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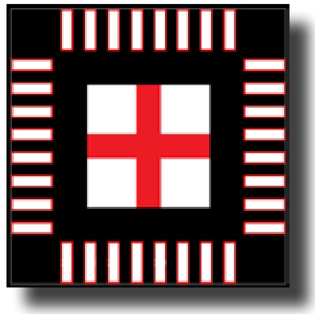

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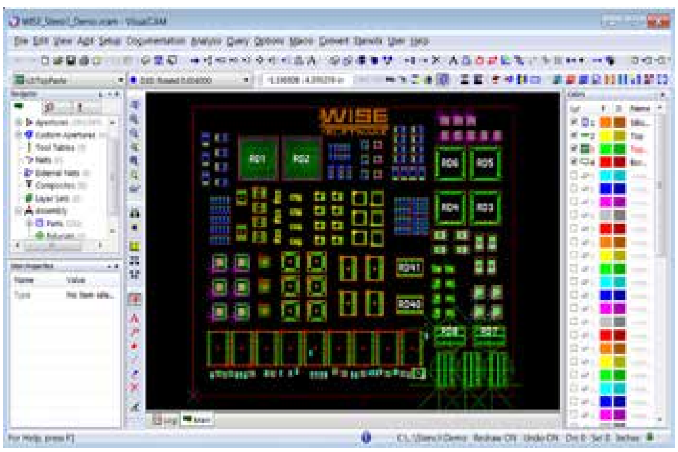

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内容

PRINTED CIRCUIT DESIGN & FAB CIRCUITS ASSEMBLY

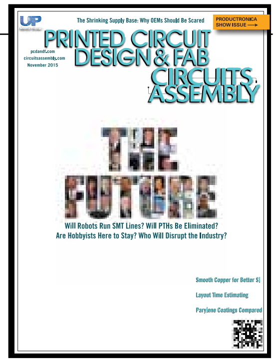
FEATURES

20 **SIGNAL INTEGRITY**
Copper Roughness Electromagnetics 101
Most electrical engineers working with high-speed differential interfaces such as PCIe are aware of the effect of rough copper on insertion loss – and know it is to be avoided. What they may not understand is exactly why that's true. Why smoothing copper for better signal integrity could degrade mechanical performance.
by JEFF LOYER

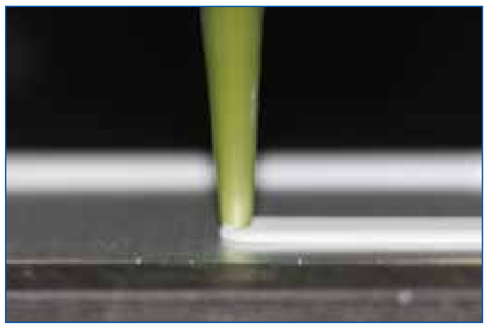
24 **SCHEDULING**
A Layout Time Estimating Tool
Necessity is the mother of invention. How that, plus insistent engineers, led to an algorithm for design scheduling.
by JAMES JACKSON

28 **CONFORMAL COATINGS**
Competitive Analysis of Parylene Coatings Based on Metrology
A study comparing the quality and performance of four Parylene C coatings investigated whether variations in surface roughness, contact angle, and crystallinity values affect environmental protection performance. Despite differences in the coatings, similar results were seen throughout.
by SEAN CLANCY, PH.D.

34 **THE FUTURE**
Electronics 2020: What Will the Industry Look Like?
Robots, DNA-based circuits, 3D printers, supply chain migration: These are just some of the challenges – and opportunities – the electronics industry is facing today. What leading electronics experts see in the design and manufacturing landscape the next several years.
by MIKE BUETOW



ON THE COVER: The seers forecast what's ahead for electronics.



Will conductive adhesives finally widely replace solder? (Photo courtesy Henkel)

DEPARTMENTS

8 **AROUND THE WORLD**
14 **MARKET WATCH**
44 **OFF THE SHELF**
46 **MARKETPLACE**
47 **AD INDEX**

FIRST PERSON

6 **CAVEAT LECTOR**
Supply chain woes.
Mike Buetow

MONEY MATTERS

16 **ROI**
It's a material world, but it's also a small one (and getting smaller).
Peter Bigelow

TECH TALK

18 **DESIGNER'S NOTEBOOK**
A light look at LED rotation.
Duane Benson

38 **GETTING LEAN**
Bringing Lean to the third world.
Peter Sognefest

40 **TECH TIPS**
Starved joints.
Roy Akber

42 **TEST AND INSPECTION**
Big is not always beautiful. Sometimes big customers bring big pain.
Robert Boguski

48 **TECHNICAL ABSTRACTS**

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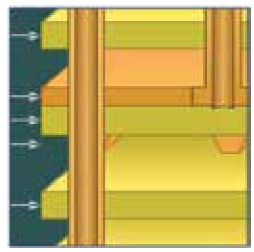

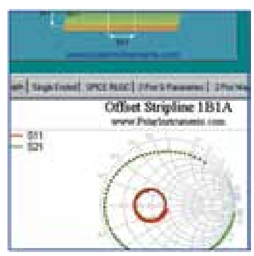

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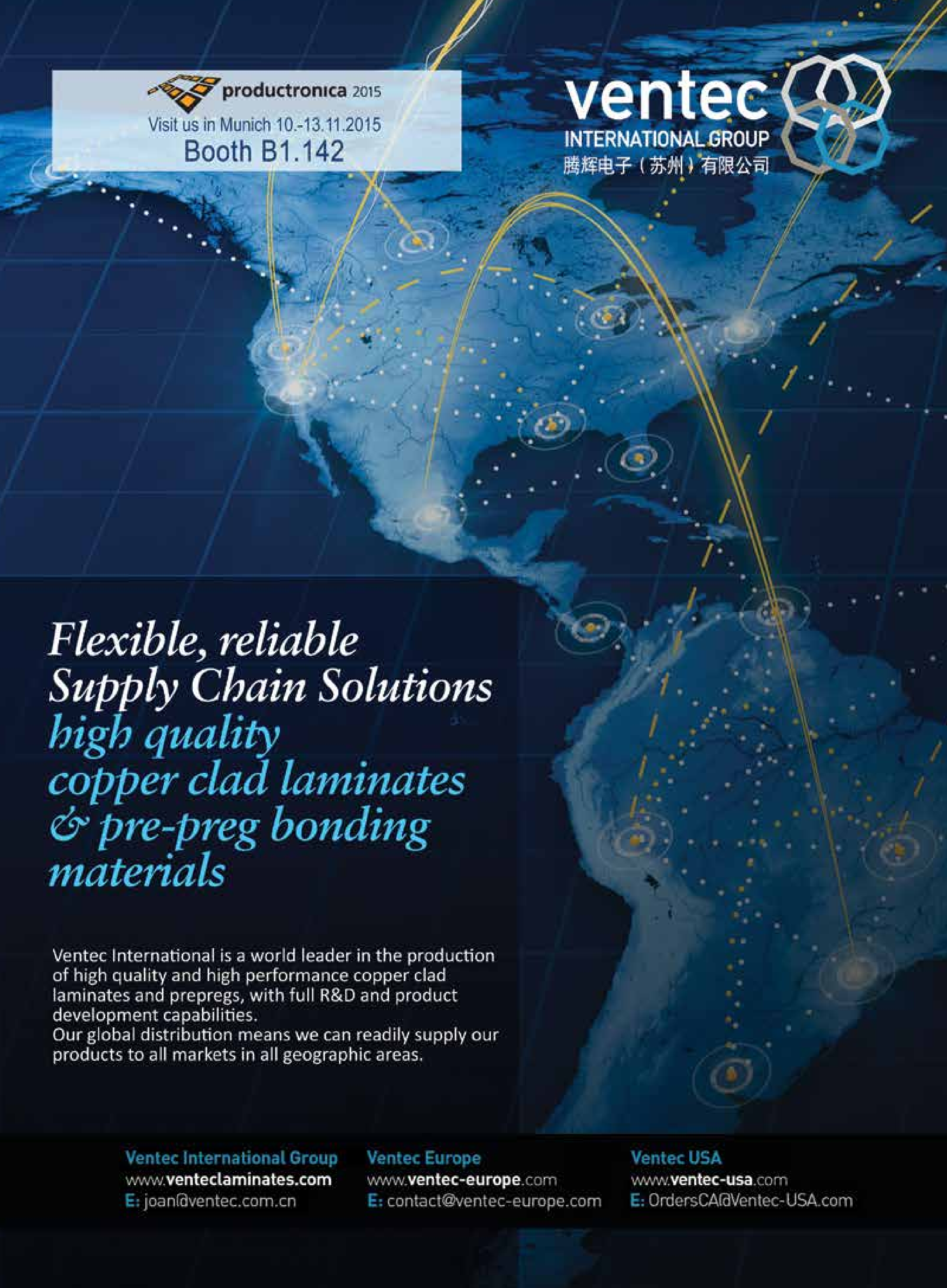
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MIKE BUETOW
EDITOR-IN-CHIEF

Is Bigger Better?

IN preparing our cover story this month, which begins on pg. 34, we asked several leading industry minds whether they see disruption coming from inside or outside the industry. How they responded was tied to where they think innovation will come from.

The electronics industry lives on innovation, and the antecedent to innovation is competition.

Consider AT&T and the monolithic pace at which new features were rolled out during much of its lengthy history. While in grade school in the early 1980s, I remember finally migrating to touch tone (push button) from rotary dialing on our family's "company leased" wall-mounted phone. That was nearly 20 years after Bell commercialized the technology. While the Buetow family never was an early adopter for, well, anything (my dad, now 82, has used the same manual rotary lawn edger my entire life), it wasn't like AT&T was rushing to widely update the marketplace; the concept for push button phones dates to at least 1887.

Its government-ordered breakup in 1982 removed local service from Ma Bell, leaving it with long distance, R&D and phone-equipment manufacturing. Progress came in short order. Caller ID, 15 years in the making, arrived in 1984 (making the prank phone call a thing of the past); fiber optics replaced copper for long-distance hauls; cellphones (pioneered by Bell Labs in the mid 1940s) began showing up in the hands of everyday consumers in 1983 when Motorola rolled out the DynaTac phone on a network built by Bell spinoff Ameritech. Now even my pre-teen kids have them.

