based on revenues (under $20 million; $20 million to $100 million; $101 million to $500 million, and over $500 million).

Equipment, material or software supplier awards will be presented in each of the following categories: component storage systems; automation and handling equipment; cleaning processing or materials; device programming equipment; dispensing; pick-and-place; repair and rework; screen printing; test and inspection; materials (solder, encapsulants and adhesives); soldering equipment; automation/manufacturing software; and supply-chain/ERP/MRP software.

Non-manufacturing service providers will be honored in the following categories: test laboratories; recycling, cleaning or other non-manufacturing process providers; and design service bureaus. Reps or agents and/or distributors will also be honored.

CIRCUITS ASSEMBLY will honor winners in person at SMTA International on Oct. 11 at the Minneapolis Convention Center in Minneapolis, MN. Participants will receive their report as an Excel file after the show.

“Datest offers testing, engineering, analytical, and other value-added services, all geared to speed, flexibility, and results. We need a mechanism for obtaining meaningful feedback from customers on a regular basis. We also share that feedback with our AS9100 auditor. The CIRCUITS ASSEMBLY Service Excellence Awards are ideal for capturing those honest reactions that make us a better company,” said Robert Boguski, president, Datest.

For more information, click here.

To register, click here.


# TTM Technologies to Close 3

# Manufacturing Facilities

SANTA ANA, CA – TTM Technologies announced in February that it will close three PCB manufacturing operations in Anaheim and Santa Clara, CA, and Hong Kong, and plans to consolidate the business from these sites into its remaining facilities.

TTM said it expects to close the three sites over the course of this year, and while some employees will be transferred to nearby facilities, the company said it expects a total reduction of approximately 750 employees, or around 5% of its global workforce.

The company said it expects to see between $22 million and $28 million in separation, asset impairment and disposal costs related to the closures, and projects an annual profit increase of around $22 million to $27 million after the facilities are closed and operations are consolidated within its remaining footprint.

“Although demand for our Aerospace & Defense business remains very strong, current macro-economic conditions are causing a softening of demand for our commercial business. This has necessitated the need for us to streamline our manufacturing operations,” said Tom Edman, president and CEO of TTM Technologies. “We expect the action plans that we are announcing today will allow us to better serve our customers with more focused operations as well as a lower cost structure. We will be working with our customers to transfer their business to other facilities in our footprint.

“These are extremely difficult decisions, and we realize these actions will likely have a significant impact on the lives of our dedicated employees at the Anaheim, Santa Clara, and Hong Kong locations. We will work with our employees to assist them through this transition,” he said.

# Icape Group Ends Operations

# in Russia

FONTENAY-AUX-ROSES, FRANCE — PCB supplier Icape Group announced it is ending its operations in Russia.

In a statement released by the company, Icape said it had decided to terminate its Russian operations and stopped taking orders on Jan. 1. Negotiations on the condition and exit of the company's assets are underway and should be concluded as soon as possible, and the withdrawal from Russia should not have a significant impact on revenue and results, the company said.

# MKS Instruments Investigating Ransomware Attack

ANDOVER, MA – MKS Instruments is investigating a ransomware attack that occurred in early February and affected its production-related systems.

In a filing to the SEC, the company said it had temporarily suspended operations at some of its facilities as part of the effort to contain the attack. MKS said it is working to complete its investigation and restore the company's systems and impacted operations as quickly as possible, and the full scope of the costs and impact from the attack is not yet known.

# Camelot Electronics Tech Plans $340M Expansion

QINGYUAN CITY, CHINA – Camelot Electronics Technology plans to invest around $339 million to expand its printed circuit board fabrication operations.

The fabricator, whose clients include Huawei, ZTE, Siemens, Honeywell and ABB, mainly focuses on the automotive PCB market. Its products are used in Tesla, BMW, Audi, Mercedes-Benz, NIO, Xiaopeng, Volkswagen, Toyota, Chrysler, Nissan, Peugeot-Citroen, Hyundai, Yutong, Geely and other automotive brands.

Camelot has two production bases in Qingyuan and Anlu, Hubei Province, and plans to form PCB production capacity of 5.2 million sq. m. per year. The production base in Qingyuan is 40,000 sq. m. with a production capacity of 1.2 million sq. m. per year. The Anlu site is 261,000 sq. m. and has an annual production capacity of 4 million sq. m. HDI (high-density interconnection) and rigid-flex PCBs.

# ECIA GIPC Publishes Report on Paperless Certificate of Compliance Initiative

ATLANTA – The Electronic Components Industry Association's Global Industry Practices Committee (GIPC) in February published a report outlining the results of a two-year initiative to create a streamlined process to digitally exchange manufacturer Certificate of Compliance documents. Analog Devices Inc. (ADI) agreed to participate in the pilot project with Digi-Key. They began with the manufacturers' certificate of compliance while considering other compliance documents. The report from this initiative is available to industry.

The process for the exchange of compliance documentation in the electronic component supply chain is cumbersome and inefficient as it is still largely done manually. Compliance documents are currently in paper form and must accompany the components when shipped

from the manufacturer to the distributor and on through to the end-customer. This, says GIPC, drives unnecessary costs with manufacturers, distributors and customers in the form of time and effort spent locating and tracking paper documents and the actual costs of printing and handling them. Throughout the supply chain, those responsible for complying with these requirements are dissatisfied and frustrated with this inefficient process.

"In theory, this should be low-hanging fruit to save time, money, and trees by changing to digital communication," said Don Elario, vice president of industry practices, ECIA. "However, the benefits only accrue when component manufacturers and distributors decide to participate in the new process. This is why GIPC decided to take on this initiative and use their platform to bring the component industry together on this issue. Continued innovation is needed in this area."

To this end, in 2019 the GIPC organized an SME (Subject Matter Expert) Work Group consisting of two manufacturers and two distributors to explore ways to address this problem. The goal was to design an architecture to digitally transmit compliance documentation. Analog Devices and Digi-Key began work on a pilot program to determine precisely how to digitally transmit documents during component transactions from manufacturer to distributor to customer. The report outlines the status of the work and what remains to be done.

# Artaflex Acquires Custom Rapid Solutions

TORONTO – EMS provider Artaflex has acquired Custom Rapid Solutions, a provider of quickturn PCB assemblies in the Toronto area.

"CRS has been manufacturing quickturn PCBs, as well as low- to medium-volume production, in the industrial segment since 2005 and has a reputation for delivering timely and quality service to its long-standing customer base," said Gerry Iuliano, EVP of business

development, Artaflex. “When you couple the addition of five SMT lines from CRS and their focus around power, sustainable/renewable energy and the industrial automation markets with our focus on higher-volume PCB assembly, box build, systems integrations and test (SIT), our new combination will be offering the most comprehensive suite of services in the Southern Ontario region.”

“With the ever-changing competitive landscape, combining with Artaflex at this stage of our growth will be of great benefit to all our stakeholders, both now and in the future,” said CRS founding partner Edward Nova, who is staying on to lead CRS. “Artaflex and CRS have displayed the same vision and approach to business since our inception which was extremely important for us to find in an acquisition partner.”

CRS will continue to operate as a standalone entity at its existing facilities in Vaughan, Ontario.

# Guh Holdings Expands into EV Business

PENANG, MALAYSIA – In a move to broaden its revenue base, PCB maker Guh Holdings is expanding into the electric vehicle business with the recent acquisition of a 70% stake in Star Wheels Electronics, a company involved in the sales, distribution, manufacturing, assembly and repair of electric scooters, hoverboards and spare parts.

“Star Wheels generates RM2 million ($459,000) to RM3 million ($689,000) sales per annum. The company has nine sales outlets in the country and distributors in the Philippines and Australia,” Guh managing director Datuk Seri Kenneth H’ng told StarBiz about the RM2.1 million ($483,000) transaction.

“For example, the e-scooter-sharing business in Malaysia is expected to hit RM29 million ($6.7 million) in 2023 and is projected to grow at an 18.9% compounded annual growth rate

over the 2023-2027 period to reach RM58 million ($13.5 million) by 2027," he said. "In the e-scooter-sharing segment, the number of users is expected to amount to 1.1 million by 2027. User penetration is 1.9% in 2023 and is expected to hit 3.2% by 2027."

H'ng said the group's PCB business, its core activity, is still stable despite inflation and higher interest rates.

"Our PCBs are manufactured by international brand names and used in electrical and electronic household appliances, automobiles and medical fields. The forecast for our PCBs is still stable," he said.

Guh plans to invest RM10 million ($2.3 million) in EV and EV-related businesses, H'ng said.

# StenTech Acquires Advanced Tooling Design

CLEVELAND – StenTech has acquired fellow stencil and fixture designer Advanced Tooling Design for an undisclosed amount.

ATD designs and manufactures stencils, tooling, fixtures and related accessories used in the electronics assembly industry, with applications across a range of end-markets. Headquartered in San Jose, ATD expands StenTech's facility footprint into California, the largest market for stencil and pallet manufacturing in the US.

"We were looking for a partner who shared our commitment to SMT manufacturing excellence," said Vicki Hamada, president and CEO, ATD. "A combination with StenTech will carry on ATD's rich legacy while ensuring our customers continue to benefit from our intense focus on customer service while gaining access to the expanded resources and facility footprint of the broader StenTech platform."

“This acquisition is an important strategic step forward in the growth and evolution of StenTech. I’m thrilled to be joining forces with the team at ATD,” said Brent Nolan, president and CEO, StenTech.

StenTech is owned by Align Capital Partners, which acquired the stencil maker in May 2022. The transaction marks the first add-on for the company.

“We expect this to be the first of many growth opportunities for StenTech and we look forward to supporting the company through continued investments in technology, sales and operating resources,” said ACP managing partner Chris Jones.

# Niche Electronics Purchases L-Tronics

SHIPPENSBURG, PA – Niche Electronics, an electronics manufacturing services company based in south-central Pennsylvania, has announced the purchase of Waltham, MA-based L-Tronics. Terms were not disclosed.

Founded in 1990, L-Tronics manufactures printed circuit assemblies, wire harnesses, and OEM electrical mechanical devices. The integration of L-Tronics’ 8,000 sq. ft. facility and 30 employees will equip Niche with redundant sites in three geographical locations, making it able to shift production in the event of service interruptions from machine outages, natural disasters, fires or other unforeseen circumstances, the company said in a release.

Niche Electronics crafts high-complexity circuit board assemblies for many industries, providing services from new product introduction to volume production. Niche has operated from its 20,000 sq. ft. headquarters in Pennsylvania since 1997, and its 21,000 sq. ft. facility in Sarasota, FL since 2016.

Niche CEO Frank Bowman said the completed integration will enable the company to handle increased demand for its services and provide personalized service to the entire East Coast

and into the Midwest.

“This new addition represents the beginning of a more accelerated period of planned growth for us,” he said. “We’re excited about our increased presence in an industry whose own growth shows no sign of slowing.”

# Éolane Begins Operation of New Factory in China

SUZHOU – Éolane has opened a new 4,000 sq. m. factory here to serve its customers in the industrial, medical and rail sectors – particularly CRRC, a major Chinese rail company.

The company inaugurated the factory in November after seeing growth of more than 21% in 2022, and the expansion brings the total surface of its factories in China to 11,500 sq. m.

“The construction of our new production site in China demonstrates our ability to remain at the forefront of all technologies in order to provide the best quality of service to our customers, as close as possible to their needs. This new site validates the success and development of Éolane China, by reinforcing our production capacity, which will allow us to welcome a business volume of 50 million euros via new orders from our historical customers and the arrival of new customers,” Éolane China managing director Grace-Lingjia Colin said in a release.

# Bonfiglioli Acquires Selcom Group

BOLOGNA, ITALY – Bonfiglioli, a manufacturer of drive systems, gearboxes and inverters, has announced an agreement to acquire Selcom Group, an Italian producer of PCB

assemblies.

Selcom employs around 750 employees across four production plants in Italy and two plants in Shanghai. The acquisition of Selcom Group is meant to strengthen Bonfiglioli's electronic core and will increase the company's development capacity, Bonfiglioli said in a release.

"We saw in Selcom an excellent opportunity for Bonfiglioli: it is a company with great electronic technical skills, both in terms of design and process, absolutely complementary to ours," said Bonfiglioli CEO Fausto Carboni. "Moreover, at a commercial level, it is an extremely dynamic and motivated company, rooted in Europe and China, two strategic markets where it serves numerous clients among the largest and most important in their sector. This is a strong testimony to the professionalism and competitiveness of the company."

# Austin American Technology Merges with Aqua Klean

AUSTIN, TX – Austin American Technology and Aqua Klean Systems will merge, the companies said in a joint statement. Operations will continue at the firms' existing facilities in Austin and Anaheim, and all employees will be retained. Financial terms were not disclosed.

Austin-based AAT has developed equipment for printed circuit board cleaning, surface-mount technology, stencil and misprint, flip chip, BGA and other cleaning applications for more than 35 years. Founded in 1996, Anaheim-based Aqua Klean assembles cleaning systems for virtually any process.

Together, the companies serve clients ranging from small shops to the largest electric vehicle brands, and the medical device, military, space and other markets. The merger permits the companies to combine resources and expertise to offer superior cleaning equipment for their clients, the statement said.

“AAT and AKS both have the desire to develop and grow the best cleaning company in the industry,” said Todd Rountree, president and COO, AAT. “This involves being on the cutting-edge of technological advancements, cleaning efficiencies and the sleekest designs. These, coupled with the best customer service, will position the merged company to lead our industry far into the future and provide the best resource for our customers. The timing could not have worked out better and we are all excited about the opportunities this merger has made available. With service and manufacturing in both California and Texas, we will have the farthest reach and depth of anyone in our field.”

“We are thrilled to be joining forces with Austin American Technology,” said Mike Schwager, president, Aqua Klean Systems. “Our companies share a commitment to delivering innovative and reliable cleaning solutions to our customers. We believe that the combination of our expertise will help us continue to grow and expand in the future. We look forward to working together and continuing to deliver the highest quality cleaning solutions with exceptional customer service.”

# Lorom Acquires Segue Manufacturing Services

TAIPEI – Lorom Holding Company, a manufacturing solutions provider focusing on specialized cable manufacturing and assembly, in February announced the acquisition of Segue Manufacturing Services. Terms of the acquisition were not disclosed.

Segue is a global contract manufacturer specializing in complex electromechanical integration, cable, and harness assembly and engineering services for the medical, industrial automation, capital equipment, and device OEM end-markets. The company has manufacturing operations in in Billerica, Massachusetts; Xiamen, China; and Monterrey, Mexico.

According to a release from Lorom, the transaction is meant to combine Segue’s expertise in

complex electromechanical and cable assembly with Lorom's experience in wire and cable manufacturing, while enabling Lorom to expand its manufacturing footprint in North America and build out its vertically integrated platform at a greater scale.

In October 2019, Lorom received an investment from Cornell Capital, a private equity firm based in New York and Hong Kong, to accelerate the company's continued growth across Asia, Europe and North America and strengthen its financial performance.

"We are pleased to welcome Segue to the Lorom family and look forward to supporting its future growth," said Joyce Hsu, chairperson of Lorom and chair of Asia at Cornell Capital. "Segue's expertise in complex electromechanical and cable assembly is the ideal complement to our proficiency in wire and cable manufacturing. Lorom will help us deliver an enhanced customer experience and broader reach with its leading position and exceptional reputation for quality within the North American marketplace."

"This strategic transaction provides Segue with multiple growth opportunities, including additional manufacturing capacities on an international scale and the ability to leverage additional engineering support," said Brian Desmarais, chief executive officer of Segue. "With Lorom's specialized expertise in wire harness, interconnect solutions, and cable manufacturing, Segue's customers will benefit from our enhanced vertical integration capabilities. On the heels of our 30th anniversary, we couldn't be more excited about the future of Segue."

# Icape Acquires Fimor Electronics

FONTENAY-AUX-ROSES, FRANCE – Icape Group in February acquired Fimor Electronics, a French manufacturer of human-machine interface solutions and distributor of custom-made technical parts.

Fimor Electronics specializes in the trading of custom-made technical parts, an activity that represents 80% of its revenue, and also owns a factory specializing in the manufacture of human-machine interface solutions, which is the company's second activity and generates 20% of its annual revenue. The company has a portfolio of 350 customers, mainly in the medical, automotive, high-tech and telecommunications sectors. The company also includes a service office in Foshan, China, in charge of commercial and technical relations with about 10 suppliers at the local level. In 2021, Fimor Electronics generated a net annual revenue of more than €6.2 million ($6.6 million) and EBITDA of €600,000 ($642,000).

In a press release, Icape said the acquisition of Fimor Electronics will consolidate its market position of "custom-made" electromechanical parts and enrich the product offerings of its custom-made parts shop, Cipem. Through the acquisition, Icape Group expects to benefit from the existing sales and supply chain synergies with Fimor to reinforce its growth in the technical parts market, which represents nearly 20% of its current annual revenue. Icape is also setting up a new factory in Europe, which will be dedicated to local production for high value-added industrial sectors.

"Fimor Electronics is a very promising company. The team developed a business model, a factory, and a reputation based on excellence and seriousness in France to achieve their objectives and secure a solid customer base," said Cyril Calvignac, CEO, Icape Group. "Icape Group is developing its production network after the acquisition of Trax in South Africa, and MMAB in Sweden, two printed circuit board factories. We are confident that this new acquisition will be a perfect addition to offer the highest quality of services to both Fimor Electronics and Icape Group's customers, and increase the footprint of our companies in France and the border countries. It's also important for us to support and offer a local production solution."

"I am sure that Fimor Electronics and its customers will benefit from this international presence," said Manuel Zuckerman, CEO, Fimor Electronics. "Cipem professionals will bring added expertise, a larger product portfolio, and the energy of a highly motivated team. Fimor Electronics associates are very enthusiastic about joining Icape Group and looking forward to unleashing their potential."

# Foxconn Secures Manufacturing Site in Vietnam

TAIPEI – Foxconn has signed a $62.5 million lease with Saigon-Bac Giang Industrial Park Corp in Vietnam to build a new manufacturing facility.

The move to secure a new manufacturing site comes after the Apple supplier's iPhone plant in Zhengzhou, China, saw an exodus of tens of thousands of employees and violent worker protests amid stringent pandemic control measures imposed during a Covid-19 outbreak that began in late October.

The Vietnamese site, located in the Bac Giang province east of Hanoi, was rented through Foxconn's subsidiary Fulian Precision Technology Component Co. The lease will run through February 2057, the company said.

Foxconn previously announced that it will relocate some of its MacBook production to Vietnam, and has also announced plans to quadruple the workforce at its iPhone plant in India over the next two years.

# PCD&F

**Altair** has signed a multiyear campuswide license agreement with **TU Delft,** the Netherlands' oldest and largest public technical university which is ranked 10th for engineering and technology in the QS World University Rankings.

**Compass Diversified** in February completed its previously announced sale of **Advanced Circuits** to **APCT.**

**Nano Dimension** received a purchase order from a supplier to the US government defense industry for a DragonFly IV additive manufacturing 3-D printer.

**Nano Dimension** has been granted a patent in the area of AI, specifically relating to the neural network that supports its cloud-based manufacturing platform.

**Sunrise Electronics** installed a **DIS** MFS manual flex bonder.

# CA

**Altest** purchased 10 **Tagarno** digital microscopes for its PCB assembly manufacturing facility in San Jose.

**APCT** has purchased a **Hentec Industries/RPS Automation** Pulsar solderability testing system.

**ASMPT** upgraded its WORKS smart shopfloor management suite with a Material Demand Calculation to dynamically calculate material requirements for definable time intervals, taking all incidents into account and continuously adjusting material requirements.

**Aven** appointed **ARK Manufacturing Solutions** manufacturers' representative in Arizona, New Mexico and Southern Nevada.

**BOE Technology Group,** China's largest display maker and a supplier to **Apple** and **Samsung,** is reportedly investing $400 million in two new factories in Vietnam.

**Cal-Comp Electronics** will set up four additional EMS factories in Thailand.

**Celestica** is laying off 44 workers at its Silicon Valley facilities, including 40 in Fremont, and four in San Jose.

**Compal Electronics** disclosed plans to set up an assembly plant for automotive electronics products for new energy vehicles in Mexico with mass production scheduled to begin in the third quarter at the earliest.

**Datest** announced a representative agreement with **PIT Equipment Services** for the US East Coast.

**Dixon Technologies,** India's largest domestic EMS company, is considering setting up a plant in Tamil Nadu, according to a top executive. Dixon currently has factories in three Indian states but not in Tamil Nadu, which is a hub for electronics and automotive manufacturing.

**Goepel Electronic** has opened a subsidiary in Malaysia.

**Incap Electronics** purchased a **Mirtec** MV-3XL Omni AOI, and its Estonia plant added an SMT line and upgraded two others.

**Kitron** entered into a production agreement with **Easy Aerial,** a developer of autonomous UAVs (unmanned aerial vehicles).

**Kitron** in 2023 has invested in six new SMT lines across four factories.

**Promex** Industries installed a **Finetech** Fineplacer Sigma die bonder.

**Retronix** installed **Gen3** NC25 PCB cleaning systems at its factories in Scotland and the US.

**Salcomp** plans to double its workforce in India to 25,000 over the next three years, targeting annual revenue in the country of at least $2 billion to $3 billion by 2025. Salcomp will have a “significant role” in Apple’s supply chain, the company said.