Consolidation in the supply chain – i.e., reduction of competition – should be reason enough to make even the most capitalistic among us uneasy, which is why two major emerging stories in the bare board market could reverberate for years to come.

First, the pending Platinum Specialty Products acquisitions of a pair of competitors' PCB chemicals units. Second, the consolidation of the high-end laminate materials market.

Platinum, as readers will know, is aggressively buying companies in the solder and electroplating/finishing materials space, first with its bid for OMG's PCB chemicals unit (the former Electrochemicals) and, now having cleared most regulatory hurdles to acquiring Alent, the former Cookson Metals divisions, which include Enthone and Alpha.

On the laminate side, Rogers' acquisition of Arlon coupled with Isola's financial outlook gives reason for concern over how the supply chain will change.

For the rights to OMG and Alent, Platinum will pay, in aggregate, about $2.67 billion, including assumed debt. That will add to the debt Platinum assumed when it acquired MacDermid in 2013 for $1.8 billion.

Platinum paid nearly $40 million in interest in the first quarter alone, and its operating profit for the period was just $2.2 million. The additional acquisitions will further stress a balance sheet that carried $1.4 billion in debt as of Dec. 31. The weight of these transactions is making folks inside and outside the industry a bit cautious, with credit rating service Moody's among those expressing reservations about the debt load.

Dan Leever, the man at the helm of Platinum following its buyout of MacDermid, knows the PCB industry inside and out, but it's unclear how much further they can go before running into a Viasystems-like situation.

Likewise, just last month Moody's also went negative on Isola, citing deteriorating credit-worthiness due to dwindling cash on hand, the lack of a credit facility, and higher debt leverage. "Moody's expectation of weakening business trends could result in additional cash burn in 2016, further compromising the company's liquidity," the firm wrote.

Isola's troubles come at the same time Rogers is said to be phasing out certain lower-cost equivalents to its own 4300/4350 low-loss materials acquired with its purchase of Arlon in January. According to PCB fabricators I have spoken with, especially smaller ones, the effect has been immediate and pronounced: longer lead times and rising prices.

How soon will the impact be felt by OEM customers? As lines are pared, manufacturers (and likely, OEMs) face higher costs as they are forced to reevaluate materials and change their designs.

Longer-term, will a substantial world market share coupled with staggering debt service slow new product introduction? Will the incentive remain to invest heavily in R&D?

Much of the hand-wringing over consolidation to date has centered on ensuring a secure supply of PCBs to the US Defense Department. But US spending on military electronics, in the neighborhood of $11 billion annually (not including missiles), is a fraction of the worldwide electronics market. What will happen once the IBMs, Ciscos, Samsungs and Apples feel the burn? And which disruptors will seize the opportunity?

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PCD&F People

EDAC selected Mentor Graphics chairman **Wally Rhines** as recipient of the 2015 Phil Kaufman Award for contributions to the EDA industry.

MacDermid named **Joe D'Ambrisi** vice president, Global Electronic Solutions.

DuPont named **Jon D. Kemp** (left) president of its Electronics Communications business.

Park Electrochemical appointed **Don Burns** applications and technical service engineer.

NCAB Group hired **Ray Vandal** as general manager, Southeast US Division. He held a number of management positions with Viasystems, and was quality director for ITC PCB.

Mentor Graphics promoted **Richard Trebing** to vice president finance and chief accounting officer.

Charlie Huang will step down as executive vice president and general manager of Cadence's System & Verification Group this month.

PCD&F Briefs

Cadence issued a call for papers for CDN-Live 2016.

CST has acquired all intellectual property of the CoupleFil software developed by **InnoDev**.

Washington State University researchers have discovered how to stretch metal films used in flexible electronics to twice their size without breaking.

Cirrex installed a second **Excellon** laser at its Santa Clara, CA, plant.

Würth Elektronik has integrated WEdirekt online shop into **CadSoft's** Eagle software.

First Sumiden Circuits is investing about $64 million to expand its flex circuit operation in Laguna, Philippines.

KSL Kuttler said its newest investor, Tao Zipeng, is adding staff, and revenue is on the rise.

Platform Specialty Products said proposed acquisitions of **Alent** and two **OM Group** businesses are proceeding as scheduled, and the company has sufficient cash to fund its deals.

The copper-clad laminate market grew 7.1% year-over-year in 2014 to 760 million m^2.

PCB West 2015 Attendance Up 10.4% YoY

ATLANTA – Show attendance at PCB West in September rose 10.4% year-over-year to more than 1,900 attendees, UP Media Group announced. It was the annual printed circuit board industry trade show's highest turnout in over a decade.

Show registration was up 9.2% from 2014, as PCB designers, fabricators and assemblers turned out for the largest Silicon Valley-based trade show for the PCB industry.

The most popular sessions included common PCB design errors and signal integrity, while the sold-out show floor featured more than 100 companies.

Exhibitors were uniformly enthusiastic about their leads from the consistently busy show. "Thanks for another great show," said Joe Clark, cofounder, DownStream Technologies. Added Amy Clements, director of marketing communications, Zuken: "Thanks for another great PCB West. Lots of buzz about it around the office!"

"PCB West 2015 was very good. I would say it was the most well-attended show I have been to in the past two years," added Matt Kehoe, Southeast sales manager, Colonial Circuits.

PCB West was held Sept. 15-17 at the Santa Clara (CA) Convention Center. Overall, more than 1,900 printed circuit board designers, fabricators and electronics assemblers, managers and suppliers attended the trade show, UP Media Group said.

"This year's show was characterized by steady, often heavy traffic from start to finish," said Mike Buetow, editorial director of UPMG. "There was a lot of interest from the design side in signal integrity presentations, and the free assembly sessions were a positive and well-received addition to the technical conference." – *MB*

Mentor Updates ODB++ Data Transfer Format, Will Support IPC-2581

WILSONVILLE, OR – Mentor Graphics said the latest version of its ODB++ electronics data transfer format, released Sept. 10, has virtual documentation capability that seamlessly translates all data files, drawings, and documents from PCB design through the manufacturing flow.

Simultaneously, Mentor announced its support to the IPC-2581 Consortium and accompanying format standardization efforts.

ODB++ version 8.1 provides a single and open data structure for transferring printed circuit board designs into data for fabrication, assembly and test. The open format, Mentor said, eliminates the need to create and validate disparate documentation content, supporting all electronic design automation tool flows.

Users of the new ODB++ version will be able to share all the necessary manufacturing instructions as electronic data, making NPI more efficient for all partners in the supply chain.

"The idea behind virtual documentation content is to replace a disparate set of drawings, documents and instructions with data elements that allow the recipient tool to automate the planning and execution of the manufacturing process preparation actions. An example would be to define the solder mask finish color within ODB++ so that a PCB fabricator can automatically generate the process, material and routing instructions for that individual factory," Mentor said.

ODB++ v. 8.1 also includes support for EDA-based design net connectivity shorts. For designs in which one or more nets are intentionally shorted into a single net, v. 8.1 now carries that net attribute so all downstream processes can be streamlined and automated.

Additionally, content for rigid-flex buildup zones to define regions within the basic stack-up (either unique or within the same region) on the board can be carried forward into analysis and in the actual material-based stack-up definition. This feature delivers accurate impedance calculations, using tools such as the Frontline InStack for this capability. By accurately identifying the physical boundary of different stack-up areas for a rigid-flex circuit, the correct DfM rules can be applied

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Rockwell Collins named **Firan Technology Group's** Tianjin, China, subsidiary a qualified supplier of PWBs.

Toray Composites America completed a multimillion dollar expansion project at its production facility in Tacoma, WA.

Multilayer Technology purchased an **Orbotech** Sprint 120 inkjet printer.

TCT Group has acquired two of **Tapco Circuit Supply's** business units for an undisclosed amount.

ALA Software Solutions purchased multiple **Nano Dimension** 3D printers.

CA People

Celestica named **Jack Lawless** executive vice president, diversified markets. He was CEO of Associated Air Center, a subsidiary of StandardAero.

IEC promoted **Jens Hauvn** to senior vice president of operations.

Valtronic named **Kristin Jamroz** customer service and order entry representative.

Ducommun promoted **Douglas Grove** to chief financial officer.

Inovar named **Bernie Schneider** vice president of operations. He has 20 years' experience in electronics manufacturing with Solectron, Flextronics, Paramit, Plexus and several OEMs.

Mike Konrad, CEO of Aqueous Technologies, has released a new book on cleaning printed circuit boards. *The Reasons for Cleaning: A Handy Guide for Cleaning Circuit Assemblies* (aqueoustech.com/book-1-download) features a selection of short articles about why companies clean, how they clean, and how clean is "clean."

Aim Solder named **Elson Liu** sales manager for south China.

CA Briefs

Nordson has acquired **MatriX Technologies**, a manufacturer of automated x-ray inspection equipment, for an undisclosed price. Nordson expects the acquisition to be accretive to earnings in the first full year of operation. MatriX's 2014 revenues were approximately €26 million.

Kinpo Electronics shifted some printer production capacity at its factory in southern China to a factory of **Cal-Comp Electronics** in Thailand, citing continual wage hikes and short labor supply.

automatically, and rigid-flex circuit manufacturers can easily and accurately calculate the impedance values for the circuit using their choice of materials.

"With our latest ODB++ intelligent product model format, we now offer customers a complete and open design-through-manufacturing ecosystem," said A.J. Incorvaia, vice president and general manager of Mentor's Systems Design division. "Our mission is to provide our customers with the best tools and technologies to increase overall product quality and productivity. This includes support for ODB++ and IPC-2581, giving our customers a choice in data exchange formats for hand-off to manufacturing." – *MB*

Gerber Standard Adds Nested Step-and-Repeat Function

GENT, BELGIUM – The caretaker of the Gerber electronics data transfer format is proposing efficiency improvements for handling fabrication and assembly panels.

Ucamco has embellished the Gerber language with nested step-and-repeat to accommodate panelized boards at assembly without severely expanding the file size. A draft specification is available for review and comment.

The revisions focus on the step-and-repeat process for creating multiple identical boards for a single panel (array). Repeating the same image several times increases the file size and slows CAM processing, a problem Gerber resolves by storing the PCB data only once, along with instructions to step-and-repeat.

This works well at the fabrication level but not assembly, where the arrays are "nested," Ucamco said in a press release announcing the revisions.

"One way to represent the PCB instances is with a so-called flat file. The objects representing the PCB are simply copied *n* times in the file, each time at the appropriate place. While this defines the correct image, it blows up the file size and slows down processing the image in CAM and on the production equipment. A more efficient way is to store the PCB objects only once and add an instruction to step-and-repeat the PCB over the image, which the current SR command in Gerber does."

As assemblers migrate to processing panels (arrays) as opposed to standalone boards, the images are represented by a nested step-and-repeat. The single PCB is stepped into an array, and the array is stepped into the production panel. With a nested step-and-repeat, the PCB data again are contained only once in a file.

"The problem with the SR in Gerber is that it supports only one level, no nesting. So, one has to flatten either the array or the working panel. The resulting big files can become a problem when a small but complex piece of electronics such as a smartphone is fabricated."

Ucamco is addressing this issue by extending the Gerber language with nested step-and-repeat. Tests performed with Via Mechanics in Japan reportedly demonstrated "dramatic" productivity increases in writing and reading the files, as well as in processing them.

Ucamco has created a new command, called SN, to accommodate legacy Gerber readers that do not yet support nested step-and-repeat and might, when receiving an SR with nesting, not notice this and produce the wrong image, without warning.

Another issue, Ucamco said, is the step-and-repeat only allows repeating of object blocks in a regular array. To allow more general repeats, Ucamco introduced a command called AB that creates a block aperture that can be flashed in any location and orientation.

New attributes unequivocally identify the fabrication panel, assembly panel, and the single PCB.

"Nested step and repeat and block apertures will make Gerber more efficient with panelized data. Furthermore, the block aperture is a powerful general construct that will no doubt have many other applications. Together, they are a powerful extension of the Gerber format," Ucamco said. – *MB*


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Zestron standardized all its product labels and Safety Data Sheets to the UN GHS system.

DARPA released photos of what its anti-counterfeit electronics chip might look like.

Ionics is working to bring **IBM's** IoT Foundation to organizations across industries.

SMTC moved its corporate headquarters to San Jose.

The EOS/ESD Association issued a call for papers for the 2016 International Electrostatic Discharge Workshop (esda.org/events/iew).

To head off vast e-waste problems, a **University of Illinois** researcher wants to trigger the "destruction" of electronics devices in such a way that it leaves nothing behind.

Sparton will close its electronics assembly factory in Lawrenceville, GA, by mid 2016 and lay off up to 82 workers.

Flex will acquire a former **Nokia** electronics production site in Manaus City, Brazil, where it will build smartphones and Xboxes for **Microsoft**.

Nortech Systems has launched PCB assembly at its facility in Monterrey, Mexico.

Nordson Dage named **Crest Group** distributor in Malaysia, Thailand and China.

EMS firm **Digicom Electronics** has expanded at its Oakland, CA, location.

Concurrent Manufacturing, a contract assembler with three assembly sites in the US and Mexico, has auctioned its 50,000 sq. ft. plant in Missouri.

Saki America named **SMT Equipment**, **Bench Top Solutions** and **Contek Sales & Marketing** distributors in the US.

Inovar installed four **MIRTEC** MS-11 SPI systems.

Scienscope appointed **Assembly Solutions** exclusive manufacturers' representative in Washington and Oregon.

AIM Solder named **Kirby & Demarest** representative in Oregon, Washington and Idaho.

Rocket EMS installed a **Spea** 4060 flying probe tester.

Super Dry appointed **Restronics** representative in Southern California.

Para Tech Coating opened a new coating center in Wisconsin, expanding regional capabilities beyond its California and Connecticut operations.

Omron will acquire intelligent robot maker **Adept Technology** in an all-cash deal worth about $200 million.

AZ Court Finds for Isola in Latest Patent Battle with TUC

PHOENIX – An Arizona jury in September said TUC Technology Corp. owes Isola USA more than $11 million in damages for willfully violating multiple patents for PCB materials.

In a unanimous verdict, the jury also determined Isola's patents were valid and did not violate existing patents held by a third party, striking an important counterclaim TUC was asserting.

In the latest chapter of a suit launched in June 2012, TUC was found to have directly infringed Isola patent no. 6,509,414, and to have induced others to infringe the patent as well.

TUC, also known as Taiwan Union Technology, asserted in its counterclaim that the Isola patent no. 6,509,414 was invalid for failure to meet the written description requirement. It also claimed Isola patent 8,022,140 was invalid, as it was anticipated by Nelco N4000-13.

The jury disagreed on both counts, however, and awarded Isola $8.5 million in lost profits and $3 million in royalties.

The '414 patent, granted in 2003, describes a prepreg comprising FR-4 epoxy resin advanced with TBBPA and other optional crosslinking materials. The '140 patent, issued in 2011, describes a prepreg comprising an epoxy resin, a first cross-linking agent of a styrene-maleic anhydride copolymer and a second co-cross-linking agent.

The products found to infringe were TUC's TU-872 laminate and prepreg products. – *MB*

TTM to Close 3 Sites, Lay Off 550

COSTA MESA, CA – TTM Technologies plans to close three facilities and expects to lay off approximately 550 employees. Manufacturing operations in Cleveland and Milpitas, CA, will be combined with nearby TTM locations in North Jackson, OH, and the Silicon Valley, respectively.

In addition, the PCB manufacturer will close its EMS facility in Juarez, Mexico.

Over the next three to six months, TTM will close the three affected sites and transfer some employees to other facilities nearby. Separation and other benefits will be extended to those employees who are not transferred to other TTM sites.

The plant closures are part of a plan the company put into place after the acquisition of Viasystems on May 31. – *MB*

Flex Opens Massive Medical Plant

TIJUANA, MEXICO – Flex has opened a 530,000 sq. ft. medical device manufacturing facility and Center of Excellence here, calling it the "showcase" location for the EMS company's medical operations.

The site is located 10 minutes from San Diego and employs 2,400 workers. The site will produce diagnostic and treatment devices for everything from cardiovascular diseases and diabetes, to hearing impairment, neurological diseases and skin ailments.

"Tijuana is an ideal location for our medical Center of Excellence, as it has a highly trained local workforce, strong local universities and a geographic location that makes it highly accessible and convenient for our customers," said Javier Gonzales, Flex vice president of operations and general manager in Tijuana.

The new facility is dedicated exclusively to medical device manufacturing and includes over 120,000 sq. ft. of class 7 and class 8 level clean room space, with plans for additional expansion.

Flex has been in Mexico for 17 years and employs more than 20,000 workers in Tijuana, Ciudad Juarez, Aguascalientes, Reynosa and Guadalajara. – *MB*

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A/V PICTURE BRIGHTENS

Trends in the U.S. electronics equipment market (shipments only).

	% CHANGE			
	JUNE	JULY	AUG.	YTD%
Computers and electronics products	-0.2	-0.3	0.7	2.3
Computers	2.3	1.6	-5.1	-7.8
Storage devices	3.5	0.8	-3.5	-24.8
Other peripheral equipment	4.3	-4.2	-6.4	2.4
Nondefense communications equipment	2.8	-0.9	-3.1	3.0
Defense communications equipment	-8.7	10.6	-2.9	-11.3
A/V equipment	-1.6	-0.8	1.2	-26.9
Components[1]	3.6	1.6	-1.0	24.5
Nondefense search and navigation equipment	-1.0	0.4	2.3	8.7
Defense search and navigation equipment	1.2	2.3	-0.5	2.8
Medical, measurement and control	0.8	1.9	1.6	5.9

[r]Revised. *Preliminary. [1]Includes semiconductors. Seasonally adjusted.
Source: U.S. Department of Commerce Census Bureau, Oct. 2, 2015

Design Software Sales Slip in Q2

SAN JOSE – PCB and MCM design software revenue fell 13% year-over-year to $155.3 million in the June quarter. Overall electronic design automation industry revenue increased 8.5% year-over-year in the period to $1.9 billion. The Americas, EDA's largest region, purchased $870.3 million of EDA products and services in the quarter, up 9.5%.

Flip Chip Device Volume to Double by 2020

LYON, FRANCE – The volume of devices packaged using flip chip technology will double from 16 million wafers per year in 2014 to 32 million wafers per year in 2020, reaching $25 billion, says Yole Développement.

Expected growth is supported by the wider adoption of Cu pillar technology, as well as Moore's law pushing beyond the 28nm node and "More than Moore" evolution in DDR and 3D ICs, according to the research firm.

Gold-plated wafer bumping will grow, driven by demand for IC display drivers for 4k2k ultra-HD TV and high-resolution and large screens for tablets and smartphones. Yole expects capacity to expand at a CAGR of 4%, from 4.3 million to 5.4 million wafers from 2014 through 2020.

The firm expects a slight decline in gold stud bumping capacity, mainly due to radio-frequency devices moving from flip chip to wafer-level CSPs.

The firm estimates flip-chip bonders' total market value will reach $435 million in 2020, a CAGR of 7%.

METALS INDEX

DATE	10/6/14	7/6/15	8/3/15	9/7/15	10/5/15
LME Cash Seller and Settlement for Tin	$9.28	$6.51	$7.26	$7.03	$7.11
LME Cash Seller and Settlement for Lead	$0.95	$0.79	$0.76	$0.76	$0.74
Handy and Harman Silver (COMEX Silver)	$249.90	$227.45	$214.76	$215.20	$227.89
LME Cash Seller and Settlement for Copper	$3.05	$2.53	$2.35	$2.40	$2.33

3D Printer Shipments to Grow 103% in 2016

STAMFORD, CT – Worldwide shipments of 3D printers will reach 496,475 units in 2016, up 103% from the predicted 244,533 units in 2015, says Gartner.

3D printer shipments are forecast to more than double every year between 2016 and 2019, by which time worldwide shipments are expected to reach more than 5.6 million.

Seven technologies constitute the 3D printer market, with material extrusion forecasted to lead 2015 shipments at 232,336 units, increasing to 5,527,493 units in 2019 (97.5% of the total).

3D printers costing less than $1,000 will make up one-fourth of the sub-$2,500 printer market in 2015, but will grow to 41% by 2019.