**SMT Tooling,** a division of **PSA Systems,** named **The JW Corporation** manufacturers’ representative.

**StenTech** opened a facility in Huntingdon Valley, PA.

**TEXMAC/Takaya** appointed **Quality Associates** manufacturer’s representative for Indiana and Kentucky.

**TopLine** installed a **Hentec/RPS Automation** Odyssey 1750 robotic hot solder dip component lead tinning system.

**Treston** named **MaRC Technologies** representative in the US Pacific Northwest.

**Viscom** named **PB Technik** distributor for Poland.

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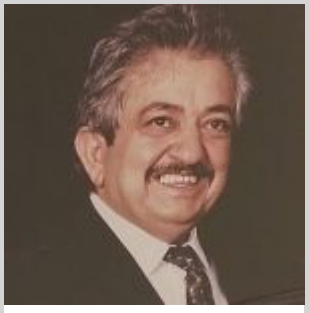
# PCD&F

Dan Amiralian



Vince Valeri

Colin Gouveia

Laura Martin

Alpha Circuit named **Matt Kehoe** southern US sales manager.

Freedom CAD Services announced **Dan Amiralian** as chief strategy officer.

Gardien Group named **Rick Meraw** president.

**Vince Valeri,** cofounder of Dynamic & Proto Systems, has passed away.

Pakistan Detectors Technologies named **Samina Khalid** printed circuit board design engineer.

Quantic Ohmega named **John Andresakis** director of business development.

Rogers appointed **Larry Schmid** senior vice president, global operations and supply chain.

Rogers also promoted **Colin Gouveia** to president and chief executive, replacing the retiring **Bruce Hoechner.** Gouveia was senior vice president and general manager of Rogers' Elastomeric Material Solutions (EMS) business unit.

Summit Interconnect promoted **Gary Sullivan** to director of sales and named **Laura Martin** director of applications engineering.

# CA


Andrew Coleman

Nash Bell

Taylor Wang

Amanda Hartnett

Ernesto Pollano

Christophe Sut

Brian Tharp

Juan Briceño

ACDi named **Tom Dykeman** vice president of sales.

Advanced Instruments promoted **Joe Perault** to director global operations.

AIM Solder appointed **Mehak Sharma** Canadian national sales manager. AIM also named **Andrew Coleman** regional sales manager for the US Midwest.

BEST named **Nash Bell** president, replacing **Bob Wettermann,** who is retiring.

Foxconn has appointed **Michael Chiang** as the new boss for its iPhone assembly business.

Indium introduced **Taylor Wang Yong Xing** as China Country sales manager and **Amanda Hartnett** as product manager for Engineered Solder Materials (ESM).

Kimball Electronics named **Ric Phillips** chief executive. Phillips was most recently president and CEO for Elkay Manufacturing.

Koh Young promoted **Enrique Hernandez Diaz** to regional sales manager and **Rafael Matute Rohwedder** to service manager for Mexico and South America.

MicroCare promoted **Ernesto Pollano** to general sales manager, Mexico/LATAM.

Plexus named **Todd Logue** global director of program management.

Scanfil has signed an agreement with **Christophe Sut** to become CEO, effective Sept. 1.

Sellectronics named **Jon Hurrell** managing director.

STI Electronics named **Brian Tharp** quality manager and **Cesar Santos** kit room

associate.

Viscom named **Juan C. Briceño** vice president of sales – Americas.

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PCEA **CURRENT EVENTS** **NEWS**

# Nanocoating Webinar, Flex Circuit Presentation Highlight Upcoming Meetings

PCEA in April will host a free webinar titled “Engineered Reliability: Safeguarding Electrical Components and Devices with Nanocoating Technology” by Richard Weiland, director of Nanocoating Applications for HZO Inc.

Thin-film nanocoatings can protect critical electronic circuitry that is used throughout a variety of applications and can be a powerful solution to implement to ensure reliability. Only requiring nanometers- to microns-thin coating, plasma-enhanced nanocoatings are dense, highly cross-linked, multilayer films that create a physical and chemical barrier around components to enable an envelope around the circuitry at a molecular level. The result is dependable functionality in harsh environments that may include moisture, sweat, etc. Plasma-enhanced nanocoatings leverage various liquids and gas chemistries to provide fast deposition cycles that are repeatable and scalable to projects of different sizes, use environments, and performance standards.

Every connected electronic has a unique set of parameters that should be recognized and evaluated to confirm that conformal coating solutions are customized to the application and desired functionality. Whether it’s a specific engineering design, manufacturing limitation, or cost requirement, significant considerations are analyzed before a coating ever reaches an

end-product. A vast amount of data regarding conformal coatings, and specifically plasma-enhanced nanocoatings, are available. Fitting the data to an intended purpose, however, can be time-intensive and challenging. In this presentation, Weiland will focus on real-world examples where significant product challenges were presented (such as humidity, temperature, or corrosion) and the investment of time and resources focused on device dependability and functional testing. Data analysis from industry standard testing methodologies as well as application-specific approaches will be presented to demonstrate that nanocoating solutions ultimately provide the protection required for challenging end-use environments encountered during everyday operation.

The one-hour webinar is scheduled for April 25 at 1 p.m. Eastern. To register, visit click here.

**Eptech tour.** PCEA will cosponsor a guided tour of the Eptech trade show in Toronto on May 9 (eptech.ca/location/toronto/). Ata Syed of PFC Flexible Circuits and Nick Koop of TTM Technologies plan to invite students from various institutes and give a tour of the show from an industry point of view. Contact pcea@pcea.net for details.

**EMC control workshop.** Rick Hartley will present a two-day workshop on high-speed and EMI control for printed circuit board design in the Atlanta area in early June. Visit pcea.net or pcb2day.com for details.

**PCB West.** Abstracts were due Feb. 3 for PCB West 2023. We have received 67 abstracts to date for the technical conference. The Conference Task Group will meet this month with the goal to have the program finalized by mid-March. PCB West takes place Sept. 19-22 at the Santa Clara (CA) Convention Center. There is a four-day technical conference of paid and free classes, with a one-day (Sept. 20) exhibition.

# Chapter News

**Orange County.** In February, the Orange County Chapter held a Lunch 'n Learn meeting, exploring advances in the technology of embedding resistors and capacitors which can benefit many designs today.

Bob Carter, vice president of business development & technology at Oak-Mitsui Technologies, spoke on embedded capacitance and improved power delivery. He provided an overview of the different types of embedded capacitance as well as fundamentals of power distribution network design for high-speed digital circuits. The talk covered how it is used in various types of practical applications such as MEMs and RF modules. Using ultra-thin power and ground plane pairs as embedded capacitance layers provide superb electrical performance with regards to charge delivery. There are particular benefits for reducing or mitigating noise and improving logic transitions. Performance, manufacturability, reliability and cost analysis were discussed.

John Andresakis, business development director of Quantic Ohmega, presented on designing with thin-film embedded resistor foil. His talk gave an overview of thin-film embedded resistors and their applications, showing advantages and reliability of designing with that technology. Improvements in signal integrity can be achieved and embedded resistors can eliminate many SMT components to free up surface space while improving performance and reliability. He discussed power handling of embedded resistors to aid in thermal management as well as various types of designs, including RF and microwave applications, which can greatly benefit from adopting embedded resistor technology.

# National News

**Free content review.** The Education Committee's Free Starter Content Task Group this month is reviewing an outline of the materials that will be available through PCEA.

**Foreign language translation.** We have a proposal to add Chinese subtitles to certain presentations on the Printed Circuit University online training platform. The goal is to be able to offer these presentations in multiple languages by year-end. There are more than 120 hours of technical content on the site.

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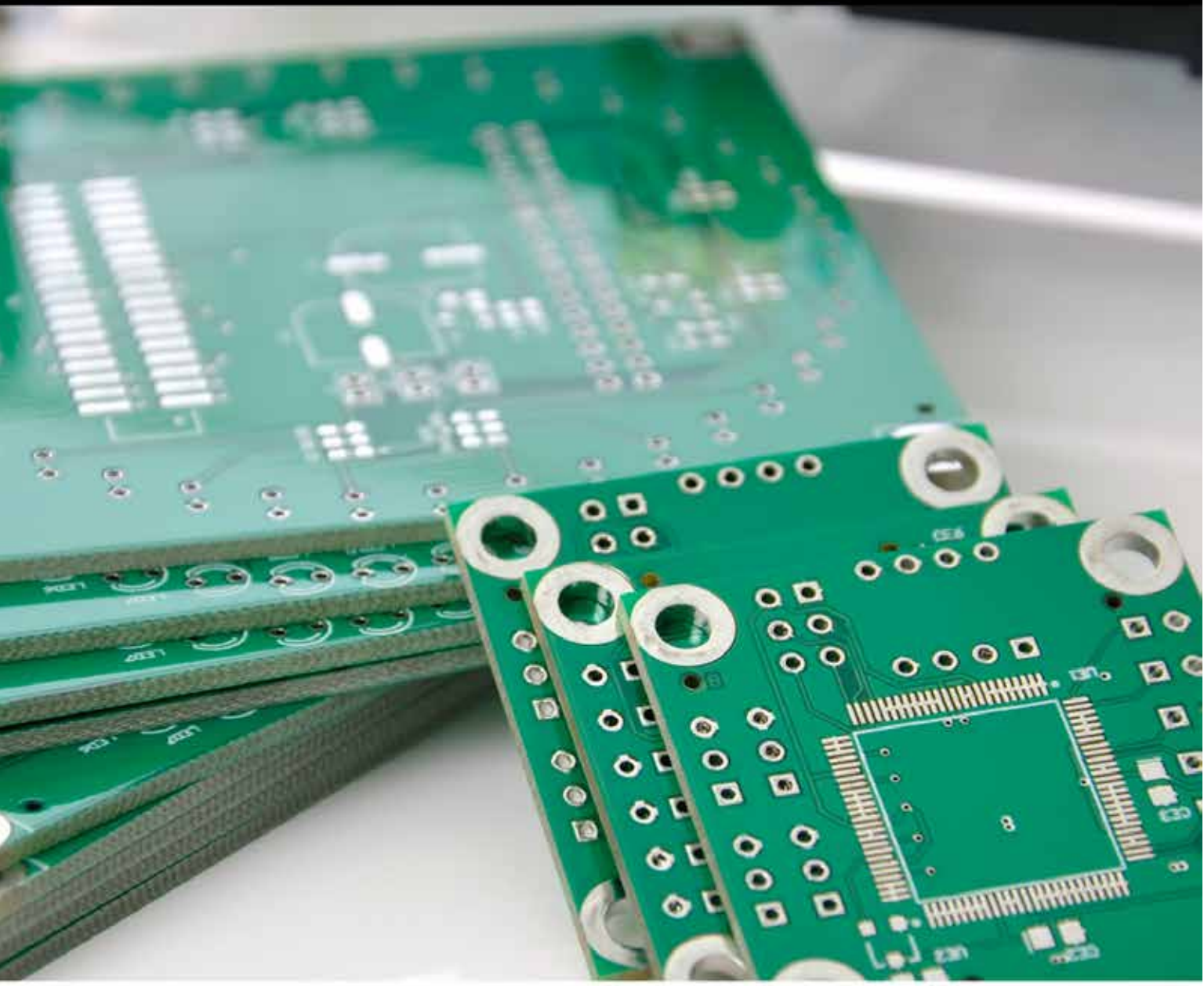

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MARKET **WATCH**

# TPCA Advises Caution for Global PCB Outlook in 2023

TAIPEI – After growing 3.2% to $88.2 billion, negative factors like geopolitics, high inflation and high inventories will likely dampen the global PCB industry for at least the first half of 2023, according to the Taiwan Printed Circuit Association.

Continued chip supply uncertainty meant IC substrates became the counter to negative factors and even the engine for growth in Taiwan, Japan and South Korea. Strong demand from high-performance computing and further upgrades to end-user product specifications all factored in the global PCB market outperforming end-user sales. PCB makers such as Ibiden, Shinko, SEMCO and LG-Innotek saw chip carrier sales account for over 90% of their PCB business, meaning carriers accounted for almost all growth by Japanese and South Korean peers. On the other hand, Chinese companies that once enjoyed rapid growth all experienced a noticeable slowdown in gross profit margins and net profits due to their focus on other products.

Chip carriers were not immune to the economic downturn in the second half of 2022, however. For example, BT carriers targeted at consumer products saw growth slow in the fourth quarter. ABF carriers for high-performance computing are also seeing mixed signals due to greater uncertainty in the future. While carriers are likely to maintain expansion in 2023 compared to other types of PCB products, that growth is expected to be lower than last year and its contribution to the global industry output not be as marked.

Weak consumer demand in the second half of 2022 slowed sales at many companies and clawed back almost all the first-half gains, and that decline will likely continue in 2023. Demand could gradually recover in the second half, and on the whole, there should be less volatility in global end-user products for 2023.

If inflation slows, the economy and consumer demand may see growth again in the second half. If that happens, global PCB sales could grow up to 3% to $90.8 billion. If one-third of global economic entities go into recession as forecast by IMF, however, the PCB industry may shrink. TPCA forecasts the decline in the value of the global PCB industry to be around 4% (to $84.7 billion).

## KEY COMPONENTS

| | AUG. | SEP. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|
| EMS book-to-bill[1,3] | 1.3 | 1.3 | 1.3 | 1.38[r] | 1.36[p] |
| Semiconductors[2,3] | 0.0% | 3.0% | 0.3% | 2.9%[r] | -4.4%[p] |
| PCB book-to-bill[1,3] | 1.0 | 1.1 | 1.3 | 1.0[r] | 0.87%[p] |
| Component sales sentiment[4] | 86.0 | 82.3 | 75.6 | 58.1 | 65.8 |

Sources: [1]IPC (N. America), [2]SIA, [3]3-month moving average, [4]ECIA, [p]preliminary, [r]revised

## COLD FINISH

Trends in the US electronics equipment market (shipments only)

| | % CHANGE | | | |
|---|---|---|---|---|
| | OCT. | NOV.[r] | DEC.[p] | YTD |
| Computers and electronics products | 0.6 | 0.1 | -0.1 | 6.7 |
| Computers | -0.04 | -0.4 | -2.0 | 0.7 |
| Storage devices | 1.1 | -2.1 | -2.0 | 12.7 |
| Other peripheral equipment | 12.3 | 3.1 | -1.0 | 51.3 |
| Nondefense communications equipment | 0.8 | -1.5 | -0.1 | 8.5 |
| Defense communications equipment | 1.4 | 0.0 | 0.9 | 6.5 |
| A/V equipment | -3.8 | 2.5 | -7.1 | 15.1 |
| Components[1] | 0.3 | 1.1 | -1.5 | 12.8 |
| Nondefense search and navigation equipment | 1.5 | 0.8 | -0.5 | 1.9 |
| Defense search and navigation equipment | 0.3 | 0.3 | 1.7 | 1.4 |
| Electromedical, measurement and control | 0.5 | -1.3 | -0.7 | 4.8 |

[r]Revised. [p]Preliminary. [1]Includes semiconductors. Seasonally adjusted.

Source: US Department of Commerce Census Bureau, Feb. 2, 2023

# Hot Takes

**Worldwide semiconductor sales** totaled a record $573.5 billion in 2022, up 3.2% compared to 2021. Fourth-quarter sales of $130.2 billion were down 14.7% from 2021 and 7.7% lower sequentially. (SIA)

PCB and MCM **design software revenue** increased 15.6% to $344.7 million in the September quarter. The four-quarters moving average rose 13.2%. (ESDA)

**North American PCB shipments** in December were up down 1.7% versus 2021. Sequentially, shipments dropped 5.1%. Year-to-date bookings were down 26.5% through December, although orders rose 8.1% during the month. Full year shipments were up 10.1%, while orders were down 6.5%. (IPC)

**Worldwide tablet shipments** grew 0.3% year-over-year in the fourth quarter to 45.7 million units, falling 3.3% overall for the year. (IDC)

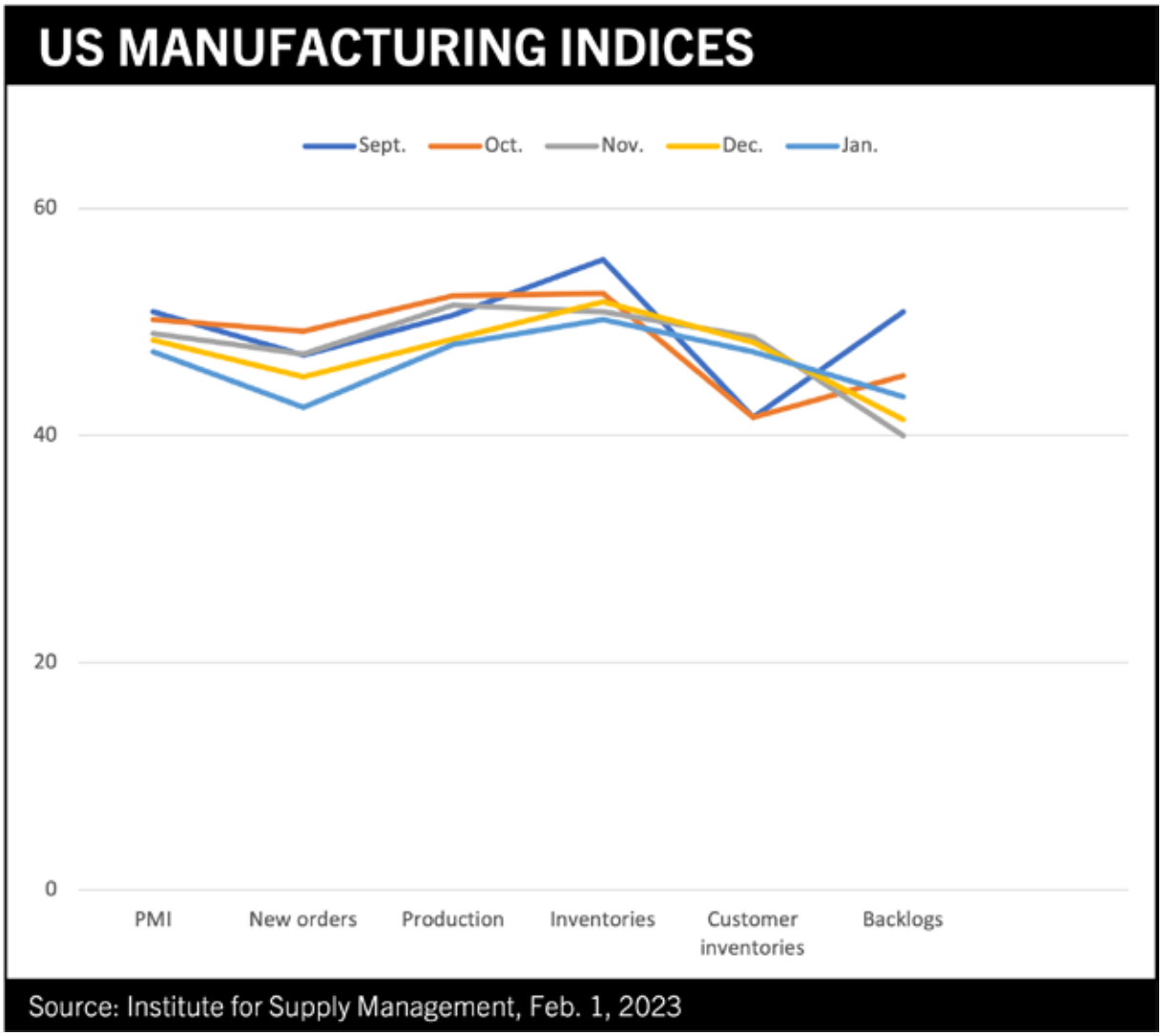
Worldwide **shipments of total devices** (PCs, tablets and mobile phones) are projected to decline 4.4% in 2023, to total 1.7 billion units, following a 11.9% drop last year. (Gartner)

**North American EMS shipments** fell 2.7% year-over-year in December, but rose 5.8% from November. Bookings dropped 22.7% year-over-year and fell 2.9% from the previous month. For the year, shipments were up 4.5% while orders were down 3.7%. (IPC)

Some 75% of **electronics manufacturers are experiencing rising material costs,** while 74% indicate that labor costs are on the rise, according to IPC's January Sentiment of the Global Electronics Manufacturing Supply Chain report. Profit margins, inventory from suppliers and ease of recruitment are presently declining. (IPC)

An 18.3% fourth quarter drop in **smartphone shipments** dragged the annual decline to 11.3%. (IDC)

The automotive industry is estimated to be responsible for 20% of **chip demand,** and the wireless communication industry is projected to drive 25% of growth by 2030. (SIA)



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ROI

# Changing of the Guard

The industry's next generation is on the rise.

I AM CONTINUALLY amazed at how many people I see and run into at each industry meeting or event – especially at technical meetings when I'm watching people leave one room and enter another for the next session. It strikes me a bit like watching the changing of the guard at Buckingham Palace – people leave one room to enter the next to do the same thing, and repeat!

One thing that makes our industry so strong and enduring is having so many people work together to contribute to developing and refining technologies, writing standards for those technologies and processes, and sharing their knowledge with others to fully understand those technologies and standards. And then as they say, "repeat."

Over the past couple years, I have noticed some changes. At first, I presumed that these changes – many of them subtle – were because of, or in some way related to, adjustments to the Covid world. More recently, however, I have realized that the changes observed were occurring for a far more fundamental reason: the passing of time!

What changes had I observed over the past several years? Simply that some of the old familiar faces – also known as "the usual suspects," whom I have known for years, if not decades – who attend events and move from room to room to either run a technical session or lead a committee were passing the proverbial baton to new, younger people. Yes, new faces were

emerging on the scene. Together with those who have been the bedrock of our industry, they are ushering in the next generation of technical industry experts.

Change does appear to be taking place, and in this case, I believe the changes bode well for the future of our industry. As in the past, new people are engaged in the technical challenges of the moment, and after learning from and working side-by-side with more seasoned industry leaders, those new additions are charting the technological course to keep our industry in a leadership position.

While chatting with some of those I have known for years, they will comment about someone who is "really sharp" or "thinking outside the box with some really interesting ideas." I imagine others in the past may have said the same about those of my generation who have been leading the charge for so long. What is so interesting to me is seeing everyone working cross-functionally, as well as cross-generationally, for the betterment of the industry. Such respect and camaraderie have long been hallmarks of our industry, and are critical differentiators between a "growth" industry versus a "mature" industry.

And that's a powerful story; a growth industry with engaged people who work together to develop technologies and then transfer that knowledge within the industry. The industry has a longstanding wealth of creative, talented and dedicated staff who have developed remarkable technology and then shared it so the industry would thrive. More important is communicating that message to college and high school students who are thinking about what type of job or career they might want, and what type of company or industry may be interesting and rewarding. Only by reaching out to the next generation early on will we ensure that the changing of the guard continues into the future.

Corporate investments in the electronics technology industries, boosted by government commitment, and recent strains on the global supply chain causing businesses to rethink where they source electronic materials and components, is increasing momentum for regional growth. Thankfully the next generation is stepping forward to enable our technologies to further develop.

Besides reminding employees and discussing with technology innovators who are developing what we produce, proactive efforts will need to be made by all to attract and develop the next generation of shop floor technicians, at every skill and experience level. The employees who plate, drill, route, inspect and operate screen printers and pick-and-place lines, all necessary skills to fabricate and assemble circuit boards, are essential for the future of our industry. Let the changing of the guard continue at all levels so every company, as well as the industry at large, prospers long into the future.

People, inevitably, are the great differentiators between success or failure. Attracting good workers may be one of the most important, yet most difficult, initiatives for business leaders. Challenges of the moment and difficulties in the past too often dampen how opportunities may be viewed and communicated during the recruitment process. Focusing instead on the great people you have worked with, both at the company level as well as industry wide, combined with knowing we are all a part of a vital industry, will make it easier to attract the best people when the changing of the guard takes place.

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

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DESIGNER'S
**NOTEBOOK**

# PCB Outline Transfer

Tips for better communication and preparation.

THE PCB DESIGNER is often the recipient of a file or series of files that provide the working parameters of the board. These documents will come from a physical designer who does the mechanical engineering for the project. In some cases, the PCB designer wears that hat themselves.

**When the PCB outline is straightforward, do it yourself.** One-off test jigs come to mind. We're probably working with a rectangle that provides ample real estate for the intended circuit. There will be room to grow and iterate, but also space for plenty of text to ease setup and debugging. Put a hole in each corner so standoffs can be installed to raise the board above the test bench.

While we're at it, larger boards may require a stiffener that prevents flexing, which can put a strain on the solder joints. Additionally, wireless sections of the PCB require a shield to keep outside signals from affecting the radio. You may be asked to come up with drawings for those shield walls and fitted lids. The bigger picture requires a different perspective from what we use at the board level.

**Design the board for downstream users.** A solid floor plan will account for all the particulars of the situation. Provide access to connectors and have awareness of how the cabling will flow while the unit is in operation. Near the edge and launching away from the

board helps when it comes to probing around the circuit.

Be aware of the factory requirements for handling a PCB with automated equipment for placement, soldering, inspection and testing. That typically involves a component keep-out region for the two longer edges of the board. The typical width of the keep-out area is about 5mm, but that will be a function of the equipment in use. These grab-rails can be removable or a permanent part of the PCB assembly.

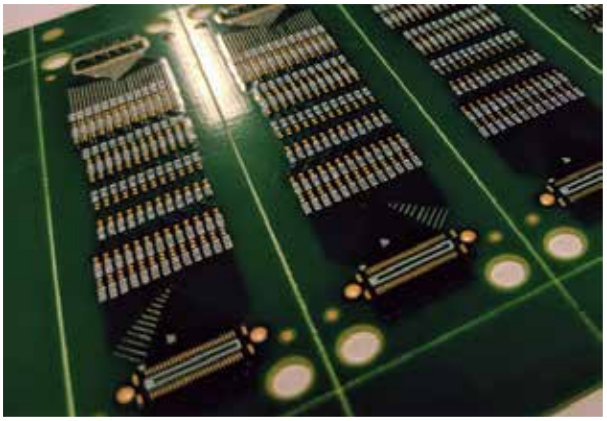

Figure 1. A simple rectangle lends itself to V-score assembly panels, an efficient use of material by comparison to routed outlines.

**An assembly subpanel is advised for smaller PCBs.** Again, DIY or better, hand it off to the fabricator. Meanwhile, the fabricator probably has software to accomplish this subpanelization task in a matter of minutes. That is something to bear in mind, especially if time is in play. You don't want to guess about their full working panel sizes or the most efficient and reliable way to hold it all together through assembly.

They can generate the array and figure out the depanelization plan whether that is V-score or a routed outline with "mouse bites." Adding proper break-off tabs for processing and using that space for test coupons or X-out fiducials and tooling holes is all part of the drawing. I'd politely ask the vendor to generate a drawing and send me an electronic copy that could be added to the document package or even incorporated with the layout in its native software.

**Various methods of data transfer from physical design to PCB design.** That brings up the potential avenues for importing data from upstream or downstream parties. I'm old enough to remember paper drawings as a means of communication. Then we got to PDF files that were no more help than paper but were at least digital in nature.

Following the raster graphics of the Adobe PDF, the de facto standard became Autodesk DFX files. The cool thing was that it used raster graphics, which could translate into actual lines and shapes for use in the PCB layout tool. The format has its pitfalls. Here's my hot take.

We have to figure out what is there by the layer names used, which are typically LAYER0, LAYER1, 2 and so on. That lack of intelligence is exacerbated by receiving the data at a scale that can be 1:1 but is more often some random size. Hopefully, you can find a reference to measure and then figure out the reciprocal to create the geometry at the correct scale. It's a bit of a drag when the original is at 3:1, for instance, so the fix is to scale it to 0.333. Now the distance that was 1.0 units is going to be 0.999 … rounding off to the system's resolution.

Other translators are around if you can incorporate them with your flow. It seems to always take a few adjustments to get cohesive results. While the step models look great, they must mesh with the way the layout symbol is generated. It comes down to orientation and the location of the datum point. Some connectors will use pin one as the datum while others go for the center, which is where a pick-and-place machine would grab it. You may have to do some arbitrary revisions to your library to make it all work as planned. I'd go that route as the most expedient.

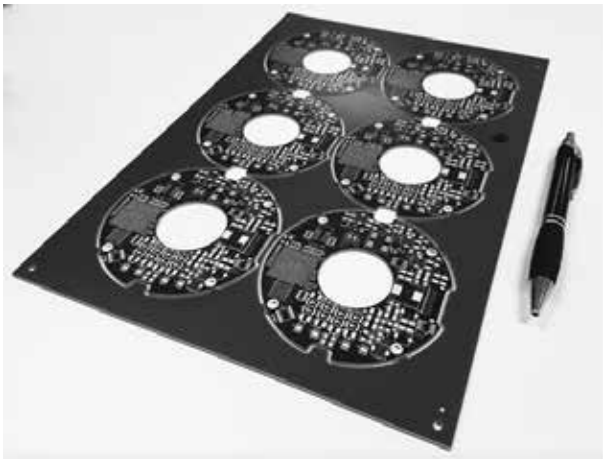

Figure 2. Let someone else figure out the panel for the circular PCBs.

**Whenever data are translated between CAD and ECAD, there's risk of something going nonlinear.** Failure to import data happens. Quite often, the root cause is regarding the way a shape is formed. Many well-meaning mechanical engineers will fashion a single shape that provides two data points. One could be the overall size of a shield and the inner space where it is safe to populate the components. This picture frame of a shape tries to depict the enclosed space within the outer space. It's a continuous line that looks like it has a void, but the inside and outside are 99.9% complete with a little gap between the two that would certainly fill over in an etching or printing process.

The issue arises when the ECAD software cannot import the shape. It must use a non-zero fill to paint the shape. That clever 1µm gap just sank that overworked shape. Getting things like this fixed takes some diplomacy unless you're already pals with the mechanical engineers around you. It's not an easy job.

Figure 3. A singulated PCBA showing how the mouse bites aligned with the mounting holes.

The models used by the hardware engineer can be entrenched in the process. They may need it to be hollow so that the individual parts can go inside. I did the wireframe stuff many years ago using CADKEY (now KeyCreator) and know only enough about it to be dangerous. Solid modeling tools such as ProE, SDRC, MathCAD, Solidworks and many others are helpful for

what we call finite element analysis. Properties apply to solids in a similar manner to timing requirements built into a memory bus.

**Some things can't be helped with data transfer.** When in doubt, ask for a drawing or a live run-through of the 3-D renderings available to the user. The physical designers face a situation where some of the specifications are driven by an outside source. We can get a conflict between what the component data sheet calls out for a hole tolerance and what the fabrication shop can achieve. The number is built into the padstack for a reason. Reality is like that on 3-D software as well, no matter which kind is used. Setting up a feedback loop and keeping it active is highly recommended – especially to acknowledge when it's "all good."

Long term, we want to improve the interface between the mechanical designs and the printed circuit board by resolving these issues in the most pragmatic way. The situations differ but the process improvement goal is still valid. Zooming out, there are companies known for a strong coupling between the two disciplines. Apple comes to mind. They have matured the process so that any components controlled by the outline drawing are immediately placed when the outline is imported.

Figure 4. The placement concern is not always apparent from a constellation of shapes. The glue that secures the connector may have to be applied around the taller chip cap (C2) while the reference designator should be moved.

I've heard stories where the tape-out is completed with a hotkey; push button, documents are

created and uploaded into the system. Of course, all the design rule checks are part of a script as well. There would be people maintaining the system full-time. Bottlenecks can delay footprint generation, simulation or any other touchpoints. It doesn't seem possible to roll a revision with a new component and get that board out the door the same day.

If it's a new outline, there would be parallel efforts for you to coordinate. Yes, people are still in a rush at times. We must learn to feed the bureaucracy to expedite a project now and then. Any innovations you might want to try could find some groups that resist change. Even soft pressure could entail blowback at some point. Going over someone's head is a last resort. Showing interest in their obstacles will go farther in winning them over. Gaining trust and getting down to root causes for each opportunity for improvement isn't just for tech giants.

Meanwhile, many of us labor away in startups and self-owned businesses where these matters are not yet defined in a fulsome way. I feel like it's part of my job to upgrade this part of the process ever since I was at Qualcomm going on nine years ago. Smarter parts and better data exchange are worth the effort when you know that the board is going to at least fit into its location. That leaves us to get to the important SI/PI issues around placement and routing. That's where the rubber meets the road. It starts with a solid foundation.

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

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MATERIAL **GAINS**

# Electric Aviation Takes Flight

Effective electrification could hold the keys to the future of air travel and air superiority.

MANY FEEL OUR lives enriched by convenient and fast mobility. Our societies and economies have become dependent on the ability to get places quickly in planes, trains and automobiles, but easy mass access to air and road travel now appears at odds with the survival of the planet. We need a zero-emission solution if we are to continue enjoying its benefits, and electrification based on renewable energy appears to offer a way forward. Adoption of electric vehicles is accelerating while development of the internal combustion engine for private automobiles has all but stopped. But what are the prospects for electric aviation?

As in the automotive world, the electric aviation landscape is populated by established aircraft constructors looking to protect their position and high-tech startups seizing the opportunity to disrupt. In the second category, the aptly named Eviation accomplished a first demonstration flight of its Alice full-electric plane in September 2022. As a nine-seater commuter, Alice is a potentially serious commercial proposition – perhaps one of the first. The demo lasted eight minutes, flying at up to 3,500 feet, which compares well with the Wright Brothers' 12-second flight at Kitty Hawk in 1903. We have come a long way since then.

But there are challenges. Swedish startup Heart Aviation has proposed the ES-19 regional airliner, which it says will have a range of up to 250 miles and fly at about 200 knots. But it will need to lift a 5-ton battery into the air as well as its passengers. To compare that with

conventional technology, one US gallon of kerosene weighs about 3kg and a twin-turboprop plane may use around 100 gallons per hour, meaning a two-hour flight may need about 600kg of fuel. On the other hand, the ES-19's electric motors are considerably less expensive than comparable conventional turboprop engines, and maintenance costs are vastly lower.

As always, we are engineering our way past these problems. Battery development is progressing at a fast pace, driven by universal global demand. Leveraging innovative materials and nanotechnologies will undoubtedly continue to increase the available energy storage per kilogram.

Hydrogen can offer an alternative solution to the weight issues that batteries face. Hydrogen is not only abundant, but it also has the highest energy per kilogram of any fuel. Among established aircraft companies, Airbus is developing hydrogen combustion turbines as well as hydrogen fuel-cell electric engines. A critical challenge, however, is storage. In its gaseous state, at ambient temperature and pressure, hydrogen has very low density. A huge volume of gas would be needed to provide power for a journey. Airbus is addressing this with plans to build its first liquid-hydrogen refueling facility by 2025, as part of a joint venture with ArianeSpace, in time to begin demonstrating its hydrogen-powered planes. Other storage options include ammonia ($NH_3$), which can be liquefied using less extreme temperature and pressure. Challenges here include ammonia's toxicity and its energy-intensive production methods.

One way or another, zero-emission aircraft are needed if consumer air travel is to have a future. However, electric planes will need to fly farther – and much faster – than at present to be a suitable replacement for military jets. When the sole objective is air superiority, the only option is to choose the technology that gives the upper hand. Clearly, sustainability and the environment are not key priorities for the military – although effective peacekeeping can arguably save wasteful destruction and the environmental burden associated with the rebuilding that comes afterwards.

Reliance on jet fighters may diminish, however, as the influx of new technologies like small and low-cost drones changes the nature of military engagements. These are driving creative

new fighting techniques such as “swarming,” or using hundreds of drones to mount a coordinated attack. When weapons like these can be procured in large numbers at relatively low cost, a defense that is expensive to maintain will eventually lose. These include rapid-fire conventional weapons, which have been used effectively against incoming missiles at close-range. They consume vast quantities of ammunition, which also presents storage and transportation challenges.

New laser – or “directed energy” – weapons could be the answer. Some of you may recall the “Star Wars” plan from the Ronald Reagan era, although the power needed to destroy large targets rendered this unfeasible at the time. Today, an entirely achievable 300kW or so can quickly knock out small vehicles like drones. There is no need to store and feed ammunition, and the weapon can be operated at relatively low cost. Even bullets can be electrified, it seems.

The US Navy’s latest aircraft carrier, the USS Gerald R. Ford, is touted as a potential testbed for anti-drone lasers. It is not only large enough and important enough, but it also has twin nuclear reactors that generate several times more power than its predecessors and can handle the electrical demands from several lasers mounted on board. With further technical development, these weapons could become smaller and more efficient while also increasing their effectiveness – simply replicating the exponential improvement that our industry has delivered in numerous technologies from computing and communication to renewable energy.

Electrification looks set to become a critical support for our decarbonized and sustainable future. The sustainability of the trend, however, depends on workable supply chains, and these have become stretched and dispersed over the past few decades as expertise and manufacturing capacity has migrated across the world.

I have commented before about the difficulties of reshoring in relation to the PCB industry. Now, western governments are becoming concerned about technology security in general, from supplies of 5G communication infrastructure to manufacturing capabilities for advanced semiconductors. Re-establishing control will demand considerable financial

investment as well as coordination with partners over an extended period. Action is needed if we are to continue setting the pace of electrification in the future.

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PHYSICS **OF ELECTRONICS**

# Permittivity vs Permeability: What's the Difference?

Some areas of physics have considerable impact on PCB designs. **BY DOUGLAS BROOKS, PH.D.**

PCB designers have had exposure to *electronics* (some more than others). And most of what we do falls under the field of electronics. But designers often have little or no exposure to *physics*. And some areas of physics have considerable impact on our designs. Here we look at two physical properties of the dielectrics we work with, and why they are important to understand (Note 1).

**Permittivity.** Why are some capacitors able to store much more charge than others? What is the relative dielectric coefficient associated with dielectrics and why does it matter? The answer relates to a property called permittivity. Before we get too far into this topic, we need to clarify some terms.

Dielectric constant is an out-of-date term that means the same as permittivity, $\varepsilon_{m.}$ The permittivity of a vacuum, $\varepsilon_{0,}$ is given as 8.85418782 x $10^{12}$ Farads/meter. The relative dielectric constant, $\varepsilon_{r,}$ or relative permittivity, is the ratio of the material permittivity to the permittivity in a vacuum, or

$\varepsilon_r = \varepsilon_m / \varepsilon_0$

$\varepsilon_r$ is the variable we are familiar with that impacts such things as controlled impedance and signal propagation speed. It is a measure of the electrical polarization that can occur in a material in response to an applied charge, or voltage, across the material. **FIGURE 1** illustrates a board with a differential pair of traces on either surface (or it could be a trace over a plane). The waveform illustrates a snapshot of a signal propagating along the trace from left to right. Prior to any signal, all electrical charges are distributed randomly throughout the material. When the signal polarity is one direction, the atoms and molecules in the dielectric are pulled in one direction (by Coulomb's Law, opposite charges attract). As the signal changes polarity, the atoms and molecules are pulled in the opposite direction. This action tends to electrically *polarize* the material.

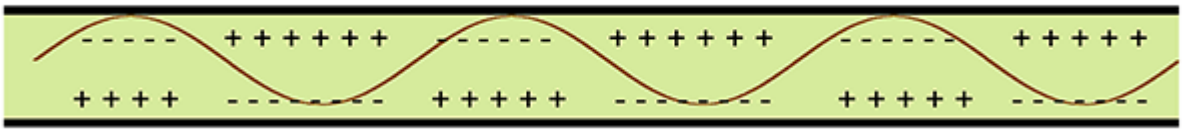

Figure 1. Signal propagating through a dielectric.

Materials with high relative permittivity polarize to a greater extent. That means they can store more charge. If such material is between the plates of a capacitor, that means the capacitance increases. **FIGURE 2** provides relative permittivity values for several materials. Materials typically used in capacitors have relatively high relative permittivities (tantalum ≈ 25, ceramics ≈ 38).

| Material | Min. | Max. |
|---|---|---|
| Air | 1 | 1 |
| Amber | 2.6 | 2.7 |
| Asbestos fiber | 3.1 | 4.8 |
| Bakelite | 5 | 22 |
| Barium Titanate | 100 | 1250 |
| Beeswax | 2.4 | 2.8 |
| Cambric | 4 | 4 |
| Carbon Tetrachloride | 2.17 | 2.17 |
| Celluloid | 4 | 4 |
| Cellulose Acetate | 2.9 | 4.5 |
| Durite | 4.7 | 5.1 |
| Ebonite | 2.7 | 2.7 |
| Epoxy Resin | 3.4 | 3.7 |
| Ethyl Alcohol | 6.5 | 25 |
| Fiber | 5 | 5 |
| Formica | 3.6 | 6 |
| Glass | 3.8 | 14.5 |
| Glass Pyrex | 4.6 | 5 |
| Gutta Percha | 2.4 | 2.6 |
| Isolantite | 6.1 | 6.1 |
| Kevlar | 3.5 | 4.5 |
| Lucite | 2.5 | 2.5 |
| Mica | 4 | 9 |
| Micarta | 3.2 | 5.5 |
| Mycalex | 7.3 | 9.3 |
| Neoprene | 4 | 6.7 |

| Material | Min. | Max. |
|---|---|---|
| Nylon | 3.4 | 22.4 |
| Paper | 1.5 | 3 |
| Paraffin | 2 | 3 |
| Plexiglass | 2.6 | 3.5 |
| Polycarbonate | 2.9 | 3.2 |
| Polyethylene | 2.5 | 2.5 |
| Polyimide | 3.4 | 3.5 |
| Polystyrene | 2.4 | 3 |
| Porcelain | 5 | 6.5 |
| Quartz | 5 | 5 |
| Rubber | 2 | 4 |
| Ruby Mica | 5.4 | 5.4 |
| Selenium | 6 | 6 |
| Shellac | 2.9 | 3.9 |
| Silicone | 3.2 | 4.7 |
| Slate | 7 | 7 |
| Soil dry | 2.4 | 2.9 |
| Steatite | 5.2 | 6.3 |
| Styrofoam | 1.03 | 1.03 |
| Teflon | 2.1 | 2.1 |
| Titanium Dioxide | 100 | 100 |
| Vaseline | 2.16 | 2.16 |
| Vinylite | 2.7 | 7.5 |
| Water distilled | 34 | 78 |
| Waxes, Mineral | 2.2 | 2.3 |
| Wood dry | 1.4 | 2.9 |

Figure 2. Relative permittivity of selected materials.[1]

The physics of realigning the charges in a dielectric as a signal passes by takes energy. This energy is lost to the signal as it passes by. In one form, the losses manifest themselves as dielectric losses. Dielectric losses are a function of frequency (they increase as the frequency increases) and of temperature. One practical consequence of dielectric losses is that the characteristic **impedance** of the trace changes. This means there is no longer a single resistor value that can effectively terminate the trace (Note 2). And this means that signal reflections may become an issue.