Report: Automotive, Medical Assembly Still In-House

NEVADA CITY, CA – Although the worldwide electronics assembly market has nearly quadrupled in size in the past 20 years, certain markets remain in-house. While nearly half (44%) of computer assembly has been outsourced, automotive (14%), industrial (24%) and medical (25%) remain primarily at OEMs, says New Venture Research.

The cost of goods sold reached some $1.4 trillion in 2015, and outsourced electronics assembly now accounts for approximately 40% of all electronics manufacturing production. The remaining 60% is manufactured by OEMs.

US MANUFACTURING INDICES

	MAY	JUNE	JULY	AUG.	SEPT.
PMI	52.8	53.5	52.7	51.1	50.2
New orders	55.8	56.0	56.5	51.7	50.1
Production	54.5	54.0	56.0	53.6	51.8
Inventories	51.5	53.0	49.5	48.5	48.5
Customer inventories	45.5	48.5	44.0	53.0	54.5
Backlogs	53.5	47.0	42.5	46.5	41.5

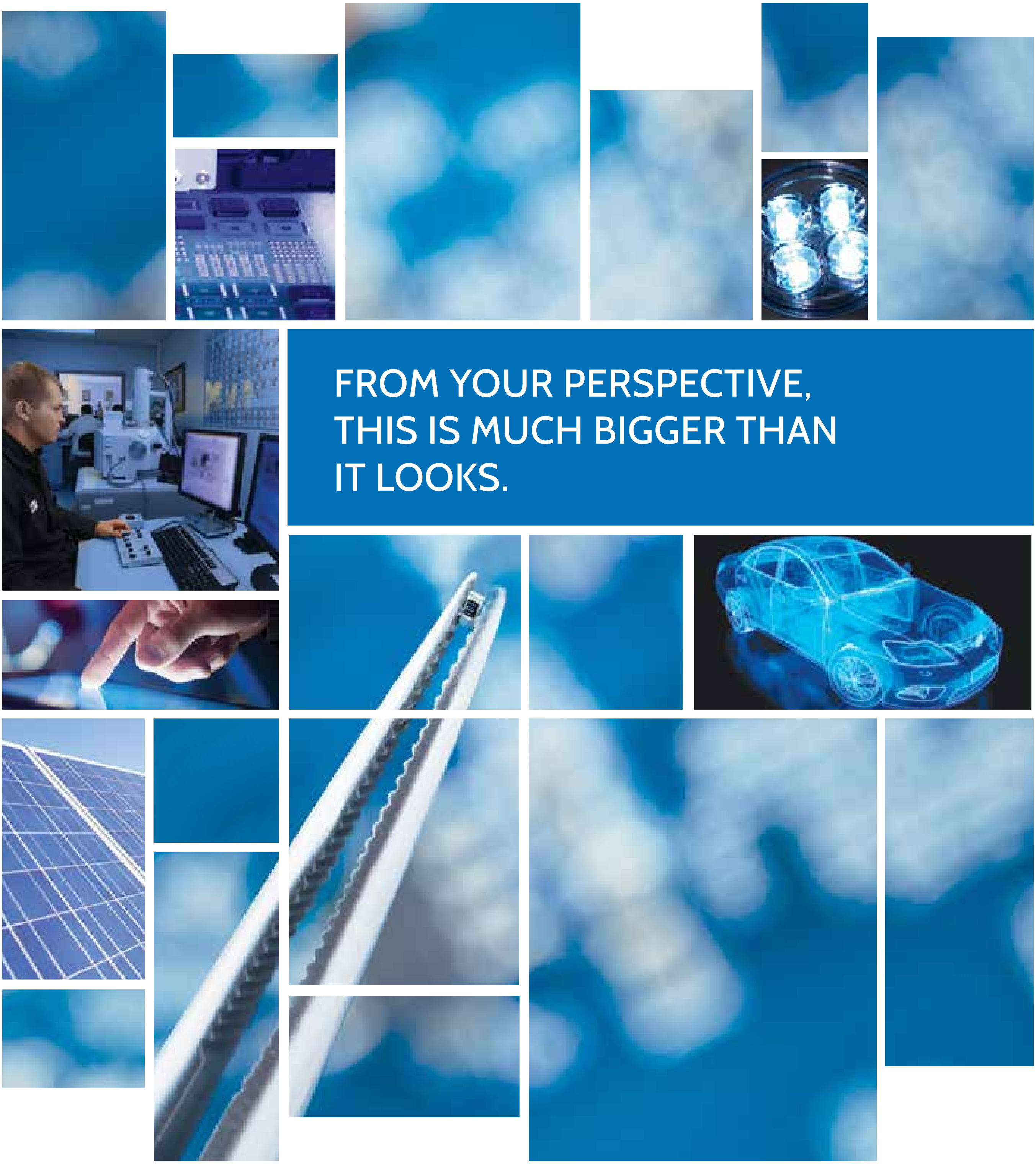
Sources: Institute for Supply Management, Oct. 1, 2015

KEY COMPONENTS

Book-to-bills of various components/equipment.

	APR.	MAY	JUNE	JULY	AUG.
Semiconductor equipment[1]	1.04	0.99	0.98	1.02	1.06
Semiconductors[2]	4.84%	4.77%	2%	-0.95%[r]	-3.01%[p]
PCBs[3] (North America)	1.02	1.02	1.06	1.09	1.13
Computers/electronic products[4]	5.95	6.01	5.94	5.88[r]	5.91[p]

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



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A Raw Deal

Are materials suppliers the weakest link in the electronics supply chain?

IF A CHAIN is only as strong as its weakest link, it begs the question, which is the weakest link of our supply chain?

For years, if not decades, the popular assumption has been this dubious honor belongs to the lowly fabricator. On one level that assumption appeared to make sense. Historically, so many fabricators have been, and remain, small "bucket shops" looked down on as low-tech and low-quality. Likewise, many larger companies historically became overleveraged, balance sheets filled with debt for everything from spanking new (albeit minimally used) advanced technology equipment to the owner's vacation house – and eventually foundered.

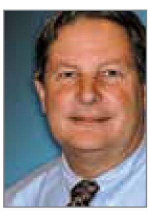
The fact is fabrication may be one of the most robust links after all. Yes, today there are fewer fabricators in North America than a decade back, but globally the number tells a different story. Locations have shifted, but the sheer numbers remain surprisingly consistent.

Insofar as viability, while every industry has its marginal players, most of the remaining PCB fabricators in North America are financially stable, if not thriving, and have established specific markets and/or capabilities that provide reasonable growth and margin. Globally, the companies that have sprung up have done so in high-growth areas of the world, focusing on high-tech markets, and therefore have been able to significantly grow and establish themselves as viable enterprises.

Despite the naysayers, predictors of doom, and those who otherwise have held printed circuit board fabricators in low esteem, this link in the supply chain is solid and far from being the weakest in the chain.

Regrettably the same cannot be said for suppliers of raw materials and laminates that all other links in the electronics supply chain rely on to fuel our industry. There, the picture looks quite different and scary. An industry that has historically been served by larger brand name companies that globally supplied laminate, film, chemistry and plating supplies is today a mere shadow of its former self. Yes, one can find laminate: FR-4, for example, is available from different suppliers across the globe. However, it is available only from relatively few suppliers and with only regional, not global, distribution. A further complication is the trend toward specialty laminates. Whether a high Tg FR-4 type material or the dielectric-driven PTFE flavor of laminate, many specialty laminates are made by only one company, with no "drop-in" replacement. If out of stock or on allocation because of a spike in demand, delivery of specialty laminates can be agonizingly long and result in lost sales. The challenge of fewer and only regional laminate suppliers, combined with the growth of specialty laminates, creates a minimally competitive industry overly dependent on just a handful of suppliers.

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



If the picture for material suppliers looks bleak, the state of chemical producers appears absolutely ghastly. With one company seemingly set on owning all the chemical companies that serve our industry, it would only take one misstep for that company to end up with a pile of debt, inadequate cash flow to remain viable, and all its customers (and customers' customers) stuck high and dry without the ability to process product through their plants. Ditto for dry film and most all of the other key raw materials every company relies on to fabricate a board.

Indeed, when it comes to a competitive and robust supply chain, our industry has never appeared so frail. And the current weakness is not because of alleged bucket shops producing so-called low-tech product but rather because of the extreme frailty of one of the most important links in the supply chain: raw material suppliers.

With the dramatically shrinking number of suppliers and the rapidly decreasing number of plug-and-play options, higher material prices will most assuredly result, and a misbalance in regional competitiveness will ensue. None of this will prove to be healthy for end-customers, assemblers or fabricators. When laminate, chemistry and other key raw materials are not globally available, consistent product suffers, and the playing field quickly tilts in one direction or another.

The real question is whether this growing vacuum will be filled by new or emerging suppliers. For many fabricators a differentiator has been the chemistry system(s) they utilized in their processes. With so few remaining companies, an opportunity exists for small regional companies to fill that void. Or an established larger regional company may take advantage to become truly a global supplier. Such a movement by the up-and-coming to fill the void may be exactly what is needed to push technology to the next level. If new, innovative thinking accompanies emerging or transplanted suppliers, then the supply chain link will become more robust.

Laminates may also prove an opportunity for lesser-known suppliers. Companies that have established manufacturing and focus on quality product may find they are more than welcome in the lower volume markets of North America and Europe, while also enjoying higher margins that come with lower volume orders. For the rest of the supply chain, additional sources of supply will provide an added level of security when committing to a laminate or tight tolerance design.

Hopefully the entire supply chain will begin to focus on the weakest link and, together, find ways to enable our suppliers to once again be strong and vibrant. Likewise, suppliers will hopefully realize their current path is straining not only their collective link, but the rest of the supply chain as well. PCD&F

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Those Danged LEDs Again

Avoid the trap: confirm the polarity on LEDs.

DUANE BENSON is marketing manager at Screaming Circuits (screamingcircuits.com); dbenson@screamingcircuits.com.

PCB DESIGNERS FACE a lot of challenges, but sometimes the simplest things cause the most common fails. I was caught by one of my own favorite "simple" traps last week: the dreaded LED footprint mess.