Higher permittivities in dielectrics increase the capacitance between the trace and underlying planes. Therefore, dielectrics with higher permittivities will lead to lower characteristic impedances for traces, affecting controlled impedance calculations. And since realigning charges absorbs energy from the signal, the signals will slow down in dielectrics with higher permittivities.

So, from an *electronic* standpoint, the capacitance of a capacitor or a trace is determined by the area of the plates and the distance between them. But the physics of the material between the plates can have a dominating effect on that capacitance.

Note that permittivity relates to charged particles (electrons) and their inherent charge. This will contrast with permeability, below.

**Permeability.** In electromagnetism, permeability is the measure of magnetization that a material obtains in response to an applied magnetic field. (Compare with permittivity, above.) Permeability is typically represented by the (italicized) Greek letter mu, or $\mu$. In the macroscopic formulation of electromagnetism, there appears two different kinds of magnetic field:

• The magnetizing field **H,** which is generated around electric currents and also emanates from the poles of magnets. The SI units of **H** are amperes/meter.

• The magnetic flux density **B** which acts **back** on the electrical domain, by curving the motion of charges and causing electromagnetic induction (Note 3). The SI units of **B** are volt-seconds/square meter (teslas).

*Relative permeability,* denoted by the symbol $u_T$, is the ratio of the permeability of a specific medium to the permeability of free space:

μ0: $u_T = u/u_0$

where $u_0 = 4\pi \times 10^{-7}$H/m is the magnetic permeability of free space.

The importance of permeability is that it "amplifies" the magnetic field created by a current. For example, if we form a current-carrying conductor into a coil, as shown in **FIGURE 3,** a magnetic (H) field will be generated inside the conductor loops. This will cause inductance in the conductor, the magnitude of which depends on the geometry of, and number of, the turns. If the core material inside the loops is air, the inductance will be relatively small. But if the core material has a high permeability (say an iron core) the magnetic field will be much larger, generating a much larger inductance in the coil.

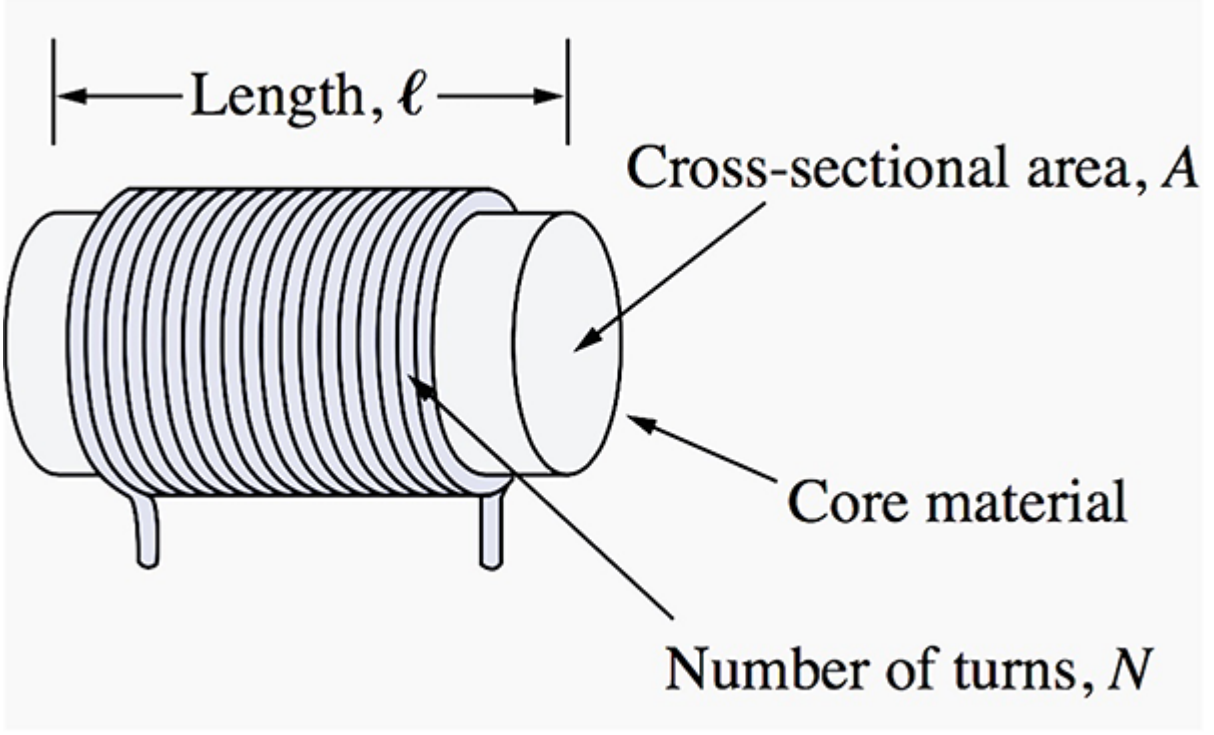

Figure 3. Wire wrapped around a toroid.

So, from an electronic standpoint, the magnitude of the inductance depends on the geometry of the coil. But the physics of the material inside that loop can have a dominating effect on that inductance.

In terms of permeability, there are three types of materials: diamagnetic, paramagnetic and ferromagnetic. Ferromagnetic materials are the only ones that significantly focus the magnetic field around a conductor. Circuit designers generally are only interested in ferromagnetic materials. Only four common elements are ferromagnetic: Fe (iron), Co (cobalt), Ni (nickel), and Gd (gadolinium, look it up!).

The root cause of permeability is electron *spin* (as opposed to electron *charge* creating permittivity). A current through a wire generates a magnetic field around the wire (Faraday's law). Electron spin creates a magnetic moment at the atomic level. In general, electron spin is chaotic and random for most materials. But the tendency (ability) of many of the electrons to align their spin in the same orientation is the characteristic that creates magnetic permeability. In some materials this orientation is only temporary and dissipates when the external magnetic field is removed. But with certain materials, and under certain conditions, a material can become permanently magnetized.

## REFERENCES

1. Aaron Thomas – Electromagnetics blog, "Relative Permittivity – Beeswax/Teflon Interface," https://sites.google.com/site/atspring2013/refraction—2009/relative-permittivity—beeswax-teflon-interface.

## NOTES

1. This article is adapted from Brooks' new book, Physics of Electronics for PCB Designers, available for free download at ultracad.com.
2. Doug Brooks, "UltraCAD's Best Articles and Application Notes," Chapter 17, 2022 (available on Amazon.com).

3. When we apply a changing current through a wire, the magnetic field it creates is the H field. That field creates a current in the opposite direction (causing inductance and skin effect. Again, see Note 2, Section 1.b). The induced magnetic field caused by the new induced current in the backwards direction is the B field.

**DOUGLAS BROOKS, PH.D.**, has bachelor's and master's degrees in electrical engineering from Stanford and a Ph.D. from the University of Washington. He owned an engineering service firm and has published multiple books, including Physics of Electronics for PCB Designers and PCB Design Guide to Via and Trace Currents and Temperatures; doug@ultracad.com.


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SIGNAL **MODELING**

# How Interconnects Work: Characteristic Impedance and Reflections

Understanding reflections caused by transmission line characteristic impedance and termination impedance mismatch. **BY YURIY SHLEPNEV**

Analysis of "digital interconnects" is the analog problem in frequency domain where interconnects are simulated as transmission lines defined by characteristic impedance and propagation constant. Digital signals in interconnects are sequences of amplitude-modulated pulses that transmit bits between components. The "digital interconnect" analysis problem is technically an analog problem of pulse propagation modeling in time-domain. The sequence of the transmitted bits (1s and 0s) is the only boundary between the digital and the analog interconnect analysis domains. That time-domain analysis problem, however, is practically always solved in the frequency domain. The pulse or sequence of pulses are transformed into a superposition of harmonics or sinusoidal signals in the time domain (more on that in Shlepnev[1]) because it is mathematically easier and more convenient to model all types of signal degradation for the harmonic signals using phasors and complex analysis. Components on PCBs in the digital domain are just connected – 1s and 0s are supposed to flow seamlessly among the components. In the analog or RF/microwave domain, components on PCBs or in a package are connected with the distributed open waveguiding structures composed of traces

and reference conductors and simulated mostly as transmission lines. To ensure the digital signal gets through, we build interconnect models that include all signal degradation factors important for a specific data rate.

In general, all signal degradation factors can be separated into three categories:

- Absorption losses in dielectrics and conductors
- Reflection losses due to impedance mismatch and discontinuities
- Coupling losses and distortion (includes crosstalk).

Absorption or dissipation losses in dielectrics and conductors were recently discussed in Shlepnev[2]. Such losses are inevitable, but can be effectively mitigated at the stackup planning stage – selection of dielectric and conductor materials and stackup geometry defines the maximal possible communication distance for a particular data rate.

Considering the reflections, they can be further separated into the following categories:

- Reflections from transmission lines and termination impedance mismatch
- Reflections from single discontinuities – vias, transitions, AC caps, gaps in reference plane, etc.
- Reflections from periodic discontinuities – cut outs, fiber-weave effect, etc.

Why do we care about the reflections? Because the reflections degrade the transmitted signal, and such degradation may cause link failure. Thus, understanding and evaluating reflections is useful for channel quality control, and there are corresponding compliance metrics in the frequency domain (bounds on reflection loss) as well as in the time domain (effective return loss, or ERL).

Here we take a closer look at the reflections caused by the transmission line characteristic impedance and termination impedance mismatch. We discussed it in our "Design Insights…" tutorial at DesignCon in 2020[3] and this article is loosely based on that.

Impedance and admittance, as well as impedivity, admittivity, conductance (conductivity?),

succeptance, leakance, voltivity, and gaussivity are the terms introduced by Oliver Heaviside at the end of the 19th century during the golden era of electromagnetic discoveries started by James Clerk Maxwell. Heaviside derived the telegrapher's equations describing transmission lines or, as we know now, any waveguiding system in general. The equations describe a one-dimensional distributed problem that for a two-conductor or one-mode (one signal and one reference conductor) transmission line looks as follows:

$$\frac{\partial V(x)}{\partial x} = -Z(f)\cdot I(x) \qquad Z(f) = R(f) + i2\pi f \cdot L(f)$$
$$\frac{\partial I(x)}{\partial x} = -Y(f)\cdot V(x) \qquad Y(f) = G(f) + i2\pi f \cdot C(f)$$

Eq. 1

Where $I$ is the current, $V$ is voltage changing along the x-axis, $f$ is frequency [Hz], $Z$ [ohm/m] is complex impedance per unit length and $Y$ [S/m] is complex admittance per unit length, R [ohm/m] and L [Hn/m] are real frequency-dependent resistance and inductance per unit length, and G [S/m] and C [F/m] are real frequency-dependent conductance and capacitance per unit length.

*Z, Y, R, L, G, C* for N+1 conductor problem or N-mode transmission line are NxN matrices in general. They are 2×2 matrices for a three-conductor differential line for instance. The impedance and admittance per unit length are frequency-dependent in general and are completely defined by transmission line type and cross-section and usually computed either with a static or quasi-static 2-D field solver or sometime with 3-D EM solvers. Note the use of 3-D solvers does not automatically guarantee higher accuracy.

A solution of the telegrapher's equation can be written as a superposition of two waves propagating in opposite directions with as follows (can be easily verified by inspection):

$$V(x) = v^{+} \cdot \exp(-\Gamma \cdot x) + v^{-} \cdot \exp(\Gamma \cdot x)$$

$$I(x) = \frac{1}{Z_c}\left[v^{+} \cdot \exp(-\Gamma \cdot x) - v^{-} \cdot \exp(\Gamma \cdot x)\right]$$

$$\Gamma(f) = \sqrt{Z(f) \cdot Y(f)} = \alpha(f) + i\beta(f)$$

$$Z_c(f) = \sqrt{Z(f)/Y(f)}$$

Eq. 2

Where *Zc* is complex frequency-dependent characteristic impedance and gamma is complex propagation constant (alpha is the attenuation constant [Np/m] and beta is the phase constant [rad/m] defined as 2*PI/Lambda, and lambda is the wavelength in the transmission line – phase changes by 2*PI over that length – see more in the Appendix).

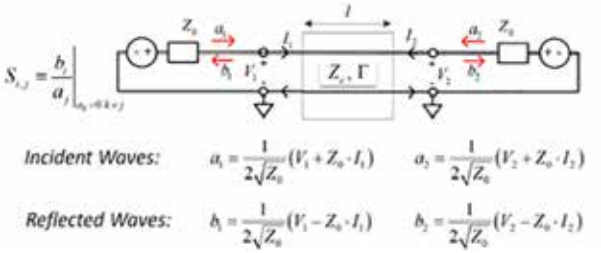
Those are the modal parameters in general; the equations above are for a two-conductor line with one mode only. If we write the solution for the wave propagating only in one direction along the x-axis, for instance (as would be ideal for signal transmission):

$$v(x) = v^{+} \cdot \exp(-\Gamma \cdot x), \quad i(x) = \frac{v^{+}}{Z_c}\exp(-\Gamma \cdot x)$$

Eq. 3

We can see the characteristic impedance is just a ratio of the voltage and current of the wave propagating in one direction of transmission line v*(x)*/i*(x)*=*Zc*. It is impedance by dimension (ohm). It is pure resistance if the line is lossless. “Characteristic” is used here because it does not depend on the position or length of the transmission line segment (independent of x), it “characterizes” it. It depends only on the type of transmission line and geometry of the cross-section. Note that for planar transmission lines, used for PCB and packaging interconnects, the definition of impedance is not unique and can be done three ways: through voltage and current, current and power, and voltage and power, but all are close to the conventional “static” voltage-current definition if the cross-section remains much smaller than the wavelength, which is usually a good assumption for PCB and packaging interconnects.

To investigate the reflections, the next step is to define properties of a transmission line segment. The telegrapher's equations introduced in the previous section are incomplete without the "boundary conditions" or terminations. The most effective way to describe a segment is to use waves and scattering parameters or S-parameters. Here is a transmission line segment with length l connected to voltage sources with all variables, to define S-parameters:




Eq. 4

Where *a1, a2* are the "incident waves," and *b1, b2* are the "reflected waves" with dimension sqrt(Wt). *V1,V2* and *I1, I2* are voltages and currents at the segment ports (pairs of terminals). *Zo* is the termination or normalization impedance (the same thing, in this context). Waves in this definition are not actual waves in the transmission line, but rather variables formally defined through voltage and current. Using equations for voltage and current in transmission line segment (superposition of two waves defined earlier) and Kirchhoff's laws at the external terminals or by following more formal procedure from Pupalaikis[4], we can define S-parameters or S-matrix that relates the incident and reflected waves for such segment as follows:

$$S(f,l)=\begin{bmatrix} \left(Z_c^2-Z_0^2\right)/D & 2\cdot Z_c\cdot Z_0\cdot csh(\Gamma\cdot l)/D \\ 2\cdot Z_c\cdot Z_0\cdot csh(\Gamma\cdot l)/D & \left(Z_c^2-Z_0^2\right)/D \end{bmatrix}$$

$$D=Z_c^2+Z_0^2+2\cdot Z_c\cdot Z_0\cdot cth(\Gamma\cdot l)$$

Eq. 5

The reflection (S11 and S22) and transmission (S12 and S21) can be expressed separately as follows:

$$S_{1,1} = S_{2,2} = \left(Z_c^2 - Z_0^2\right) / \left(Z_c^2 + Z_0^2 + 2 \cdot Z_c \cdot Z_0 \cdot cth(\Gamma \cdot l)\right)$$
$$S_{1,2} = S_{2,1} = 2 \cdot Z_c \cdot Z_0 \cdot csh(\Gamma \cdot l) / \left(Z_c^2 + Z_0^2 + 2 \cdot Z_c \cdot Z_0 \cdot cth(\Gamma \cdot l)\right)$$

Eq. 6

Note the transmission parameters include the effects of the absorption and reflections: these expressions have no approximations. This is a universal definition of reflection and transmission; it can be used for simple experiments with transmission line properties or as rigorous modelling of a segment. It depends on the definition of characteristic impedance and propagation constant used. The rest is pure trigonometry! You can start with a frequency-independent capacitance and inductance per unit length or use more complicated expressions for the characteristic impedance and propagation constant such as used in Simberian App. Note #2012¬¬_02.[5] For simple experiments, the propagation constant can be defined analytically with formulas or simply with phase delay or propagation velocity for ideal lines (see Appendix). This is very simple and an important tool for all kinds of experiments in the frequency domain with real transmission lines. It includes all reflections in time domain (if model bandwidth is properly defined per Shlepnev[1])! Nevertheless, use of frequency domain response for time-domain analysis is not as easy.[4] Simbeor software is used here for all frequency and time domain analyses as it makes our investigation much easier.

Now, what useful information can be derived from such a simple trigonometric model? Let's begin from a very simple case of the termination or normalization impedance equal to the characteristic impedance *Zo=Zc* – the reflection parameter is zero in this case as we can see from the formula! The S-matrix in this case is particularly simple and defined as follows (generalized modal S-parameters):

$$S(f,l) = \begin{bmatrix} 0 & \exp(-\Gamma \cdot l) \\ \exp(-\Gamma \cdot l) & 0 \end{bmatrix}$$

Eq. 7

Only the transmission parameters and no reflections! This should be the Holy Grail of the

interconnect design: the signal is traveling strictly in one direction. The signal, however, may still not get through because the transmission parameter depends on the absorption and dispersion in gamma (discussed earlier in Shlepnev[2]).

Considering the zero-reflection condition, why we do not do it like that all the time? First, the characteristic impedance is complex for lossy lines – it has real and imaginary parts. The zero-reflection termination is not just a resistor, it should be frequency-dependent. But this is not the showstopper. The real part of the characteristic impedance does not change the important frequencies much at all and the imaginary part is much smaller than the real part, as we can see from the plot in **FIGURE 1:**

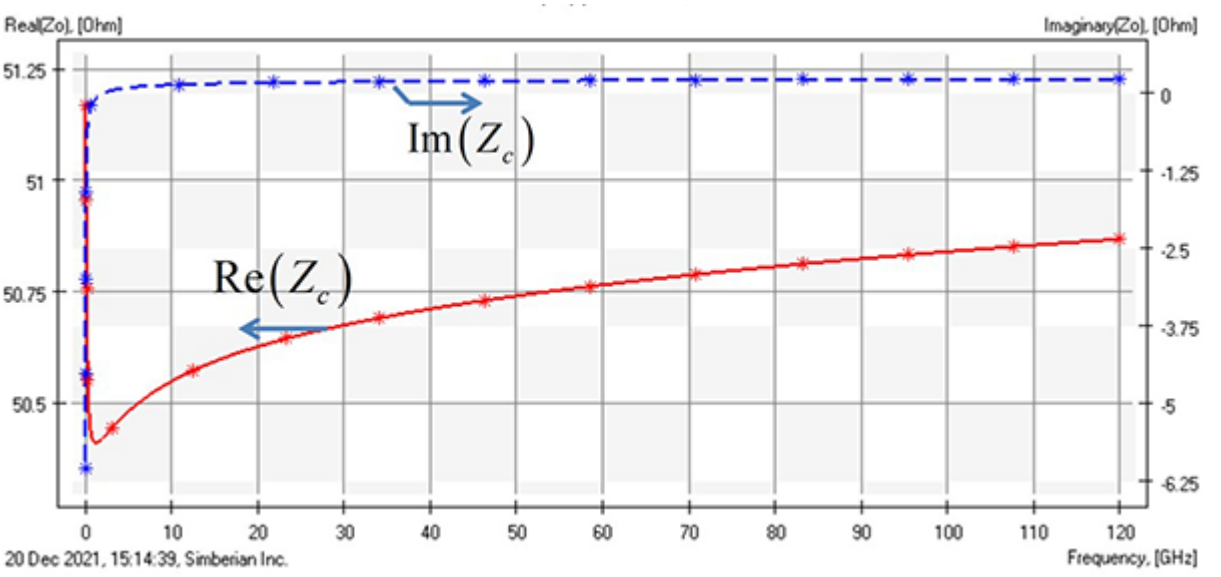



Figure 1. A typical PCB case showing real and simulated characteristic impedance.

At least theoretically, we should be able to get very close to the nonreflective case. Practically, there are more factors that do not allow it – the manufacturing variations and discontinuities such as pads and via holes are the most important ones.