I designed a board based on the Microchip PIC32 that has a number of RGB LEDs on it; it's a ChipKIT Arduino-compatible board. I used RGB LED part number LTST-C19HE1WT from Lite-On. The datasheet is easy to find, and the footprint information is right up front, just the way we like it.

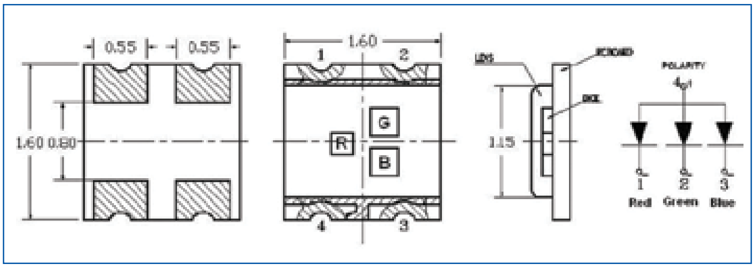

FIGURE 1. Never assume the pin numbering per the datasheet is correct.

Almost all is well, but I somehow missed taking my own advice, and I didn't double-check the footprint. The footprint I used is more or less 180° off from this one (FIGURE 1). The common anode is still on pin 4, but the numbering is different. It's got pin one in the same place; then pin two is in the lower left. Pin 3 is on the same place, and pin 4 is on the upper right. That's the conventional pin numbering order.

Fortunately, the fix won't require any mod wires. If I rotate the LEDs 180°, the anode will be in the right spot. All I'll need to do is adjust my software for the correct R, G and B pin locations.

Why waste parts? We love parts on reels. Who doesn't? But reels aren't always practical, and it's not just about cost. Cost is, of course, important, but there may be other factors to consider.

Say, for example, you need 18 180Ω, 5% 0805 resistors for the LTST-C19HE1WT LEDs. You could buy a small strip of 25 from a distributor for $0.32. That gives the 18 you need, plus a few spares just in case.

Alternately, you could buy a custom quantity reel. On the reel, you'll probably want more parts to keep the strip long enough for the feeder. Let's go with 250 parts for $1.39. The distributor might charge around $7 extra to create a custom reel, so that's a total of $8.39. Still peanuts.

For a third choice, you could buy a full reel of 5,000 for $10.64. Still peanuts. If you're going to need the same part for a lot of designs, this might make sense. But, there's more than just cost to consider. You need to store and ship it. Shipping two dozen reels gets expensive. Storing and inventorying several dozen reels can become a hassle too.

The beauty of DigiKey, Mouser and other places that sell cut strips is they essentially become your parts warehouse. You pay the 32 cents and never have to worry about whether the part is in your inventory, how many are in inventory, digging it out of wherever you stuffed the reel when you last needed it, and so on.

If you do buy and store the whole reel, ask first whether to ship it to the EMS. You might be able to cut a strip with the number needed, plus about 10% for that "just in case" (50% extra for tiny 0201 parts). PCD&F

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Copper Roughness Electromagnetics 101

Why smoothing copper for better signal integrity could degrade mechanical performance. by JEFF LOYER

Most every electrical engineer working with high-speed differential interfaces such as PCIe is aware of the effect of rough copper on insertion loss – and knows it is to be avoided. What they may not understand is exactly why that's true. There is a common explanation that seems intuitively correct but isn't, that the current follows the longer contour of the copper, and that's responsible for the increased loss when using rough copper. To understand what's actually happening, we have to move from a "circuit" model of signal propagation to a "fields" model.

Modern high-frequency signals are at microwave frequencies, forcing even digital designers to understand different fundamental physics than we're familiar with. We are used to a "circuit" model of signaling, where current leaves the signal pin of the transmitter and returns via the ground pin of that transmitter, making a loop through the PCB and receiver, completing the circuit. In the "fields" model that we have to get comfortable with at higher frequencies, however, the transmitter sets up electric fields between the signal and ground pins, and the energy in those fields is guided by the package, PCB, and connector features (such as pins, traces, and vias) to the receiver. The "fields" model better explains the effects of vias, return path transitions, and attenuation of the signals due to dielectric and copper losses. Why does rough copper absorb more energy than smooth copper? In short, it isn't because the "current" travels farther (as in the "circuit" model); it's because the electromagnetic energy is exposed to more copper surface.

A "circuit" model explanation of why rough copper absorbs more energy than smooth copper as a signal propagates from transmitter to receiver focuses on the "current" traveling a longer path due to the rough copper. For instance, in **FIGURE 1**, it's intuitively clear the current travels a shorter distance on the surface of smooth copper than rough copper; thus it loses less energy (assuming the notion of "skin depth" forcing "current to flow on the surface of conductors" has been explained elsewhere).

There are some problems with this intuitive explanation, however. If it were accurate, the signal would be delayed in rough copper proportionally to its lost energy. Measuring the propagation delay of signals on rough and smooth copper doesn't support that; their propagation delays are very similar. Also, note in the area circled that the rough copper may not be continuous from left to right. What happens here? Does the current loop back? We have to use the "fields" model to better understand what is really happening.

In the "fields" model, the signal propagates from left to right as an electromagnetic wave in the dielectric, inducing current density waves in conductors subjected to those waves (both signal and "ground," or any other adjacent conductor). For instance, in **FIGURE 2**, we have a simple step source

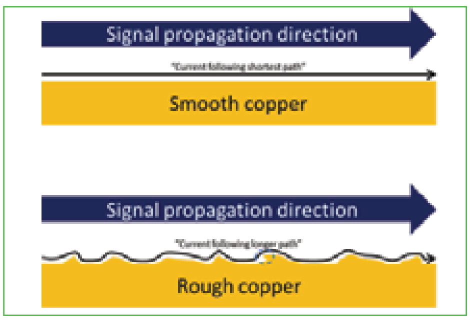


FIGURE 1. "Current" on smooth and rough copper.

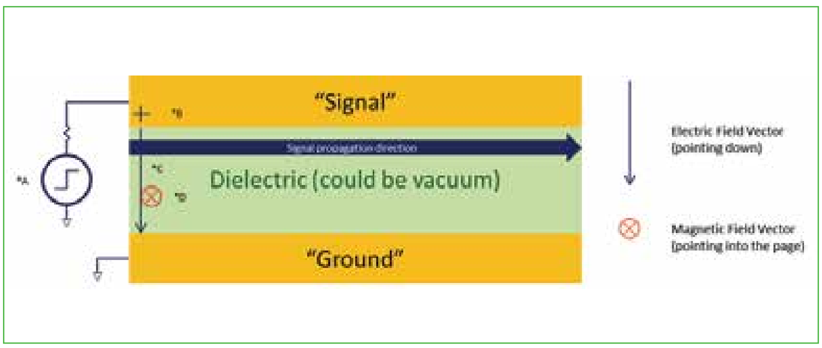
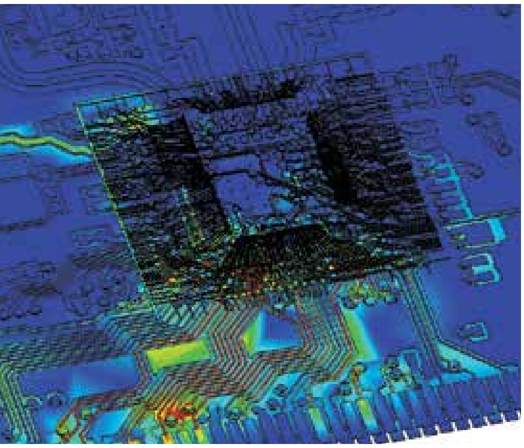


FIGURE 2. Signal propagating from source.



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generating a fast rising edge voltage on a signal trace (*A). At the instant it's applied to the trace, that changing voltage generates a positive-going charge on the "signal" (*B) and a changing electric field ("e-field") between the signal and "ground" (*C).

The changing e-field induces a changing magnetic field ("h-field," *D) into the page, since the signal propagates from left to right. That changing h-field induces an e-field to the right, and this continues as an e-field/h-field leap-frog, as long as the signal and "ground" are well-behaved, allowing the signal to propagate through the dielectric, guided by the signal and ground structures. The wave propagation is in the direction of the cross product of the electric and magnetic fields. Using the "right hand rule," with the index finger of the right hand pointing in the direction of the electric field (down) and the middle finger pointing in the direction of the magnetic field (into the paper), your thumb will point in the direction of propagation (to the right). This use of the right hand rule is called the Poynting vector.

As the signal propagates in the dielectric, electric charge density changes on the surface of the conductors (both signal and "ground"). Those waves of current charge density follow the signal, making it appear there is a current flowing from left to right in the conductor, and right to left in the "ground." This is how it appears in the "fields" model. This model might seem awkward to comprehend at first, but it has a distinct advantage in explaining the effect of copper roughness. Rather than thinking of current flowing on the surface of the conductors, we can instead think about the effect of the electromagnetic field on those surfaces.

If we focus on the dielectric/conductor interface, basic electromagnetics forces very different behaviors within the dielectric and conductor. Inside the dielectric, on the surface of the conductor, the e-fields must be perpendicular to the conductor surface (perfectly so for a perfect conductor, or PEC, nearly so for a "good conductor"). Inside a good conductor, the changing e-field can't continue in the vertical direction. The changing h-field, however, is continuous across the boundary of the dielectric and conductor. Inside the conductor (assuming it isn't a *perfect* conductor), that changing h-field induces changing e-fields and associated eddy currents. The propagation of this energy is, however, in a completely different direction than that within the dielectric, and is much slower. Inside the signal conductor of Figure 2, the electromagnetic energy propagates from bottom to top at a rate thousands of times slower than in the dielectric.[1] The magnetic field will be in the same direction (into the page), but the electric field will be left to right, and the energy propagation is from bottom to top. An analogy to the propagation of energy in the conductor due to that in the dielectric is the wake of a speedboat – it travels orthogonal to the boat's direction of travel.