Now, armed with the theory, let's investigate a simple 5cm stripline segment with characteristic impedance about 50.4Ω at 1GHz (changing with frequency as shown above) on FR-408 simulated as Wideband Debye with Dk=3.8, LT=0.0117 @1GHz, copper with RR=1.2, Causal Hammerstad Roughness Model: SR=0.4, RF=2. The problem is as realistic as can be and the only simplification is the absence of discontinuities.

**FIGURE 2** shows the transmission line segment response in frequency and time domains (computed with Simbeor software).

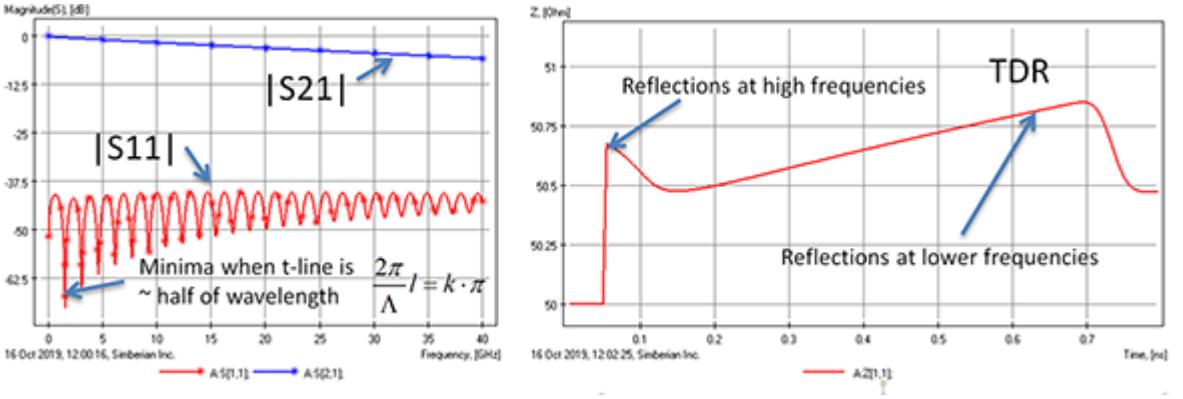



Figure 2. The transmission parameter magnitude is smooth and is defined mostly by the absorption by dielectric and conductors.

Both ends of the transmission line segment are terminated by 50Ω (exactly). Magnitudes of the reflection |S11| and transmission |S21| parameters are shown on the left plot and corresponding TDR on the right plot (reflection from 20ps step response in Ohm). S-parameters are shown in dB (20log(|S11|) and 20log(|S21|)). First, we can observe that the reflection is not zero, but very low: below -37.5dB (only about 13mV is reflected with 1V excitation, as good as is usually not possible).

Consequently, the transmission parameter magnitude is smooth and is defined mostly by the absorption by dielectric and conductors. Notice that the reflection parameter has some minima and maxima. The first maximum is at a frequency where the segment length is about equal to a quarter of the wavelength in the transmission line, defined by Gamma (see Appendix) and repeating every half of the wavelength. The first minimum is at about half of the wavelength and is repeated every half of the wavelength (explained below). The value of the reflection at one frequency point may be misleading. Considering the TDR, we can see that it shows some variations consistent with the variations of characteristic impedance – see more on that at Simberian App. Note #2009_04.[6]

What if the characteristic impedance of the transmission line is significantly different from the termination impedance? Let's look at about 25Ω stripline in the same stackup as above

**(FIGURE 3)**.

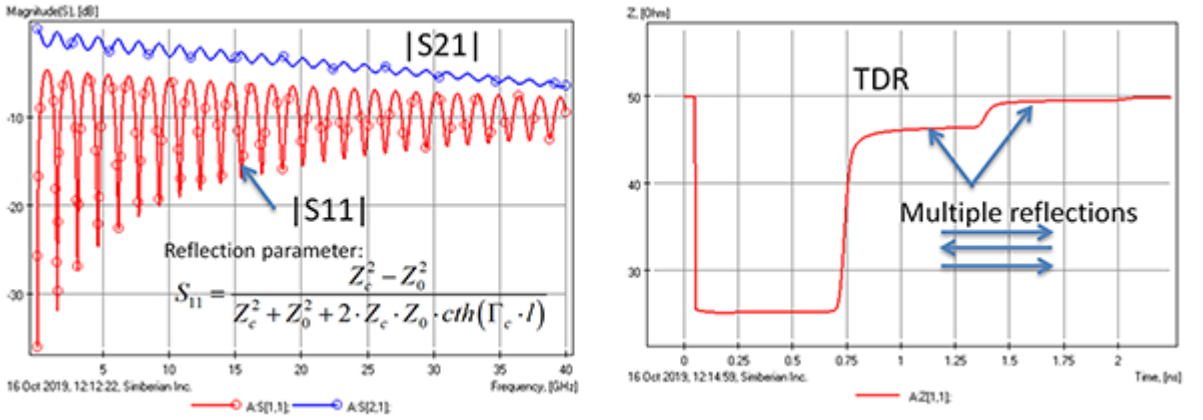



Figure 3. In this example, reflection went up considerably, meaning more signal energy is reflected. As result, the transmission (insertion loss) went down at some frequencies.

Magnitudes of the transmission (insertion loss) and reflection in dB are shown on the left plot and TDR on the right. The reflection went up considerably, meaning more signal energy is reflected. As a result, the transmission or insertion losses went down at some frequencies: less signal energy is transmitted. The insertion loss is now wavy and repeats the reflection pattern – the maxima in the reflection are the minima in the insertion losses. The signal energy here is either reflected or absorbed. The left plot also has the expression for the reflection parameter. The hyperbolic tangent in the denominator explains the minima and maxima: it is trigonometry! (Although with complex numbers.) S-parameters are used directly to compute the TDR, which in this case shows multiple reflections from the ends of the segment.

Another case with considerably larger characteristic impedance of about 75Ω (cannot be exact) and same segment length and 50Ω terminations is shown in **FIGURE 4.**

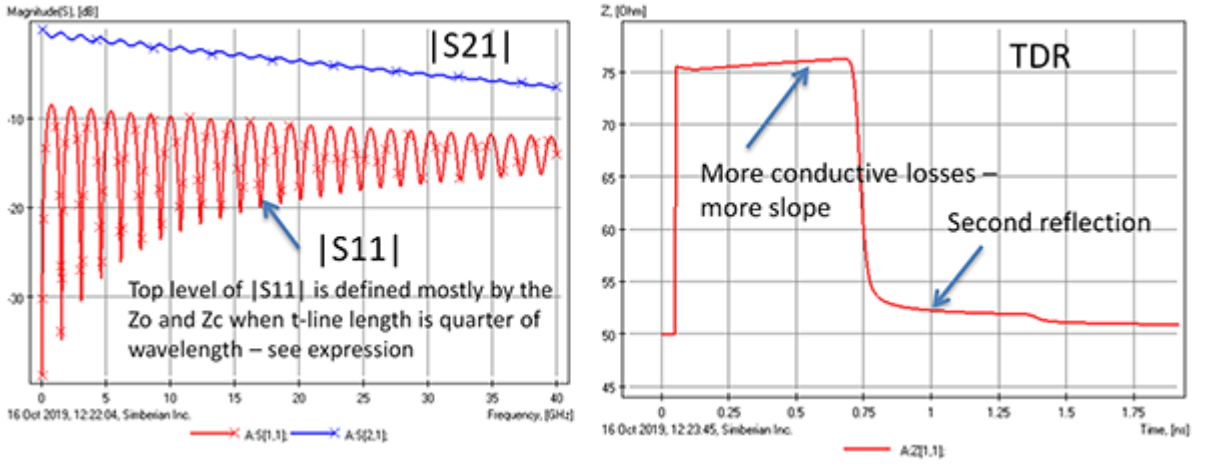



Figure 4. This example has more conductive losses, and the narrow transmission line shows more resistance.

On an S-parameter plot, it looks very similar to the previous case. It has more conductive losses, however, and the TDR goes up instead of down, and shows more resistance (slope up) in the narrow transmission line as expected. In both "reflective" cases, only one or two reflections are significant – it disappears quickly due to the absorption losses (losses are our friend in such reflective cases).

If you are wondering why a characteristic impedance equal to 50Ω is usually selected for single-ended and 100Ω is selected for differential PCB or packaging interconnects, you are not alone. It can only be explained by the historic reasons and convention for the component terminators. In fact, there are no reasons to stick with this number. As the story goes, 50Ω was the tradeoff impedance of an air-filled coaxial transmission line between the maximal transmitted power and minimal losses.[7] Indeed, a coaxial line always has a minimum in losses versus impedance. Though it is dependent on the dielectric fill, it happens to be close to 50Ω for coaxial lines filled with PFTE-type dielectric with Dk close to 2 (this can be easily verified[7]). As we know, striplines are descendants of the coaxial transmission lines, but the stripline losses do not have a minimum on the loss versus impedance function. **FIGURE 5** shows the attenuation in dB/m for a stripline modeled with Dk=3.5, LT = 0.002 @1.0$^{e9}$, Huray-Braken roughness model: SR = 0.1μm, RF = 9 as a function of dielectric thickness and characteristic impedance at 10GHz (computed with Simbeor SDK for Matlab).

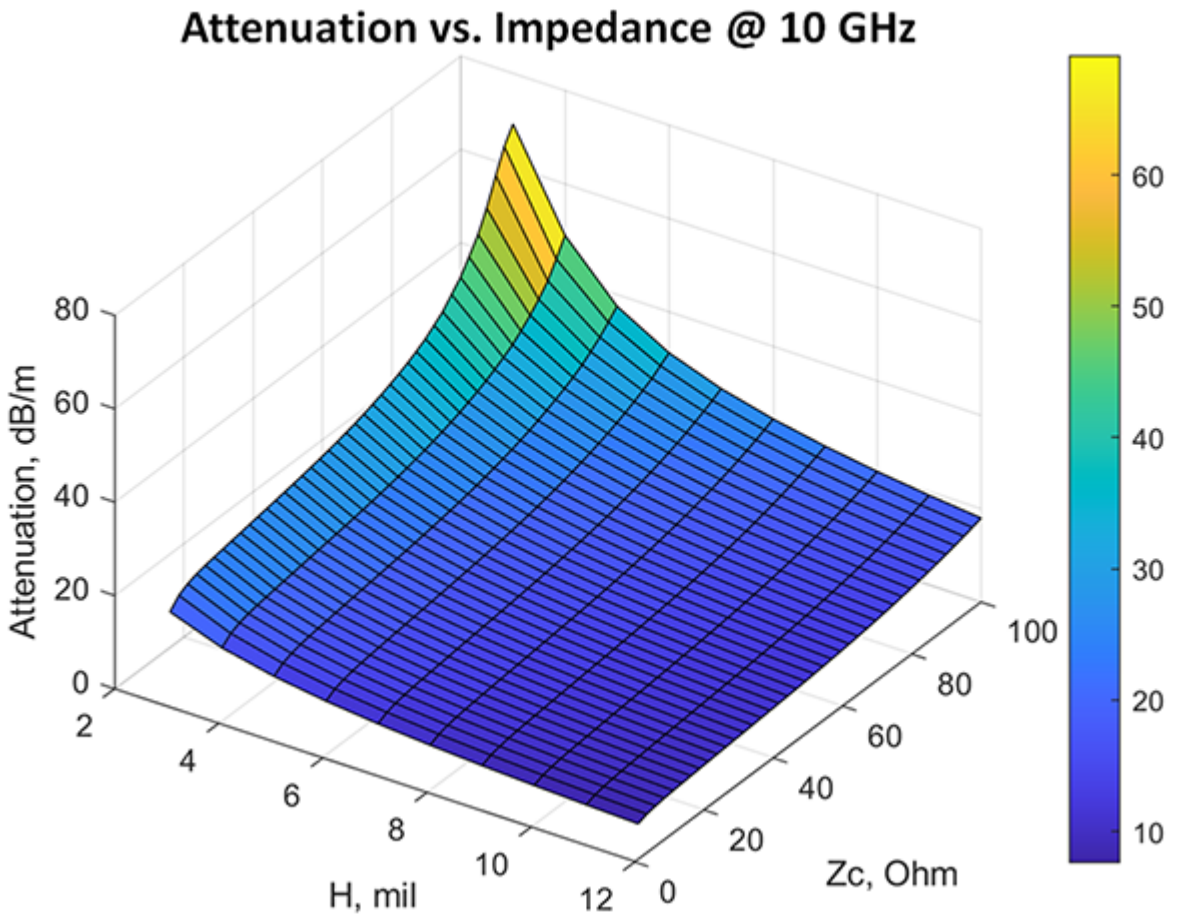



Figure 5. Attenuation (in dB/m) for a stripline model.

The attenuation is simply smaller for the smaller characteristic impedance (Zc axis) as well as for the thicker dielectrics (H axis). As was shown in Shlepnev[2], the conductor losses dominate in striplines with very-low-loss dielectrics. It means the cross-sections with more metal and lower impedance have smaller losses in general. The single mode propagation condition and layout density, however, may put additional bounds on the increase in cross-section size and on the lowest impedance as well. So, is lower impedance always better? Not really, if our goal is to minimize power absorbed by the interconnects and terminators. For instance, if we need a 0.1V signal at the receiver and compute power required at the transmitter side (Pin=20log(Vout)-10log(|Zc|)+Att_dB*Length, dBW), we will see some minima (same example as above at 10GHz, computed with Simbeor SDK for Matlab) **(FIGURE 6)**.

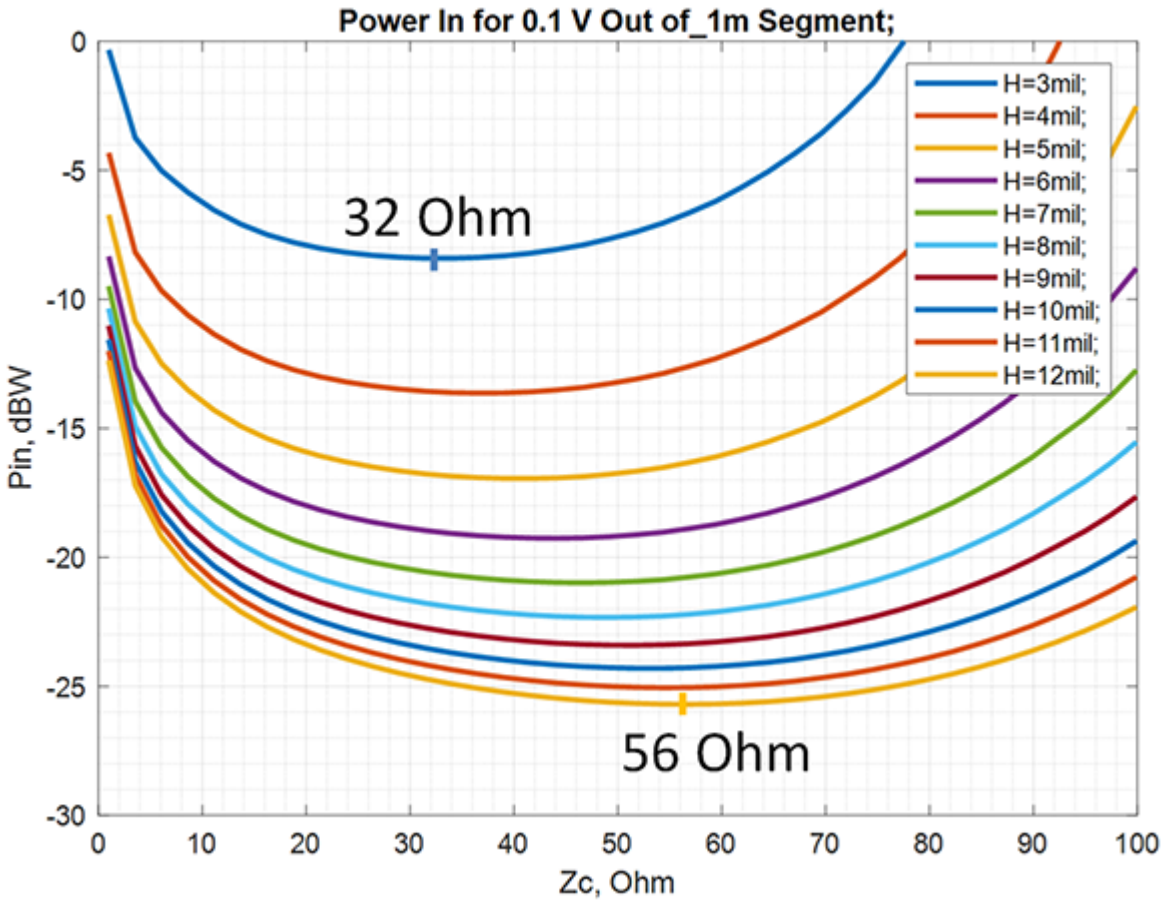



Figure 6. The minimal power depends on the geometry and length, with smaller impedance considered for thinner dielectric layers.

The minimal power depends on the geometry (dielectric thickness H above and below trace and trace width adjusted to have impedance value on the horizontal axis) and length (the graphs shown in Figure 6 are for a 1m segment). Smaller impedance should be considered for thinner dielectric layers. Strip widths in this example are set to have the impedance shown on the horizontal axis (Simbeor SDK used for computations). Terminations in this case were set equal to the magnitude of the characteristic impedance at 10GHz (no reflections). As we can see, the lower characteristic impedance is not always better and may be optimized for a particular system.

Finally, constant impedance from component to component should be the design goal, but it is usually violated in practical cases. The single-ended or differential traces are the open waveguiding structures composed of traces and reference conductors, although almost all layout tools are not aware of that. As such, prior to any type of interconnect analysis,

impedance continuity should be verified with a validated field solver. **FIGURE 7** shows an example of such impedance verification for CMP-28 validation platform from Wild River Technology (wildrivertech.com) in Simbeor 2022.02.

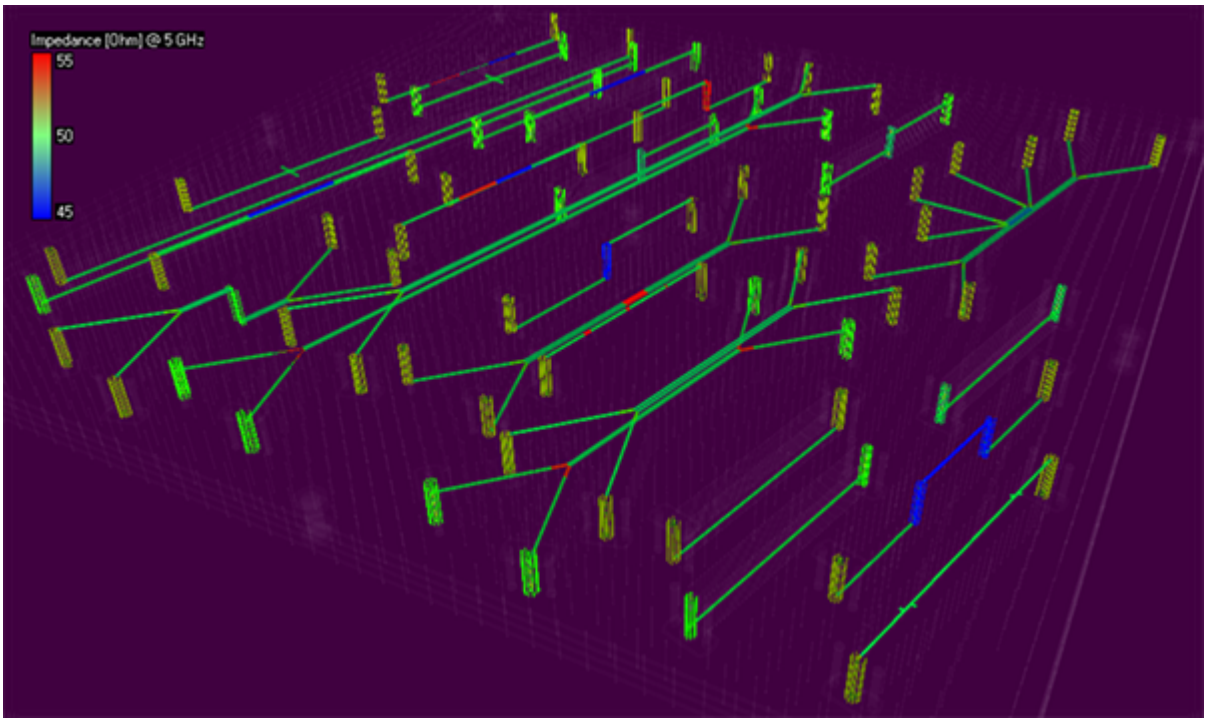



Figure 7. Impedance continuity as verified with a validated field solver.

Green is used for objects with an impedance close to the target impedance (50Ω single-ended or 100Ω differential). Objects with impedance below the target are blue and with higher impedances are red. This is a well-designed board with a small number of intentional impedance violations in some structures. Also, it comes from Wild River Technology, with measurements up to 50GHz for validation purposes.