If the frequency is low, the induced eddy currents are small; not much energy is lost as the wave propagates, and that wave might extend through the entire thickness of the conductor. This is the case where the "skin depth" is greater than the conductor thickness. As the frequency increases, the skin depth becomes very small. At microwave frequencies the copper roughness is often greater than the skin depth. For instance, at 5GHz, the skin depth for copper is

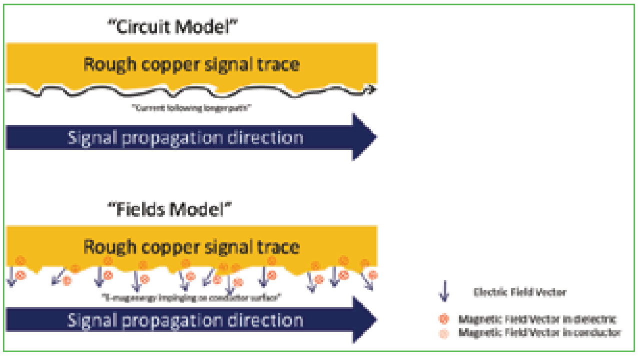

FIGURE 3. Circuit vs. fields model of trace.

approximately $1\mu m^2$, while standard 1oz. copper can have a roughness profile of 3μm.[3] In the "circuit" model we would say the vast majority of the current is traveling on the rough surface. In our new "fields" model we picture the electromagnetic energy propagating slowly into the conductor, but only traveling a very short distance inside that conductor (1μm) before being absorbed by the conductor.

FIGURE 3 demonstrates the two different models representing the same signal propagating from left to right, and its effect on a rough signal trace (conductor). We have replaced the circuit model of current traveling a longer distance on rough copper, with a fields model of the electromagnetic energy impinging on a larger surface area as it propagates from left to right adjacent to a rough conductor. The fields model gives us some intuition that the increase in loss due to copper roughness is going to be proportional to the increased conductor area that the fields are subjected to. Unfortunately for us, the peel strength of the copper is also going to be proportional to that same area. Any effort to smooth the copper for better signal integrity will degrade the mechanical performance. Laminate suppliers will have to use chemical bonding means to retain peel strength (mechanical strength) while smoothing the copper for better signal integrity.

The point is not to replace the circuit model of signal propagation with a fields model for every frequency, application, or problem. Rather, it is to augment the circuit model with another that sometimes is more useful to understand the fundamental physics behind an issue. There are other cases where a fields model can enhance the intuition behind a problem (crosstalk and via impedance, for instance); it's a good idea to understand it at microwave frequencies. PCD&F

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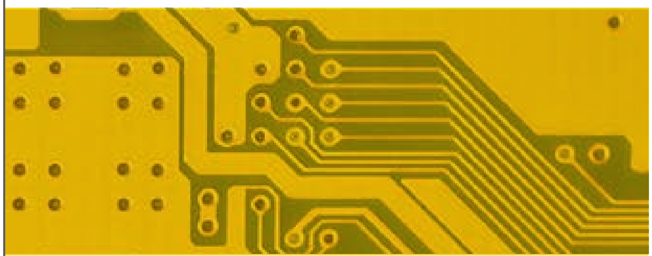

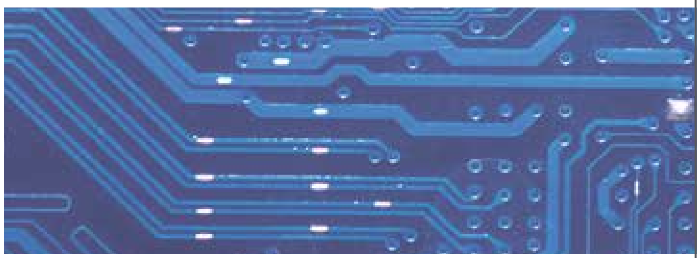

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A Layout Time ESTIMATING TOOL

Even with autorouters, accurate design schedulers need to consider soft issues. by JAMES JACKSON

When I first began laying out printed circuit boards, giving estimates was reminiscent of the movie *The Money Pit*. The engineer or project manager would hand me a schematic (or netlist), and ask, "How long to do the layout for this?" My reply was invariably, "Two weeks!"

When they came back after two weeks and asked, "Is it done?" the answer, of course would always be "no."

"Well, how long until you finish it?"

"Two weeks."

Unlike the movie, though, my reply was out of ignorance on how to estimate schematic capture and PCB layouts.

Indeed, I have been asked many times through the years how to estimate the amount of time it takes to do a board layout. There is no simple answer to this question. The algorithm and method I use have evolved over the years to what they are today.

When I first started doing PCB layouts, we used light tables and Bishop Graphics tape and "dots." The company I worked for usually had large contracts, and the amount of time it took did not really factor in overall to the cost. As a result, the question "how long will it take?" was not that important, and was more of a scheduling issue.

My introduction to computer-aided design layout came when I transferred to a group that was using PCs to perform electronic capture of the schematic and then create the PCB layout on a computer using CAD software. The initial CAD was on a blazing IBM 6MHz AT computer, using some sort of bridge board that ran Unix software. The operating system and program resided on 16 5-1/4" floppy disks.

I well remember the computer going haywire and tech support telling me to "reload the OS." This process took two or three hours of feeding one floppy after the other. I soon gave up on calling tech support, cutting out the middle man, and would reload the software when things went awry. This, of course, did not bode well with upper management, who expected a layout to be finished in a timely manner.

The group I'd transferred to created space flight computers and hardware. When they asked "how long will it take?" it was still a scheduling question, but the answer was more important because, if you did not finish the layout on time and give the engineers some hardware to populate and program, you might miss the flight into space on that rocket.

I also attribute this "get it right the first time" attitude to working in this section, as I was often told that if there were any issues with the PCB, I would be sent to fix them. In orbit. It was meant as a joke, but I got the point, and always strove to have an error-free layout. (There also was a contract and funding element, as management's quote for the project was sufficient to do only one spin of the PCB.)

The Myth of the Autorouter

In its efforts to cut down this "two weeks" turnaround time, I recall management thinking training would be helpful. The issue, however, was the instructors were also expected to help me complete a layout during the five-day training class. Anyone who has attended training for CAD software will attest five days are usually just enough time for instructors to conduct the training, with no time left for additional help. So when I came back from class, their question, "Did you finish the layout while in class?" was met with a "no."

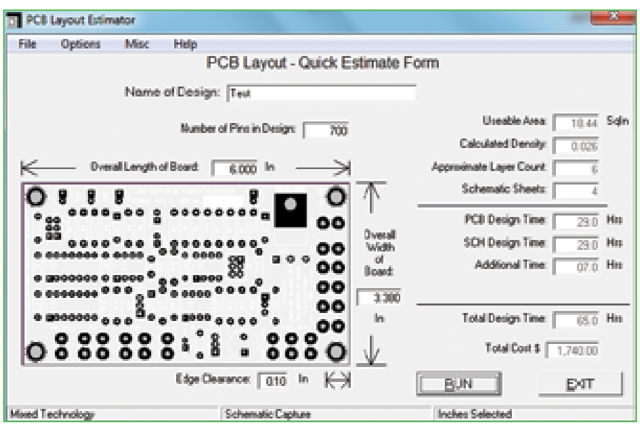


FIGURE 1. In the main form, a user enters the number of pins and the x and y dimensions.

Eventually, management realized the CAD software we were using was barely able to keep up with demands, and we upgraded to a much larger CAD hardware/software package. This Unix-based software was awesome for what it did at the time, but I was still giving estimates of “two weeks.” The other issue was this CAD package also came with an autorouter I was expected to use, to shorten that two-week estimate to something like two days. After all, all I had to do was press a button, and the computer would do the rest, right?

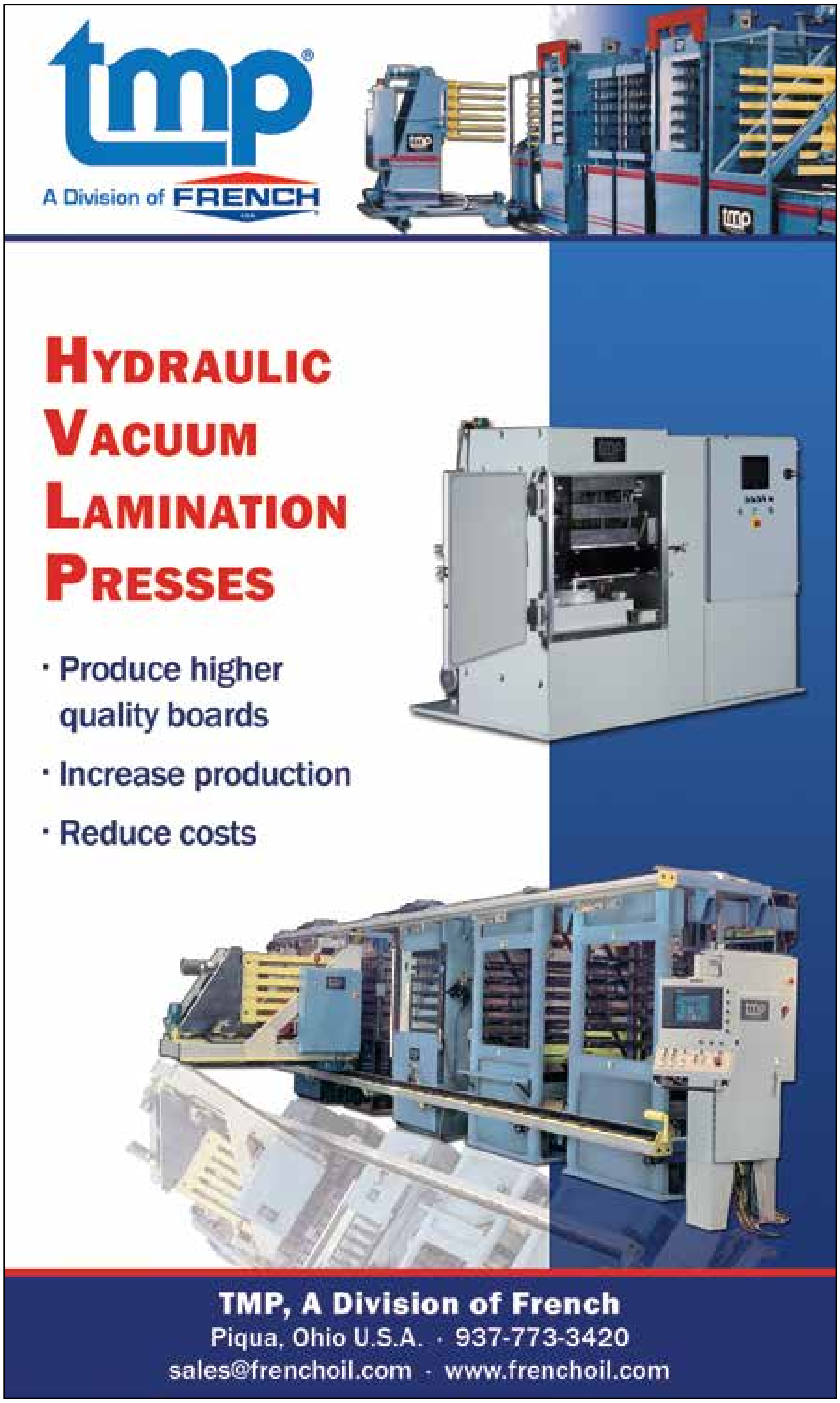
Not quite. I remember using the autorouter on the layout of a very dense board. It had something like 12 layers for planes and traces. I remember getting it set up and pressing the autoroute button. It would take no fewer than 23 hours to run the course of route, rip-up, route, push-and-shove, etc. I could come back the next day, and the routing would be about 89% complete. That left me with whatever the autorouter could not complete. This was not too bad, other than the router did not conform to any grid I was using, and so any leftover routes required more work to complete than would have been needed had I done the routing myself. It also led to another unexpected “feature.” The engineers, now realizing I could autoroute the boards, would add changes to the schematic and design at the last minute. After all, I could now autoroute the board in 24 hours, right? CAD designer frustration ensued.

I left this company to work for a service bureau in a nearby city. The owner-manager of the company already had a spreadsheet on his computer that he would use to create an estimate, but I was interested in how to create this estimate separately. The question was compounded by the addition of us also creating the schematic for some clients.

Somewhere along the way, I snagged a set of service bureau forms, which had distilled the estimation to a fill-in-the-blank process. I copied these forms many times and used them initially to assist my layout estimates. I could not understand the algorithms used, however, as they did not seem to be a linear estimation of time. Starting with the number of pins and the board size, it was determined how long in hours (or days) it would take to create the layout. The time varied based on density. There were also upcharges for expediting the layout.

I would sit at a local coffee shop in the mornings working through the numbers, trying to decipher the process for estimating layouts. Then one day it made sense. The algorithm took into account factors beyond the number of pins and board size. It took into account the amount of time every job has for setup and processing (or housekeeping). Once I figured this out, I set about to create my own algorithm based on my own capabilities.

My first attempt resulted in a set of forms similar to the service bureau forms I’d “borrowed.” It was a two-page set of forms where the prospective



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client (or me) would fill in the numbers, generating a layout estimate result in hours (or days). I used this set of forms, but soon realized there was a repetitive nature to the calculations that was best-suited to an automated process (read: computers). I also realized the solution needed to be portable, so if I were at the client's office, I could still access this information to create an estimate.

Tweaking the Algorithm

With this in mind, I started using a state-of-the-art TI-68 calculator that could be programmed, much like a modern-day computer. It allowed one to create semi-complex equations like Alpha = B + C. Beta = D + E. Gamma = alpha + beta.

I spent time getting my algorithm programmed into this calculator, and then exercised it with example inputs from my past (and present) layout experiences. In the process, I also refined the algorithm based on the results I was getting. I was tweaking it for the two extremes, like the extremely complex layout that actually would take more than "two weeks," and the extremely simple design that should only take a couple days. This is where many spreadsheet estimators fall short on accuracy.

After using my calculator for a while, the Internet began to take off, and people were creating websites. I realized it would be handy to have my estimation algorithms accessible from almost anywhere in the world where I had access to the Internet, so I revised it using html to create an interactive website. This was an awesome experience, and also showed me it was possible to programmatically set up my algorithm on a computer.

FIGURE 2. At the setup screen, options such as schematic size are input.

By this time, I was learning to program in C and also Visual Basic. It occurred to me the algorithm lent itself well to a Visual Basic program. I set about to create this application in a program that was "visual," and allowed the user to input the required variables to get a resulting estimate.

I was also tweaking the algorithm to take into account other things that go into an estimate, like project meetings, design reviews, parts research and creating a bill of materials (BoM).

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These impact a design. Another feature I added allowed for various types of designs (surface mount, through-hole or mixed technology), and whether the design was new, rework or a ReGen (or data recovery) in nature. These all affect the outcome of the estimate.

The generated estimate takes the following into account:

- Pattern creation (for that odd pattern or two that a good designer does not already have in a well-stocked library).
- Netlist import.
- Pattern placement.
- Manual routing.
- Gerber and drill file generation.
- Fabrication and assembly drawings based on a designer who uses templates to reduce time.
- Other post-processing files that take minutes but add to the total estimate.

The estimates generated assume manual routing of the PCB. It has been determined that even if an autorouter is used (and there are always exceptions to this), cleanup and finishing of the autorouted layout often take as long as a manually routed design, especially since the designer may execute three or four autoroute iterations until they get the desired results.

The calculations are meant for the designer who has their process under control. That is, they know the steps involved to create a layout with no surprises. But even if the engineer makes a change midway through layout, the estimate drops to an "hour-by-hour" estimate, until the new netlist has been imported and the layout is back to the point where it left off.

At this point, the balance of the estimate kicks in. This can be stipulated upfront. Engineers usually accept this as a valid condition, as they still have something to plug in their project planning software, which usually has a column for project slippage when estimating time.

One last feature I added allows the designer to increase the estimates by percentages from 10 to 50%. This feature is for those occasions when perhaps the designer is using a CAD system they are not completely familiar with; the odd design that is more complex than normal; or the designer is a novice.

Although I had been testing the results, once I completed programming, I needed independent verification of the quotes. I posted online in a CAD forum that I frequented, and received responses from several members. One individual used a spreadsheet and entered copious information on each part used in the design, which took many hours to get an estimate. I ran his information (number of pins, x and y dimensions) on my program. His response was that my program created an estimate in a few minutes that was comparable to his estimate that took him hours to generate. Another individual gave me input on a recently completed design they had kept time on. Their response was that my estimate was very near to the actual time it had taken to do the design.

While my program is not 100% accurate, I have found through years of using it that I can estimate layouts to within 10% of the actual time it takes to do a design. PCD&F

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Competitive Analysis of Parylene Coatings Based on Metrology

Do variations in surface roughness, contact angle, and crystallinity values affect environmental protection performance? by **SEAN CLANCY, PH.D.**

The quality and performance of four Parylene C coatings were compared. Two additional companies were approached, committed, and then declined to participate in the project.

From the providers that chose to participate, thickness targets of 2 and 7μm were requested, as well as a request to not use an adhesion promoter.

Coupons were provided as 4" and 8" silicon wafers, as well as 4" copper disks. The coatings were examined with the following types of metrology:

- Adhesion testing.
- Corrosion testing using salt fog and 10% nitric acid exposure.
- Surface roughness by AFM.
- Contact angle measurements.
- Crystallinity by x-ray diffraction.
- Tensile strength.
- Hardness and reduced modulus.

In this study, comparisons were difficult due to some of the providers not following proper instructions when depositing coatings on the samples. Examples included coating the wrong side of samples, coating at the wrong thickness, and the use of adhesion promoters. Even when sample runs had to be repeated, a few of the issues still occurred. The most egregious was Company C, with the results noted in each section.

Coating adhesion was evaluated on four silicon wafers using the cross-cut test method. The cross-cut test assesses the resistance of coatings to separation from substrates when a right-angle lattice pattern is cut into the coating, penetrating through to the substrate. After cutting, a brush pen is brushed over the lattice in a diagonal direction five times, or tape is placed over the cut and removed with Permacel tape. The final step in the method is evaluating the grid with an illuminated magnifier or microscope to determine how much of the coating has flaked from the edges of the lattice cuts. Depending on the amount of material remaining, the sample is rated on a scale from 0B to 5B, where 5B is the best result.[1]

TABLE 1 shows results of the testing, and **FIGURE 1** shows images of highlighted samples. Note that Company B samples used an adhesion promoter, which helped ensure a strong result. The reason behind the poor performance of the Company C and the Company A 9.3μm sample is unknown, but is likely some form of surface contamination introduced through the handling process.

Salt Fog Test Results

Salt fog testing followed a procedure from ASTM B117-07, where the chamber was raised to 35°C, and a salt fog, consisting of five parts by weight sodium chloride and 95 parts by weight water, was introduced into the chamber and permitted to contact the samples for 168 hr. (seven days).

FIGURE 2 shows an example of uncoated and Company D coated IPC-B-25A D coupons evaluated by Trace Laboratories

TABLE 1. Adhesion Testing Results for Parylene C Coated Samples.

SAMPLE	THICKNESS 1	ADHESION 1	THICKNESS 2	ADHESION 2
Company A	4.9μm	4B	9.3μm	2B
Company B*	2.0μm	4B	4.8μm	4B
Company C	1.6μm	0B		
Company D	1.7μm	4B	6.3μm	4B

*Used adhesion promoter

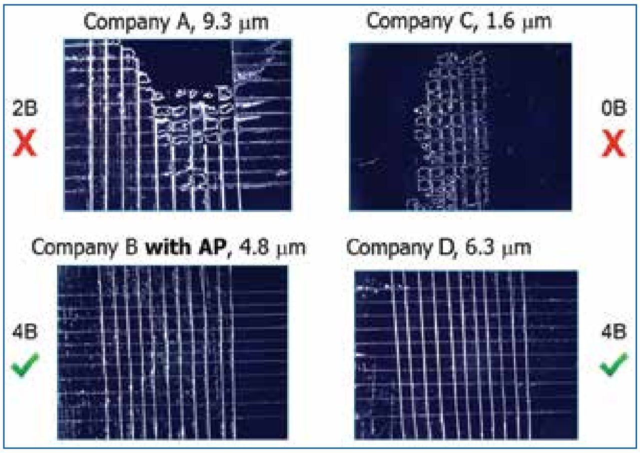

FIGURE 1. Images of the adhesion testing samples.

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in early 2014. The uncoated sample showed severe corrosion, while the Company D coated sample showed no corrosion and only minor discoloration. The discoloration was due to oxygen penetrating the coating and reacting with the copper to form copper oxide. The green corrosion products on the uncoated sample are copper chloride due to copper reacting with chloride from the salt fog.