Another example of how the reference conductors can change the impedance of traces on a design with traces going through BGA breakouts is provided in **FIGURE 8.**

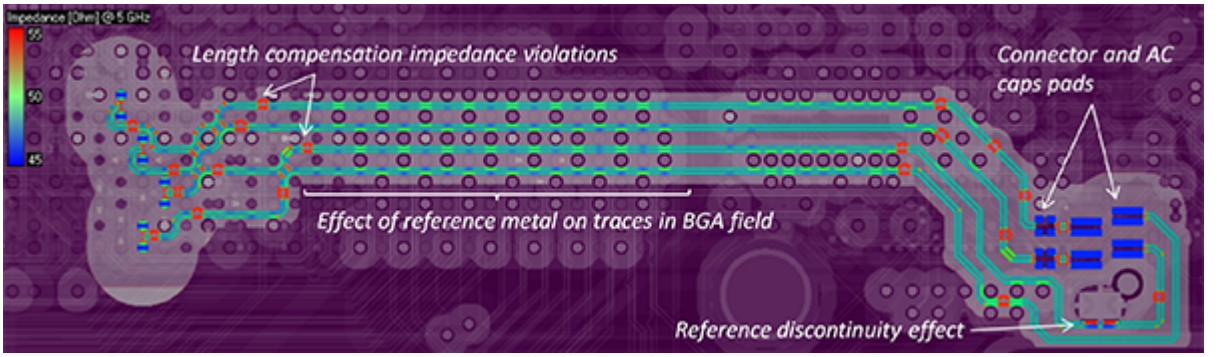



Figure 8. Another example of how reference conductors can change the impedance of traces on a design with traces going through BGA breakouts.

Here, we evaluated the effect of cut-outs and reference pads on impedance; those cannot be avoided. We can see the impedance of the connector and AC coupling pads is below the target and the impedance of the length compensation sections is above the target (a layout mistake). The discontinuities in the reference conductors also create impedance violations (another layout mistake). Most of those violations may not kill the signal and are important at relatively high data rates, however.

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3. Y. Shlepnev and V. Heyfitch, "Design Insights from Electromagnetic Analysis & Measurements of PCB & Packaging Interconnects Operating at 6- to 112-Gbps & Beyond," DesignCon, January 2020.

4. P. J. Pupalaikis, *S-parameters for Signal Integrity*, Cambridge University Press, 2020.

5. "Can Conductor Roughness Effect be Accounted for in Dielectric Model?" Simberian App. Note #2012¬¬_02.

6. "Micro-strip Line Characteristic Impedance and TDR," Simberian App. Note #2009_04.

7. Microwaves 101, "Why Fifty Ohms?" microwaves101.com/encyclopedias/why-fifty-ohms.

## APPENDIX

Other useful transmission line modal parameters derived from the complex propagation constant (Gamma) and useful for understanding of transmission line behavior (omega is the radial frequency [rad/s]):

$$\Gamma_n(\omega) = \sqrt{z_{n,n}(\omega) \cdot y_{n,n}(\omega)} = \alpha_n + i\beta_n$$

$\alpha = \mathrm{Re}(\Gamma)$ attenuation constant [Np/m]

$\alpha_{dB} = \frac{20 \cdot \alpha}{\ln(10)} \approx 8.686 \cdot \alpha$ attenuation constant [dB/m]

$\beta = \mathrm{Im}(\Gamma)$ phase constant [rad/m]

$\Lambda = \frac{2\pi}{\beta}$ wavelength [m]

$\varepsilon_{eff} = \mathrm{Re}\left[-\left(\frac{c \cdot \Gamma}{\omega}\right)^2\right]$ effective dielectric constant

$p = \frac{c}{\upsilon_p} = \frac{c \cdot \beta}{\omega}$ slow-down factor, $c$ is the speed of electromagnetic waves in vacuum

$\upsilon_p = \frac{\omega}{\beta}$ phase velocity [m/sec]

$\tau_p = \frac{\beta}{\omega}$ phase delay [sec/m]

$\upsilon_g = \frac{\partial \omega}{\partial \beta}$ group velocity [m/sec]

$\tau_g = \frac{\partial \beta}{\partial \omega}$ group delay [sec/m]

Appendix Equation

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VIA-IN-PAD

# A Quick Fix for Fillet Starvation

## Not enough solder? Blame the via design! BY AKBER ROY

Vias in pads can be "solder thirsty" and suck up solder from pads at terminals during reflow, creating what may appear to be solder insufficiency at the joints. This problem is typical of a via-in-pad design. It's unpredictable as well; solder will randomly tend to fill those vias during the reflow process and some locations may appear worse than others, for example.

With a via-in-pad design, solder paste printed through an aperture of normal dimensions for the "toe" end of a pad at a rectangular end cap connection **(FIGURE 1)** may not provide enough solder during reflow to make a good solder fillet. The fillet may appear to be "starved," because much of the solder that should be available to form a good solder joint will have wicked down the via and away from the end cap. The volume of solder lost will vary with the size and length of the via, the size of the component's solderable surface(s) area, and other factors.

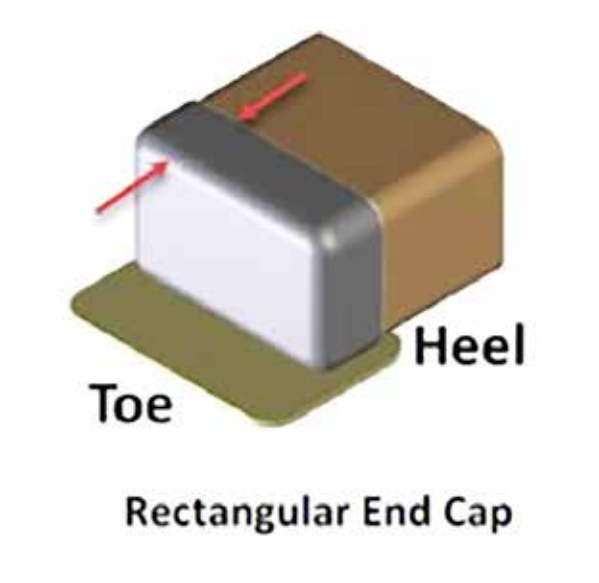


Figure 1. A rectangular end cap heel and toe.

There really is only one solution: provide more solder to replace that which is drawn off by the via. Adding that extra solder, by enlarging the print aperture on the toe side of the SMT pad by 35% **(FIGURE 2)**, doesn't do any harm, and is a quick fix because there will now be enough solder to satisfy the via's "thirst" and form a good fillet.

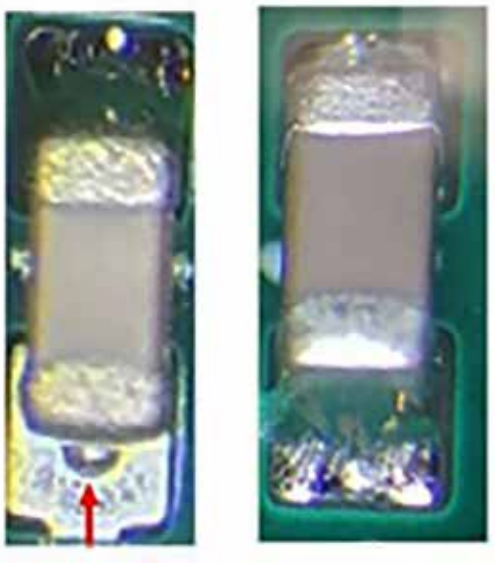

Figure 2. A stencil aperture of 1:1 (left) has left insufficient solder since it has been drawn off by the via (red arrow). On the right, a 35% increase in

aperture area at the toe now provides enough solder to form a good solder joint.

Ultimately, if one cannot decide whether the amount of solder forming the fillet is sufficient, adhere to IPC-A-610 for correct guidance.

A via-in-pad design for passive components is never desirable unless the via is plugged. It's preferable to route the via outside the SMT pad for passive components, of course, but sometimes space is an issue, so this is an alternate approach when the problem can't be solved by design.

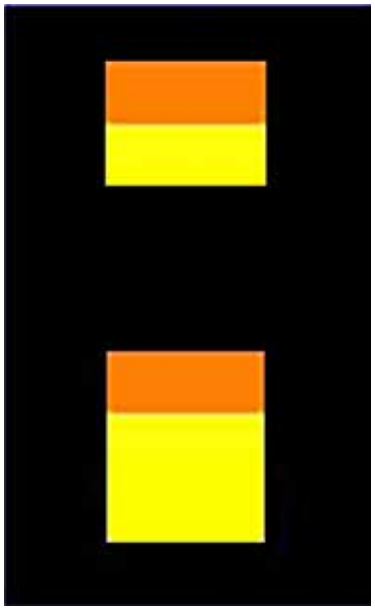

Figure 3. A normal 1:1 stencil aperture area (top), and on the bottom, an aperture area with the toe area of the SMT pad (yellow) increased by 35%.

With a greater volume of solder, depending on the application and alloy used, there are concerns that solder alloy brittleness could be a problem. To minimize such concerns, reflow

at the correct temperature for the alloy and at the solder paste manufacturer's profile recommendations. 

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**Koh Young** Software – Process Control (KPO Printer Software)
**ASYS Group** Software – Production (Extended ASYCAM Software)
**Smartsol** Soldering – Alternative (SMarTsol Soldering Robots)
**Weller Tools** Soldering – Hand Tool (WXair Rework Module)
**ECD** Soldering – Process Control (MOLE EV6 Thermal Profiler)
**SASinno Americas** Soldering – Selective (Unit-i1 Selective Soldering Machine)
**ITW EAE** Soldering – Wave (Auto Exit Wing)
**Indium** Cored Wire (CW-818 Fast Wetting, No-Clean Cored Wire)
**Shenmao** Solder Paste (PF918-PW216 Solder Paste)
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"We are thrilled to receive this prestigious annual award from CIRCUITS ASSEMBLY in recognition of our innovative work in automated optical and x-ray inspection technology," said Craig Brown, newly appointed general manager of Saki America. "Our R&D team works tirelessly to develop unique solutions that meet the need for fast precision inspections of rapidly evolving component technologies. We believe this award is not only a testament to their dedication but also serves as a reminder of Saki's commitment to providing reliable and innovative solutions for our customers around the world."

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The Europlacer Intelligent Freeform Feeder was a winner at the Circuits Assembly NPI Awards!

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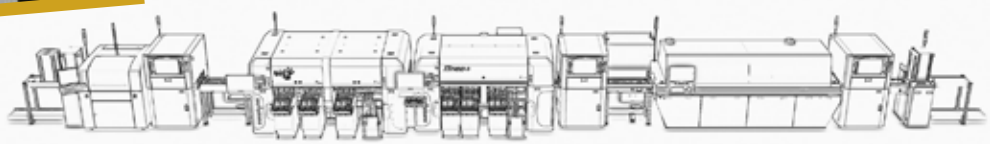

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NPI
NEW PRODUCT INTRODUCTION AWARD

2023 Winner

PCEA
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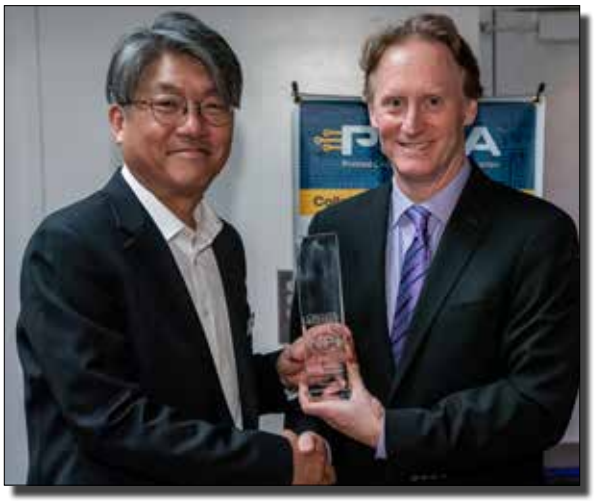
# Process Control Tools

KOH YOUNG AMERICA



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**New Product Introduction Award for Process Control Tools from Circuits Assembly**

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Superior Performance

AI-Powered Capabilities

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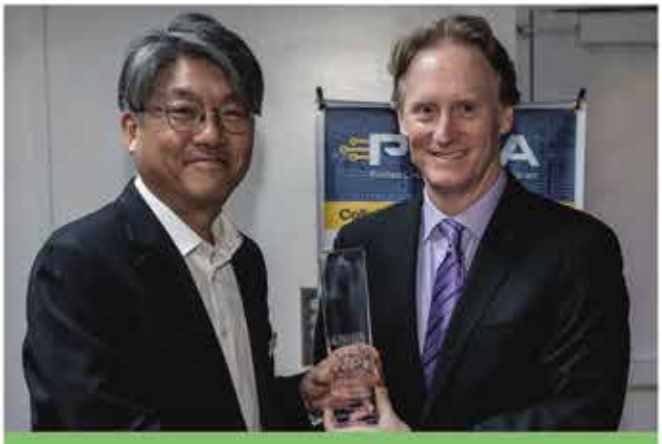
Simple, Intuitive Programming



The Neptune C allows manufacturers to secure fundamental coating technology to inspect for presence/absence, defects, foreign material, and more with a minimal investment. When the process changes, they can field-retrofit our L.I.F.T. technology (Laser Interferometry for Fluid Tomography) for non-destructive True3D inspection through multiple fluid layers regardless of transparency – at production speeds.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# Software - Process Control

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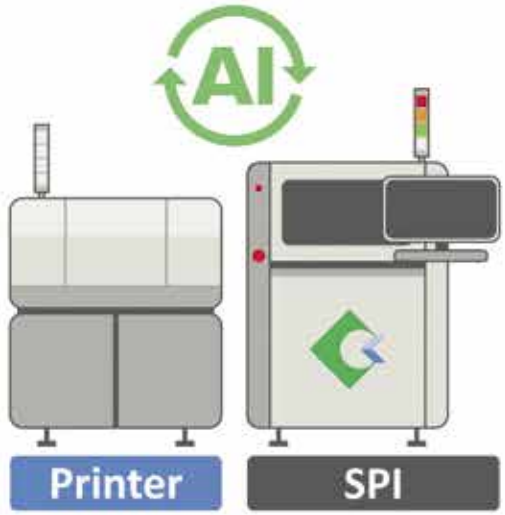
KOH YOUNG TECHNOLOGY

# AWARD-WINNING KPO PRINTER TECHNOLOGY

## New Product Introduction Award for Software Process Control from Circuits Assembly

KPO Printer uses a proprietary A.I. engine developed in the U.S. to help machines solve print process challenges. The software exercises complex algorithms to diagnose issues, recommend parameters, and improve print quality.

### KPO Printer

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APEX **RECAP**

# Good Signs: IPC Apex Booth Traffic Suggests Busy Year Ahead

## Exhibitors hope new products will keep the order books filled in 2023.

The good times of 2022 carried over into January as the industry turned out for one of the larger IPC Apex Expo trade shows in some time. The San Diego Convention Center show floor was humming for the better part of the first two days of the three-day event, and most of the more than 300 exhibitors seemed pleased with the attendance.

Most companies, in particular the assembly equipment suppliers, reported strong bookings for the quarter. Several added that they've raised their full-year forecasts as result of the surge.

A few years ago, there was a big push toward the connected factory. The branding and implementation of the machine-to-machine standard known as Connected Factory Exchange, or IPC-CFX, is now so ubiquitous, it was only sporadically mentioned throughout the week.

Noting data mining issues with PLCs, Aegis showed PLC Gateway, a web server that opens connections to PLCs, displays CFX message types and maps the two. The platform-independent system acts as an edge server and works with "anything that uses CFX," said

Jason Spera, CEO.

AIM's newest zero-halogen solder paste features improved electrochemical reliability, powerful wetting and exceptional fine-feature printing. The material is designed for automotive, LED and aerospace assemblies.

ASMPT's DEK TQ L stencil printer will be the company's primary platform going forward, ASMPT's Mark Odgen said, noting an entire shift can run on a single solvent tank and one roll of paper. The company also revealed Virtual Assist, an AI-based training tool (it learns and responds to user questions) that operates via an Android/IOS app or a browser, is adaptive and collects practical experience from the service staff throughout the whole enterprise.

ECD showed its latest M.O.L.E. thermal profiler, the EV6. A "traveling" device, it operates via a capacitive touchscreen, which allows configurations to be set up on the display, eliminating the need for a computer to conduct oven analysis. It is backwards-compatible with the legacy Rider system.

Europlacer showed its Stock Management tool which monitors and controls the supply of components to the assembly line in real time. The system is intended to reduce the time it takes to locate and replenish components on the placement machine.

Fuji's AIMEXR placement platform is designed to handle larger panels such as server boards. The machine can be outfitted with two custom heads and has additional feeder slots.

Glenbrook Technologies has a new dual x-ray image processor called the GTI-5000 that switches the field of view from 25 microns to 82mm and can show the entire part and an individual wire with a single touch of a button.

Juki's new LX-8 placement machine has a 20-nozzle head and is capable of up to 105,000cph (company rated). The 8-nozzle Takumi head can be changed on the fly, and the 160-feeder capacity allows exceptionally long runs.

Mirtec has installed a new GUI that is 25% faster than the previous version used on its inspection machines. It enhanced the image quality on the MV-3 Omni 3-D AOI, and added a PCB flipper for its inline machines.

Mycronic's inspection systems took a step forward with new head technology known as IRIS for its 2-D and 3-D AOI. The system features higher resolution and is 30% faster. The new MyWizard software has an escape tracker that automatically updates the user's library based on what the operator diagnoses is a false call or a true defect.

nScrypt showed an eye-opening range of precision dispensing products, from solder to printed antennas to curved resistors, done on a wide variety of substrates. Its SmartPump can also print active devices, including bare die, the company said.

PVA noted its Ultrafine spray valve, with a 2mm width that can get close to keepout areas.

Saki's 3Xi-M110 V3 AXI reports cycle times that are twice as fast as the machine previously could do. Its combination of planar CT for solder joint defect detection and Real 3D volumetric inspection to spot voids and head-in-pillow issues uses 40% less power per board than the older models.

Yamaha featured the YRM20DL SMT placement machine, with a high-rigidity dual-lane conveyor said to improve productivity and be capable of handling PCBs up to 330mm in width, and PCB lengths of up to 380mm in parallel mounting mode. The placement speed is 120,000cph with an accuracy of ±15μm (Cpk≥1.0).

Zestron revealed its latest cleaning technology, the X728, a pH-neutral defluxing agent.

## New Exhibitors

New to the show was DarwinAI, a Toronto-based OEM of solder inspection equipment. The three models of its VQI AOI range from mobile (capable of inspecting boards up to 13 x 17″) to inline versions (24 x 24″, max.). The top feature is its fast programming time, which in

demos took less than one minute.

One of the more interesting developments we saw was from Loveland, CO-based X2F, which supplies molding equipment for protecting electronics from heat. Using third-party materials, the system offers an alternative to potting and conformal coating by overmolding even the most viscous materials. Three platforms are available, ranging from low to high volume capacity.

## Fab Developments

The fabrication side of Apex was much smaller than the assembly segment. New printed circuit board processing equipment is hard to find at the show; many of the machines on display were first seen at Productronica in 2019 or 2021, and won't be mentioned here.

Isola emphasized its Terragreen 400G low-loss laminate and prepreg. The halogen-free material is easy to handle and has a Tg of 210°C, Td of 400°C, and a Dk of 3.5.

Ucamco showed Jayda, a website-based workflow engine tool that exposes basic characteristics of a company's data set – e.g., the board type, number of layers, line widths and spaces, etc. – and performs online quoting.

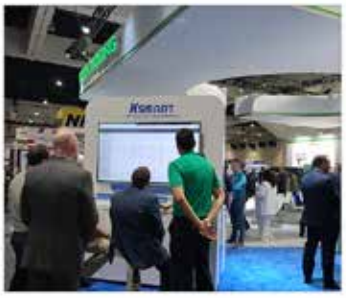
Ventec showed a host of laminates designed for RF/microwave applications. The tec-speed 30.0 RF PTFE material features a thermal conductivity of 1.15W/mK, for superior thermal performance in high-temperature applications, and a low Dk of 3.5, good insulation resistance and high dimensional stability. The new tec-speed 20.0 (VTM-1000i) is a hydrocarbon laminate, said to offer excellent thermal reliability and Dk of 9.8 and Df of 0.0023. The redesigned tec-speed 6.0 (VT-462SH NF/LF) is an ultra-low-loss low-flow/no-flow environmentally friendly material for drones and UAVs.

All-in-all, a good way to start the year.

**MIKE BUETOW** is president of PCEA (pcea.net); mike@pcea.net.


3D-AOI


SAKI
SAKI




YAMAHA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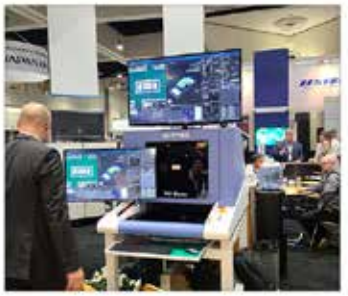
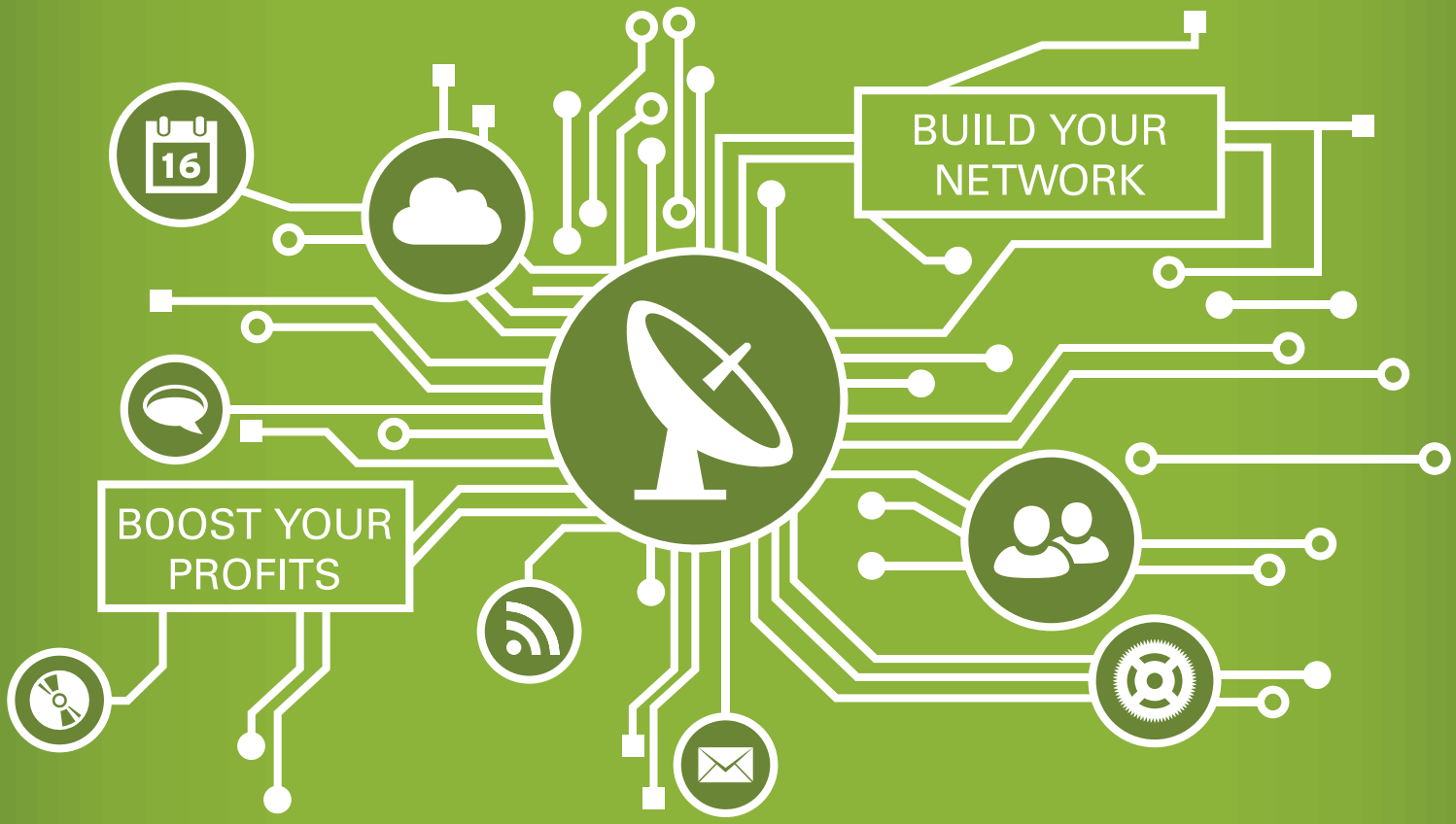


# The *Circuits Assembly* *Directory of EMS Companies*

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GETTING **LEAN**

# Aligning Six Sigma Tools with Process Reality

Identify the areas of variance in stencil design and adjust SPI programming accordingly.

AUTOMATED INLINE SOLDER process inspection (SPI) has the potential to deliver some of the highest value among all inspection steps because defects caught at this point in the process require minimal rework. It is simply a matter of cleaning solder paste off the printed circuit board (PCB). Additionally, good printing performance typically represents 80% of a successful SMT assembly process. As the bulk of workmanship-related defects tend to track back to deficiencies in solder paste deposition, closely monitoring control limits in this area has a substantial impact on eliminating defect opportunities.

Industry 4.0 technology, which connects production equipment and enables automatic correction based on trends data from SPI or automated inspection (AOI) equipment, opens the door to even better process control. As inspection imaging technologies have improved from 2-D to 3-D, the focus on solder paste inspection has gone from paste height to measurements which include volume and area as part of good process control.

Automated inspection equipment is only as good as its programming, however. As a result,

variations in stencil design created to address design for manufacturability (DfM) considerations can create issues in the way SPI equipment calculates process capability.

For example, with simple stencil design and good process control, data points measured at SPI following the printing step follow a normal distribution with a single peak, as shown in **FIGURE 1**.

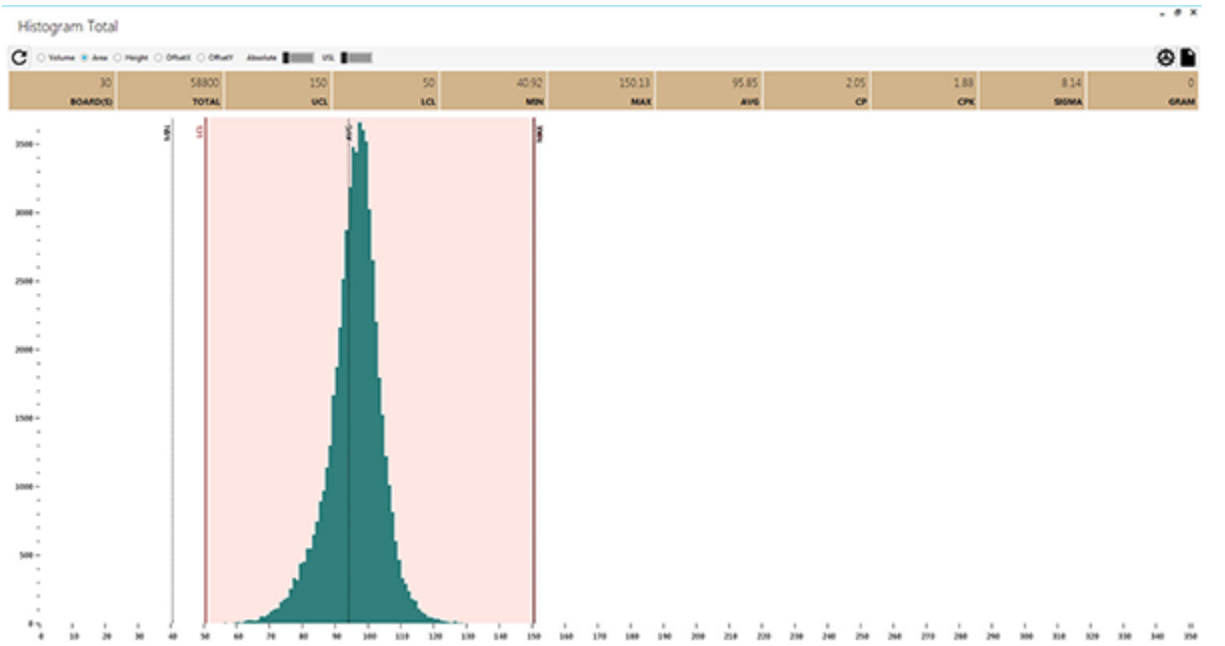


Figure 1. Typical normal distribution.

In some cases, the data points may form two peaks, as shown in **FIGURE 2**. This is known as a bimodal distribution. Each of the peaks represents a separate group data.

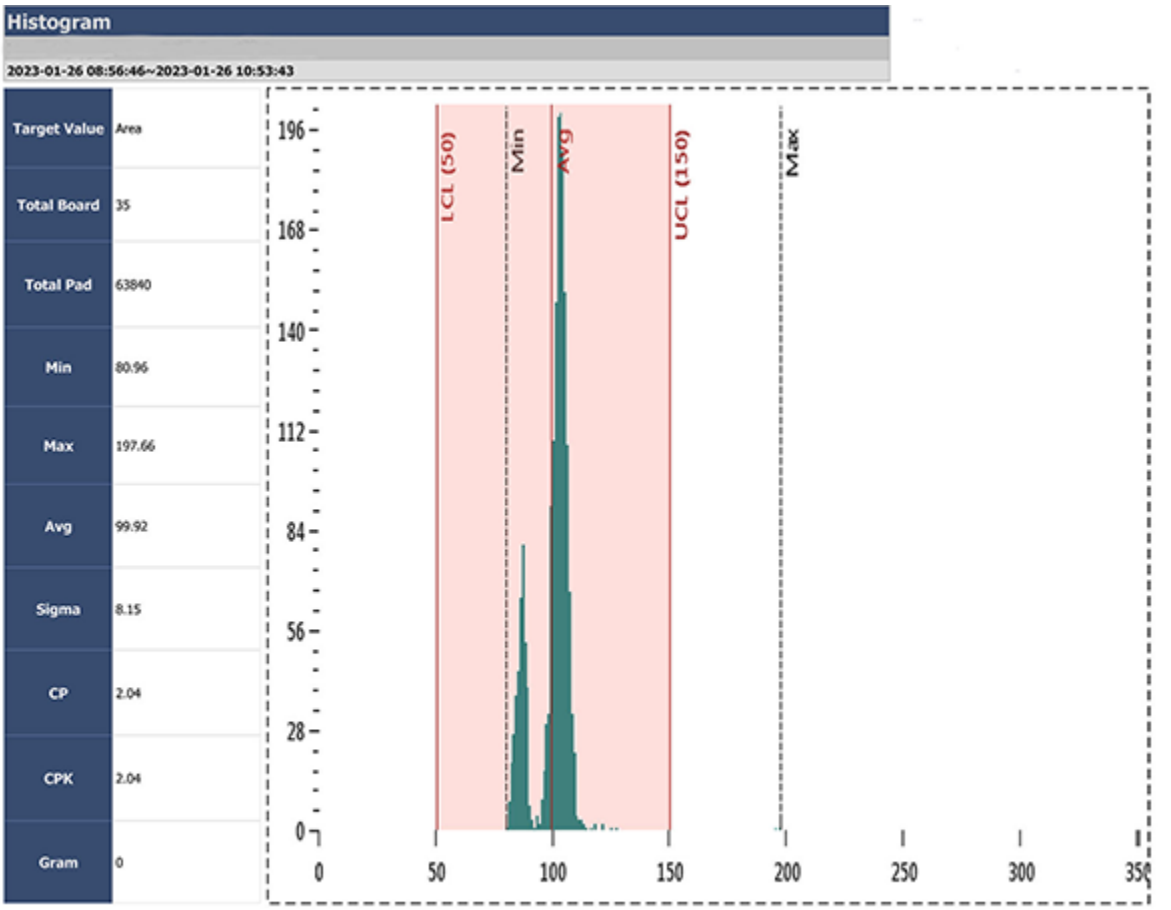


Figure 2. Bimodal distribution.

Typically, the root cause of this datapoint distribution is related to stencil design. In densely populated printed circuit board assemblies (PCBAs) or those with variations in component profiles, the PCB designer may modify the stencil design to add special geometries or steps that increase or reduce solder paste thickness to compensate for components with low or high profiles that require extra or less solder paste volume. To compensate for this, the manufacturing engineering team needs to review the stencil design for these variations and then debug the SPI equipment's programming to indicate the areas with different solder thickness. Specification limits in accordance with IPC-7725, "Requirements for Solder Paste Printing," should be set for each subgroup of components.

For example, a stencil was designed with 4 mil apertures with a step up to 6 mils for a few

components. Prior to any programming adjustments, the Cpk was 0.67. The programming was adjusted to track data for two subgroups of components based on aperture size. This eliminated the errors caused by mixing data and enabled Cpk to be tracked for each subgroup. The result was a Cpk by subgroup of 1.92, demonstrating the process was aligned with specifications.

This illustrates the importance of identifying areas of variance in stencil design and adjusting SPI programming as part of the new product introduction (NPI) process. Automated inspection technologies offer significant advantages in process control. As this example illustrates, machine programming needs to account for variances built into stencil design to adequately utilize Six Sigma core tools to measure process performance.

**FILEMON SAGRERO** is continuous improvement engineer at SigmaTron International (sigmatronintl.com) and a Six Sigma Black Belt; filemon.sagrero@sigmatronintl.com.

SEEING **IS BELIEVING**

# Mom and Pop's Revenge

Don't underestimate the speed and execution of a smaller shop.

*DEF.:* MOM AND Pop Shop. A common characterization of a family-owned company, usually small, closely held, and tightly run under original or second-generation ownership; often used as a term of derision or condescension by members of large companies; unsophisticated, provincial, or parochial; perceived as lacking in the most current skills, tools, or manufacturing methods. Often viewed as predisposed to surviving as a business and ensuring family succession first, with growth for growth's sake a secondary priority. Not innovative. Inflexible in business practices. Rarely for sale. Content to operate in their space. Stuck in their ways.

Your operation? Or perhaps someone's cursory impression of it? Certainly you have heard someone belittle a company by saying, "They're nothing more than a mom-and-pop operation." How did you as an owner feel when you got wind of that summary judgment? Was your comeback equally dismissive and snap-judgmental ("Typical remarks by someone who's never met a payroll in their life")?

Console yourself that you know what you know. You're here, actively and successfully participating in your local economy and our industry. You know you'd go crazy in a big company. The politics, the backbiting, the petty rules, the busywork, the layers of approval needed to get anything done, and the pointless mandatory "enrichment" sessions. Not for you. You're unemployable in that environment. Which in a strange way may also be consoling.

Paradoxically, it is because that corporate environment exists that your small business has part of its market. You do things the big guys can't do – or can't do well.

Take heart, second-class citizens in the Steerage Section of Entrepreneurship: I come not to bury Mom and Pop, but to praise them.

A very large and famous company, one whose name you would immediately recognize among the tech behemoths, needs help. It builds so-called autonomous vehicles. That company and its subcontractors in the EMS world produce mounds of defective AV printed circuit board assemblies that need immediate troubleshooting and failure analysis (many thanks, Industry 4.0). Said company also has the best failure analysis lab notoriety and cashflow can buy. No expense spared; no capability overlooked. Engineers can obtain precise and definitive answers to all their vexing reliability questions, so long as they're willing to wait.

For two months.

Wars are fought in less time.

Two months is ample time for small problems to become big problems. Think Petri dish.

Enter Mom and Pop, the sharp end of the commercial spear, modest appearance notwithstanding. That would be us who stand between a problem and its immediate solution.

The Big Company sought us out and signed us up to provide those gap-bridging, time-sensitive services their spit-shined, state-of-the-art lab was institutionally incapable of providing quickly enough to make a difference. We provided the same services as the big expensive lab, but in two days. We've been performing these services now for three years, week in and week out. Somebody likes us.

Mom and Pops are specialists in efficiency. Sneer at that at your peril, but corporate sclerosis is good for business.

Sophistication, *n.:* 1. the process or result of becoming cultured, knowledgeable or

disillusioned, especially CULTIVATION or URBANITY; 2. the process or result of becoming more complex, developed, or subtle, usually enlivened with a dash of cynicism, world-weariness, or nostalgic envy for past glories, real or imagined; 3. related content that is taught in "reputable" business schools, and in France.

Allegedly, what a Mom and Pop Shop is not. Quaint, yes; cutting edge, hardly, thus say our betters.

An EMS company I know is now run by its second generation of family ownership. It has grown in four decades from a niche fabrication/PCBA design business into a full-service EMS provider. Without changing hands, or brand, or vision, or focus, or mission statement. All while preserving a loyal core production team. They know what they do well, and they stick to their knitting. The bills get paid. The employees like coming to work every day. They tend to stay for years. A handful of them come to work because they'd have a hard time securing work elsewhere. At this company, the janitor is developmentally disabled. He has a job. And his dignity.

I'm familiar with another small company that kept a bookkeeper on the payroll for a year, despite showing clear signs of cognitive decline. Cognitive decline and bookkeeping do not mix well. HR takes a dim view of that combination in a large company environment. Nevertheless, the small company supported this person in the hope that an alternate job, or a medical solution, could be found, given time. Once again, peoples' self-respect matters just as much as the bottom line.

I'm aware of two husband-and-wife ownership teams who had the unique good fortune to start their entrepreneurial journeys in the trough of the 2008-09 Great Recession. Economics textbooks and business school case studies suggest that venturing forth as owners during the second-worst economic calamity in the United States since the Great Depression was suboptimal and not recommended (that's why they're the experts). Nonetheless, both couples persevered and are thriving today. Mom and Pop. They get stuff done. Was it hard? Yes. Painful in some respects? You bet. Did they build layers of knowledge and character and grit from the experience? No doubt. They're still here. Lessons like that tend to stick.

There's the family-run EMS company in New York; the well-known second-generation EMS/Iab in the eastern half of the country; the test engineering company in the DC area, also second generation. And a host of manufacturer's representatives across the country. Small- and medium-sized alike. Father/son. Mother/daughter. Husband/wife. Life partners. All family-owned, however family is defined. Mom and Pops are everywhere.

And to those who would maintain that small companies are technically deficient, I would direct your attention to the Canadian consultants, family-run, who developed a proprietary process to evaluate long-term reliability in high-end military printed circuit boards, and the instruments to monitor the process and provide data to support. The *mittelstand* is not restricted to Germany. Perhaps their marketing of such companies in North America is more self-effacing, and they just get on with it.

Stories like these rarely populate KPI charts. Auditors unravel when confronted with situations like these. They depart from the script. They're tough to categorize. That's not how sophisticated companies conduct business, with their battalions of HR "experts." And risk meetings. And decision functions. And turtle diagrams. But these are real-life working world experiences. Mom and Pop shops handle them every day. Does yours? *Can* yours?

A very large, well-known medical device company wanted to use the services of an equally well-known, but infinitesimally smaller, flying probe test service. To initiate the "onboarding" process (Mom and Pop owners wouldn't be caught dead using euphemisms like "onboarding."), the first hurdle involved signing a nondisclosure agreement. Big Med said it would take six, count 'em six, months for the NDA to transit their legal department. Hurdle indeed. And to the smaller, aspiring Big Med flying probe service supplier, Big Med's NDA administrator asked of its president, "And how long will your company's legal department need to review this nondisclosure agreement?" The flying probe service executive replied, nonchalantly, "About 20 minutes." True story.

Incredulity.

Driven by mindset.

Mom and Pops don't charge by the word. Nor do they have an inbred need to justify their existence. When you know what to look for in an NDA – and you review three to five of them weekly – it takes 20 minutes. The rest is fluff. Then it's on to actual work, unencumbered by boilerplate.

Another Large Corporate Customer was referred to a small Mom and Pop facility, looking to inspect hundreds of defective heat exchangers. A major x-ray inspection project. An event, really (actually a crisis). A welding defect had been found in one of the heat exchangers. Their customer, a major OEM (another one of those instantly recognizable names), threatened to reject the entire lot back to the factory. Some 10,000 units needed to be inspected. Now. An impossible task. Clearly, history was hanging in the balance.

But for the expertise, and speed of execution, of Mom and Pop.

The Large Corporate Customer tried their large corporate ways on the small company providing x-ray services. Haggling over price, quantity to be inspected, and delivery. Capability. Talk of free demos to show that x-ray can be done. Lots of cajolery implying, "You don't realize who you're dealing with."

Actually, they do. The Large Company failed to realize who *they* were dealing with.

Mom and Pop replied that x-ray can be done. The technology works for the application. Do you want your parts inspected or not?

More haggling and annoyance calculated to drag the situation out for a lower price by wearing the small company down.

The small company wasn't worn down.

Mom and Pop aren't stupid. No lower price. Take it or leave it. And if they leave it, they leave the solution to their problem.

Three days of pouting silence later, the large corporate customer accepted the price, amid

outbursts of righteous indignation. Being big and bureaucratic, they compounded their problems, making the tactical error, whether inadvertent or intentional, of not saying "go," in the form of a contractual agreement to start work (otherwise known as a purchase order). They also didn't indicate how they proposed to pay for the work being done.

Auras aren't enough to kick off projects. So the job is on hold until those inconvenient housekeeping questions are resolved. Tribute must be paid.

Again, Mom and Pops weren't born yesterday. They know the right answers.
They also have leverage.

**ROBERT BOGUSKI** is president of Datest Corp. (datest.com); rboguski@datest.com. His column runs bimonthly.

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  *Session Chairs: Kevin Gu (Metawave Corp) and Ivan Ndip (Fraunhofer IZM)*
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# ALTIUM DESIGNER 23.1

Designer 23.1 offers improved features spanning PCB design, product design and data management, enabling creation of more detailed harness layout drawings, saving and loading a customized view of the board, and utilizing new capabilities within comments on the design. Schematic capture improvements include compiled names of power ports, which enables the Net Labels option in the Compiled Names Expansion region of the Schematic – Compiler page of the Preferences dialog to now determine the name for a Power Port object on the compiled (physical) tab of a schematic document. Net Labels option in the Print dialog (when accessed from an Outjob file for a schematic print output with the [Project Physical Documents] option selected as the output's data source) and on the Structure Settings page of the Smart PDF Wizard also now defines how power ports will be shown in the schematic outputs. PCB design improvements include the ability to load a stored view configuration file from the View Options tab of the View Configuration panel, as well as the ability to rename the Gerber Board Outline type file in the Gerber Setup and Gerber X2 Setup dialogs. Also features improved callstack crash report content by using an enhanced method to collect callstack crash reports, and adds the ability to attach images to comments. Crimps can now be used on the Wiring Diagram (*.WirDoc) as was previously available in Layout Drawing, and parameters have been added to Twist and Shield objects in a Wiring Diagram document.

**Altium**

extensive, built-in dielectric materials library and static or frequency-dependent impedance and loss analysis and synthesis for all transmission lines. Gauss SI Pro also includes S-parameters analysis, viewing, and export; frequency-dependent properties analysis, viewing and export; and uncertainty analysis to account for the impact of manufacturing tolerances on impedance and loss.

**Avishtech**

**avishtech.com**

## KEYSIGHT EP-SCAN SIMULATION SOFTWARE

Electrical Performance Scan (EP-Scan) high-speed digital simulation tool supports rapid signal integrity (SI) analysis for hardware engineers and PCB designers. Addresses SI analysis bottlenecks through diagnostic tools to correct designs earlier and meet development schedules, and performs electromagnetic (EM) simulation on signal nets and reports SI metrics such as channel return and insertion loss. Also automates performance comparisons between different versions of a design and generates simulation reports that expedite verification prior to building physical prototypes.

**Keysight Technologies**

**keysight.com**

altium.com


# AMPHENOL TR90 MULTICOAX CONNECTOR

TR90 multicoax connector is designed to transfer high-speed signals up to 90GHz and is for use in 112G/224G, 5G/6G, and automotive radar applications. Uses solderless compliant contacts to provide a high-performing, mechanically reliable connector that can be securely mated to printed circuit boards with two screws, and can reduce connector real estate on PCBs by up to 80%. Reusable, and comes in in-line four- and eight-channel configurations, with dual-row 16-channel form factor and right-angle configurations due later. Maintains signal-to-signal spacing with lower frequency configurations at 2.54mm pitch and is designed to support microstrip, coplanar waveguide, and stripline PCBs.

**Amphenol Ardent Concepts**

ardentconcepts.com

# AVISHTECH GAUSS SI AND SI PRO STACKUP TOOLS

Gauss SI and SI Pro toolsets provide a clear and easy-to-use pathway to rapidly construct PCB stackups and simulate for impedance and loss with a few quick clicks. Both feature an

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**Avishtech**

**avishtech.com**

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**Keysight Technologies**

**keysight.com**


# KYOCERA AVX SCC SUPERCAPACITORS

SCC Series supercapacitors are tested and qualified to AEC-Q200 to meet mechanical and electrical conditions common in automotive applications. Have rugged constructed form factor, deliver high-reliability performance, and exhibit very high capacitance, very low ESR, and excellent pulse power handling characteristics. Can be used alone or in conjunction with primary or secondary batteries, to extend backup times and battery life and leverage instantaneous pulse power. Rated for 25F and 2.7V, 100F and 2.7V, 10F and 3V, 35F and 3V, and 100F and 3V, and comply with UL 810A, RoHS, and REACH requirements.

**Kyocera AVX**

**kyocera-avx.com**


# PASSIVE PLUS 1111C/P CAPACITORS

Traditional High-Q Low ESR 1111 (0.110” x 0.110”) multilayer ceramic capacitors are meant for use in UHF/microwave RF power amplifiers, mixers, oscillators, filter networks, low noise amplifiers, and timing circuits and delay lines. Available in two dielectrics (P90 or NP0); three different terminations: magnetic (100% Sn – Solder over Nickel Plating), non-magnetic (100% Sn – Solder over Copper Plating), and tin/lead (90% Sn 10% Pb – Solder over Nickel Plating); and are designed and manufactured to meet the requirements for MIL-PRF-55681 and MIL-PRF-123.

**Passive Plus**

**passiveplus.com**


## STACKPOLE CSRF2010 RESISTOR

CSRF2010 offers a 1W power rating and resistance values down to 2mΩ in 200ppm TCR or better. Is said to have long-term reliability and shows improved environmental and electrical performance compared to thick film sensing options. For portable handheld electronics, motor control, battery management, audio equipment, industrial and automotive controls, and instrumentation applications.

**Stackpole**

**seielect.com**

## VENTEC VT-4BC LAMINATE

VT-4BC metal base laminate is for use in applications requiring excellent performance in thermal management, including super bright lighting, power modules, controllers, motor drives and rectifiers. Designed to provide unparalleled reliability and improved performance over competing materials and exhibits a thermal conductivity of 10W/mK. Features excellent mechanical properties, dimensional stability, and superior dielectric properties, and is resistant to impact, moisture, and chemicals, for demanding applications – particularly for IGBT and power markets.

**Ventec**

**venteclaminates.com**


## VISHAY VPOLYTAN CAPACITORS

T51 automotive grade series of vPolyTan surface-mount polymer tantalum molded chip capacitors are designed to deliver improved performance in high-temperature, high-humidity operating conditions. Come in compact D (EIA 7343-31) and V (EIA 7343-20) case sizes, and feature a capacitance range from 6.8µF to 330µF over voltage ratings from 2.5V to 35V and a capacitance tolerance of ± 20%. Provide ultra-low ESR from 120mΩ down to 40mΩ at +25°C. Also feature a robust design for harsh environments and offer temperature operation to +125°C – with voltage derating above +105°C – and temperature load time to 2000 hr. Combined with ripple current to 2.37A, for decoupling, smoothing and filtering in switch

**Vishay Intertechnology**

**vishay.com**

CA

## AIM ZERO-HALOGEN SOLDER PASTE

Zero-halogen solder paste features improved electrochemical reliability, powerful wetting and exceptional fine-feature printing. Is for automotive, LED and aerospace assemblies and offers a robust, stable, and easy-to-implement product.

**AIM Solder**

**aimsolder.com**

## AVEN MIGHTY VUE INSPECTOR

Mighty Vue Inspector is a magnifying lamp and camera inspection system in one self-contained unit. Allows image viewing directly on an HDMI monitor, captures and stores images on the included microSD Card, and connects to PC for viewing or relocating saved images. Features adjustable color temperature (3500K-6500K) and brightness control, and ESD-safe magnifying lamp dissipates electrostatic discharge.

**Aven**

**aventools.com**

# ASMPT VIRTUAL ASSIST EXPERT SYSTEM

Virtual Assist is an AI-based expert system offering support for all onboarding, service and maintenance activities in electronics production. Can be operated via an Android/iOS app or a browser, is adaptive and collects practical experience from the service staff throughout the whole enterprise. Natural language processing (NLP) technology allows users to ask spoken questions and receive answers based on the system's steadily growing knowledge database. Features flexibly scalable licensing model and is available in three expansion stages. Basic level includes documentation of ASMPT machines, but can also feature use of structured and unstructured data to provide clear results through tutorials, troubleshooting guides and Q&As. Any documentation can be uploaded to create company-specific know-how collections for rapid troubleshooting or efficient training, and with expanded functions such as the scanning and identification of devices, can also function as a logbook and archive all service activities and problem resolutions that have been performed.

**ASMPT**

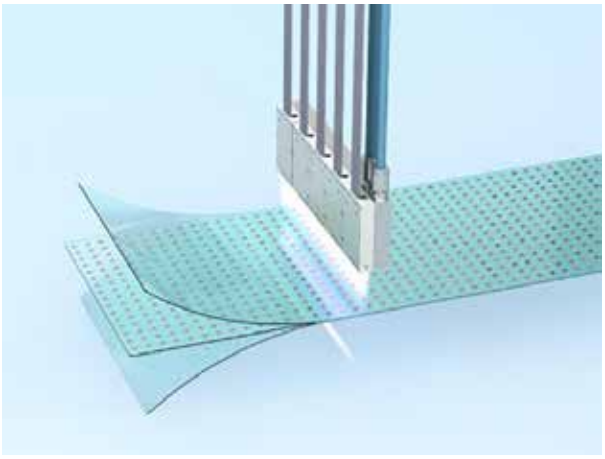
**asmpacific.com**

# AVEN WIDE-VIEW UV MAGNIFIER

Wide-View UV Magnifier includes ultraviolet and white LEDs and features a 3.6 x 1.7" rectangular glass. Five-diopter lens offers up to 2.25X magnification, and 1” diameter spot lens increases the magnification to 4X. Twenty-six UV LEDs operate at 365µm and are exceptionally bright when illuminating objects that fluoresce, such as paper, ink, PCBs, etc. ESD-safe design helps to dissipate static electric charges, protecting sensitive components from unintentional damage.

**Aven**

**aventools.com**



## DELO DELOLUX 301 LINE LAMP

Delolux 301 lamp cures adhesives and other multifunctional polymers and is suitable for highly automated processes in small and narrow production lines. Features intensity of up to 30W/cm², enabling maximum speeds for curing adhesives and other multifunctional polymers as well as working distances of up to 100mm from lamp to components. Head dimensions measure 42.7mm x 13mm x 67.2mm, and produces a linear irradiated area of 38.7mm x 8.45mm. Operable as a single head or combined to form a larger array, and comes with wavelengths of 365nm, 400nm and 460nm. Is said to have service life of more than 20,000 hr.

**Delo**

**delo-adhesives.com**

## DISPENSE WORKS RPX-SERIES DISPENSE ROBOT

RPX Series robotic dispensing machine is designed as a foundation for precision assembly, dispensing and custom solutions. Integrated parts transfer system automatically loads, unloads and processes bio sensors, printed films, sheets, etc., in and out of the dispensing and assembly areas for unattended operation. Embedded control system supports multiple vision systems, six axes of servo control and expandable I/O to provide limitless customizing capability and to any level of sophistication.

**Dispense Works**

**dispenseworks.com**


## ECD M.O.L.E. EV6 REFLOW PROFILER

M.O.L.E. EV6 traveling thermal profiler operates via a capacitive touchscreen. Offers a new design engineered to save time, simplify data viewing and analysis, and improve productivity. Delivers process calculation templates, profile viewing, and pass/fail analysis on the device, eliminating the need for a computer to conduct analysis. Also features a lithium-polymer battery, wireless Bluetooth operation, and built-in maintenance reminders.

**ECD**

**ecd.com**

## HENKEL TGF 2900LVO GAP FILLER

Bergquist gap filler TGF 2900LVO is a silicone-based, two-component room temperature curable gap filler suitable for use in a range of electronics assembly applications. Features low volatile outgassing, for applications sensitive to siloxane outgassing. Also features ultra-thin bondline thickness to optimize heat dissipation and transfer in challenging conditions, and offers easier dispensing and high shot consistency, making it suitable for high-throughput manufacturing.

**Henkel**

**henkel-adhesives.com**

## ITW POLYPROPYLENE AQUEOUS CLEANER OPTION

Heat stabilized polypropylene material option for the Electrovert Aquastorm 200 aqueous cleaner withstands operating water temperatures up to 180°F (82°C) at a lower cost than stainless steel. Plumbing and spray nozzles remain stainless steel with orbital welds to eliminate pressure drops and leaks, and plumbing sections have quick-disconnect fittings for easy maintenance.

**ITW EAE**

**itweae.com**

# SAKI 3D-AOI CAMERA HEADS

3D-AOI camera head features an optical resolution of 15µm and reportedly achieves high-performance quality inspection with the industry's fastest cycle time. Minimizes standby time by parallelizing image capture, data processing and inspection, and is capable of handling complex inspections of high-density printed circuit boards and mixed PCBs with extremely small and tall parts. Available as an option for the latest 3Di AOI, and can be quickly and easily switched with the existing 8µm head without the need to change the entire AOI within the production line.

**Saki Corp.**

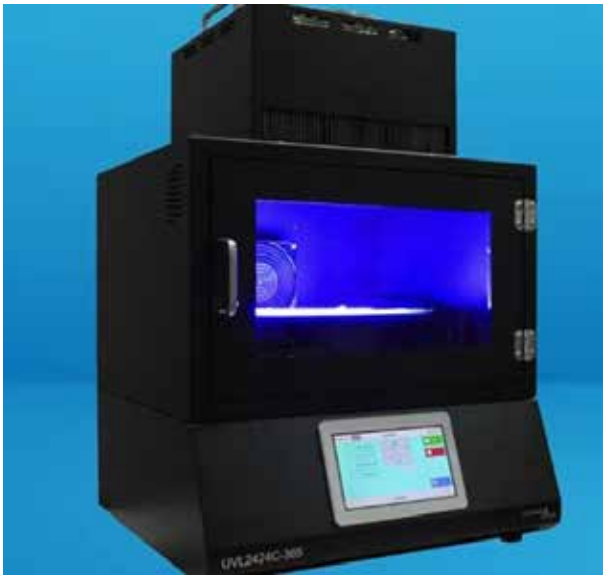
**sakicorp.com/en/**

# SAKI 3XI-M110 V3 X-RAY

3Xi-M110 V3 x-ray system delivers cycle times more than twice as fast as previously possible and features upgraded accuracy ensuring cleaner results untarnished by shadows or noise. Uses planar CT to detect solder joint defects and microstructure abnormalities in high-density PCBs. Real 3-D volumetric inspection clearly identifies voids in multilayer solder, PTH assembly and BGA head-in-pillow issues, and defective component parts based on fillet position and other factors. Maintains the same weight and footprint as the original 3Xi-M110 while consuming 40% less power per board.

**Saki Corp.**

**sakicorp.com**



# TECHNODIGM LED UV CURING SYSTEM

All-in-one LED UV Curing System combines UV chamber, touchscreen panel, and operating system in a compact design. Features 400 LEDs that offer homogeneous intensity distribution and uniform intensity across the curing area with a peak intensity of 500mW/cm$^2$ (UVA), and is designed for rapid curing of light-activated adhesives and coatings. Suitable for laboratory or low-volume production environments, can be configured to different peak intensity and curing areas, and is available in options of 365, 405 or 420nm

wavelengths to meet specific project requirements.

**TechnoDigm**

**technodigm.com**


# VITROX WI8I G2 PRO INSPECTION HANDLER

Wi8i G2 Pro offers an expansion to the inspection capabilities of the company’s existing wafer vision inspection handler, the Wi8i G2. Can accommodate inspection requirements for bare wafers (pre-dicing process) and mounted wafers (post-dicing process). Can handle wafers up to 12" and Front Opening Unified Pod wafer carrier boxes, as well as metal cassettes. Also features robust vision optics that provide high-quality images under different magnification lenses plus integrates an advanced deep-learning algorithm for defect detection and determining the defect types.

**Vitrox**

**vitrox.com**

# YAMAHA YRM20DL SMT PLACEMENT MACHINE

YRM20DL surface mounter features high-rigidity dual-lane conveyor that improves actual and per-unit-area productivity, and is built on the basic performance of the company's universal mounter YRM20. Supports a maximum PCB width of up to 330mm where the same width PCB is being conveyed at the front and rear while in dual-lane production mode. When parallel mounting, front and rear heads can operate without any interference up to a maximum PCB length of 380mm. Basic performance can achieve a reported productivity of 120,000cph (under optimal conditions), along with a higher-accuracy placement of ±15µm (Cpk≥1.0) through the revision of the layout.

**Yamaha Motor**

**yamaha-motor-robotics.eu**

# ZESTRON VIGON NX 728 DEFLUXER

# DMEMS2023

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TECHNICAL
**ABSTRACTS**

# In Case You Missed It

## Electrochemical Migration

"Effects of Concentration of Adipic Acid on the Electrochemical Migration of Tin for Printed Circuit Board Assembly"

*Authors:* Yi Sing Goh, *et al.*

*Abstract:* Continuous advancement in innovative electronic applications leads to closer interconnection spacing and higher electric field density, thus increasing the risk of electrochemical migration (ECM)-related failures. The ECM of tin (Sn) attracts great interest due to the wide use of Sn on the surface of the printed circuit board assembly. In this work, the authors investigated the effects of adipic acid (1 ppm–saturated concentration) on the ECM of Sn using the water drop test (WDT) at 5V. In situ observation and ex situ characterization of ECM products were carried out using optical and electrochemical techniques. Results show that the ECM failure probability is higher at intermediate adipic acid concentrations (10ppm, 100ppm and 1000ppm). The major ECM reactions include anodic corrosion and the formation of dendrites, precipitates and gas bubbles. ECM failure does not occur at higher adipic acid concentrations (≥5000ppm) although the anodic corrosion becomes more severe. The complexation of Sn with adipic acid to form Sn adipate complex is suggested as the main factor suppressing ECM failure at higher concentrations (≥5000ppm) by retarding ion transport. The electrochemical parameters ($E_{corr}$ and $I_{corr}$) do

not correlate with the ECM failure probability. They affect the anodic dissolution stage, but not the subsequent stages in the ECM mechanism. In this study, the ion transport stage plays a more significant role in determining the ECM failure probability. *(Journal of Electronic Materials,* March 2023, https://link.springer.com/article/10.1007/s11664-022-10155-2)

# Energy-Efficient Electronics

"Epitaxial van der Waals Contacts for Low Schottky Barrier MoS2 Field Effect Transistors"

*Authors:* Huawei Liu, *et al.*

*Abstract:* Small contact resistance and low Schottky barrier height (SBH) are the keys to energy-efficient electronics and optoelectronics. Two-dimensional (2-D) semiconductors-based field effect transistors (FETs), holding great promise for next-generation information circuits, still suffer from poor contact quality at the metal – semiconductor junction interface, which severely hinders their further applications. Here, a novel contact strategy is proposed, where $Bi_2Te_3$ nanosheets with high conductivity were in-situ epitaxially grown on $MoS_2$ as van der Waals contacts, which can effectively avoid the damage to $MoS_2$ caused during the device manufacturing process, leading to a high-performance $MoS_2$ FET. Moreover, the small work function difference between $Bi_2Te_3$and $MoS_2$ [($Bi_2Te_3$: 4.31 eV, MoS2: 4.37 eV, measured by Kelvin probe force microscopy (KPFM)], enables small band bending and Ohmic contact at the junction interface. Electrical characterizations indicate that the $MoS_2$ FET device with Bi2Te3 contacts possesses a high current on/off ratio ($5 \times 10^7$), large effective carrier mobility ($90cm^2/(V{\cdot}s)$), and low flat-band SBH (60meV), which is favorable as compared with $MoS_2$ FET with traditional Cr/Au electrodes contacts, and superior to the vast majority of the reported chemical vapor deposition (CVD) $MoS_2$-based FET device. The demonstration of epitaxial van der Waals $Bi_2Te_3$ contacts will facilitate the application of 2-D $MoS_2$ nanosheet in next-generation low-power consumption electronics and optoelectronics. *(Nano Research,* Dec. 5, 2022, https://doi.org/10.1007/s12274-022-5229-y)

# MPTMs

"Magnetoactive Liquid-Solid Phase Transitional Matter"

*Authors:* Qingyuan Wang, *et al.*

*Abstract:* Magnetically actuated miniature machines can perform multimodal locomotion and programmable deformations. However, they are either solid magnetic elastomers with limited morphological adaptability or liquid material systems with low mechanical strength. Here, the authors report magnetoactive phase transitional matter (MPTM) composed of magnetic neodymium-iron-boron microparticles embedded in liquid metal. MPTMs can reversibly switch between solid and liquid phase by heating with alternating magnetic field or through ambient cooling. In this way, they uniquely combine high mechanical strength (strength, 21.2MPa; stiffness, 1.98GPa), high load capacity (able to bear 30kg), and fast locomotion speed (>1.5m/s) in the solid phase with excellent morphological adaptability (elongation, splitting, and merging) in the liquid phase. The authors demonstrate the unique capabilities of MPTMs by showing their dynamic shape reconfigurability by realizing smart soldering machines and universal screws for smart assembly and machines for foreign body removal and drug delivery in a model stomach. *(Cell,* Jan. 25, 2023, https://doi.org/10.1016/j.matt.2022.12.003)

# Wearable Electronics

"Fully Screen-Printed PI/PEG Blends Enabled Patternable Electrodes for Scalable Manufacturing of Skin-Conformal, Stretchable, Wearable Electronics"

*Authors:* Sehyun Park, *et al.*

*Abstract:* Recent advances in soft materials and nano-microfabrication have enabled the development of flexible wearable electronics. At the same time, printing technologies have been demonstrated to be efficient and compatible with polymeric materials for manufacturing wearable electronics. However, wearable device manufacturing still counts on a costly,

complex, multistep, and error-prone cleanroom process. Here, the authors present fully screen-printable, skin-conformal electrodes for low-cost and scalable manufacturing of wearable electronics. The screen printing of the polyimide (PI) layer enables facile, low-cost, scalable, high-throughput manufacturing. PI mixed with poly(ethylene glycol) exhibits a shear-thinning behavior, significantly improving the printability of PI. The premixed Ag/AgCl ink is then used for conductive layer printing. The serpentine pattern of the screen-printed electrode accommodates natural deformation under stretching (30%) and bending conditions (180°), which are verified by computational and experimental studies. Real-time wireless electrocardiogram monitoring is also successfully demonstrated using the printed electrodes with a flexible printed circuit. The algorithm developed in this study can calculate accurate heart rates, respiratory rates, and heart rate variability metrics for arrhythmia detection. *(ACS Appl. Mater. Interfaces,* Jan. 3, 2023, https://doi.org/10.1021/acsami.2c17653)