FIGURE 3 shows the copper disks coated prior to being placed in the salt fog chamber. Scuff marks were observed near the center of the Company D 7.2µm film. Birefringence patterns were observed on both of the Company C samples. Halos or rings extending from the perimeter inward were observed on the Company A samples. Honeycomb-like patterns were observed on the Company B samples, suggesting the samples were coated upside down.

Birefringence is the double refraction of light in a transparent, molecularly ordered material, which is generated by orientation-dependent differences in refractive index.[2] These differences in refractive index for Parylene C films are affected by deposition temperature and, in turn, by degree of crystallization. The degree of crystallization in polymers describes the partial alignment of the polymer's molecular chains. Since the degree of crystallinity is affected by deposition temperature, as well as internal and external stresses, it is best to control the thermal history and stress states[3] of the films in future comparisons.

FIGURE 4 shows the same copper disks after 168 hr. in the salt fog chamber. The Company D 7.2µm sample showed some signs of corrosion where the scuff marks were observed previously, proving the scuff marks were indeed damage to the film. The Company D 2.1µm sample had very minor points of corrosion. The Company C 2-3µm sample had extensive patina corrosion product over the surface of the sample. The Company C 5-6µm sample had minor points of corrosion. Both Company A samples had extensive discoloration around the perimeter, where the halos were observed, as well as darkening of most of the disk. Both Company B samples had very minor points of corrosion, but the Company B 5-6µm sample had discoloration showing the honeycomb pattern, likely due to the sample being face down during the deposition process.

ImageJ[4] was used for image analysis on the Company C 2-3µm and the Company D 2.1µm samples for comparison and quantification of corrosion protection performance. The Analyze Particles function was used with the results summarized in **TABLE 2**. The Company C sample had more than 10 times the particles, and those particles occupied just over six times the amount of area when compared to the Company D sample.

FIGURE 5 (Ed.: the remaining figures are in the online version) shows another set of Company D coated copper disks that were exposed to 264 hr. (11 days) of salt fog with no evidence of corrosion. Again, the discoloration was due to oxygen penetrating the film, but moisture was blocked.

Nitric Acid Test Results

Additional coated copper disk samples that weren't exposed to salt fog were immersed in 10% nitric acid for 30 min. **FIGURE 6** shows a Company D 2.1µm sample with no evidence of corrosion. **FIGURE 7** shows a Company C 2-3µm sample that has marks resembling scratches all across the surface of the disk. Note that while the Company C sample was immersed, bubbles were observed on this sample, indicating that nitric acid was reacting with exposed copper.

Surface Roughness Test Results

Surface roughness was determined for the samples using atomic force microscopy (AFM) in the Micron Microscopy Suite at the University of Utah. Measurements were captured over 1 x 1 and 10 x 10µm areas on all of the samples, with measurements repeated for an additional two Company D coated samples over a 10 x 10µm area. Data for these measurements are shown in **TABLE 3** (online).

The general consensus from these data is the Company D coated samples had higher surface roughness, which is likely due to the faster deposition rate. The higher surface roughness though has not affected the performance of the Company D coating in terms of corrosion protection.

The high surface roughness may actually have other benefits in the area of LED encapsulation. In an article by Fujia Zhang *et al.*,[5] surface roughness was affected by deposition rate with 2 µm/h resulting in 15nm valley to peak and 5.6µm/h resulting in 50nm valley to peak. The surface roughness affected LED output performance parameters. In the same article, they note that the light output from a surface with nano-rough morphology is enhanced by reducing the total reflection effect, enhanced light extraction from the silicone encapsulation of LEDs with an island-like morphology surface. In addition, by examining the radiation patterns, LEDs show stronger light extraction with a wider view[ing] angle. These results offer promising potential to enhance light output powers of commercial light-emitting devices by using parylene C layer under suitable island-like morphology nano-rough surface.

Zhang *et al.* also stated that higher rates of deposition lead to poorer quality films, but that hasn't been seen by the authors. Company D's roughest film though was 23.5nm valley to peak, which was less than half of the 50nm valley to peak observed by the investigators.

Contact Angle

Contact angles for coated samples were measured using a Ramé-Hart Instrument Company Model 190 Contact Angle Goniometer and distilled water. A contact angle is formed between the solid/liquid interface and the liquid/vapor interface produced from a drop of a liquid on a solid.

A drop with a contact angle over 90° is hydrophobic. This condition is exemplified by poor wetting and adhesiveness, and the solid surface free energy is low. A drop with a small contact angle is hydrophilic. This condition reflects better wetting, better adhesiveness, and higher surface energy.[6]

In general, as roughness of a surface increases, the contact angle in a Wenzel state will generally increase on hydrophobic surfaces and decrease on hydrophilic surfaces.[7] In a Wenzel state, the liquid from a drop fills the voids below the liquid and thus occupies more surface area. In a Cassie (a.k.a. Cassie-Baxter) state, the drop rests upon the asperities with gas left in the voids below the drop. The surface area is less than it would be for a drop of the same volume and apparent contact angle on a flat or rough surface in a Wenzel state.[8] **FIGURE 8** shows the difference between Cassie and Wenzel states.

The contact angle data for the Parylene C coated samples, as well as comparisons to alumina and native oxide on silicon, are shown in **TABLE 4** (online). All the Parylene C coated samples were hydrophobic, with the Company D samples having the lowest contact angle within the set.

Based on the information above regarding increased roughness, as well as the surface roughness data, the Company D sample would have been expected to increase contact angle. The suspected reason for the decreased contact angle was increased oxygen content at the surface of the Company D coating from process termination by venting to atmosphere, where oxygen terminates free radicals of the Parylene polymer chain and leaves an oxygenated functional group, such as hydroxyl (-OH), that decreases contact angle, increases hydrophilicity, and decreases hydrophobicity. More details on this subject will be provided in a future article.

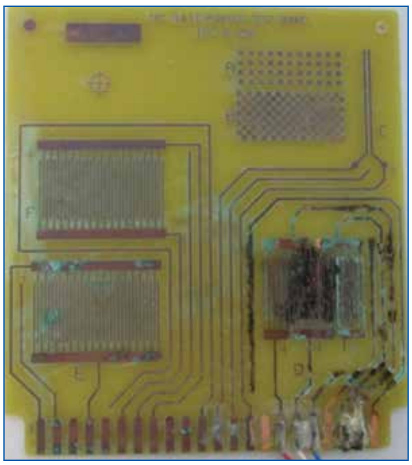

FIGURE 2. Images of uncoated control vs. Company D coated board exposed to salt fog testing at 35°C, 5 wt. % NaCl, for 168 hr. at Trace Laboratories in 2014.

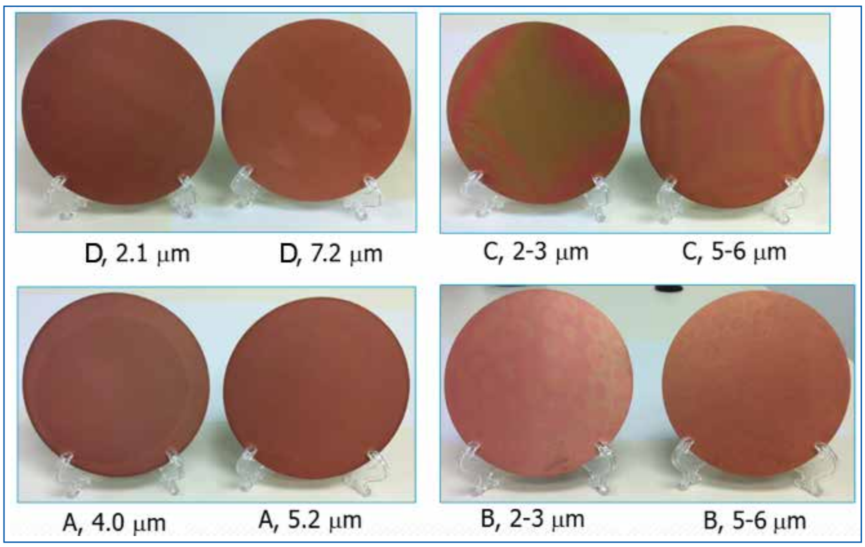

FIGURE 3. Images of the coated copper disks prior to being placed in the salt fog chamber.

Crystallinity by XRD

Evans Analytical Group performed x-ray diffraction (XRD) to determine the percent crystallinity of the coatings on silicon wafers. Wafers were mounted directly onto the diffractometer with clips. XRD data were acquired by grazing incidence XRD (GIXRD) on a PANalytical X'Pert Pro MRD diffractometer equipped with a copper x-ray tube and parallel-beam optics. The incidence angle was fixed at 0.3°.

FIGURE 9 compares the data from all four samples. Superimposed on the patterns is the ICDD/ICSD (International Center for Diffraction Data/ Inorganic Crystal Structure Database) diffraction reference pattern for polycrystalline silicon. There is almost no difference in these samples.

TABLE 5 (online) provides the percent crystallinity of each of the four Parylene C coating samples. D was found to be 40% crystalline, the lowest of the four, which was likely a characteristic of the deposition process. Again, since D's rate of deposition is considerably faster than other known Parylene providers, the polymer isn't afforded time to organize and align, becoming less amorphous and more crystalline.

Mechanical Properties

Tensile strength. The tensile strength of a material is the maximum amount of tensile stress that it can take before failure, for example, breaking. Tensile stress (or tension) is the stress state leading to expansion, and induced by pulling forces in a uniaxial manner.

Samples from Company C couldn't be tested for tensile strength, since they were deposited either too thin or with an adhesion promoter. Therefore, the films were unable to be removed from their respective silicon wafers.

The tensile strength of the samples from Company A, B and D were determined by the University of Utah using a uniaxial tensile test at room temperature, and the data are shown in **FIGURE 10**. Five samples from each coating provider were tested, and both Company A and D were within the same range, while the samples from Company B were about 20% lower.

Hardness and reduced modulus. During a nanoindentation test, the nanoindentation probe is driven into a sample and then withdrawn by decreasing the applied force. The applied load and depth of penetration into the sample are continuously monitored. A load vs. displacement curve can be generated from the data, and from that data sample hardness [H] and reduced modulus [E_r] can then be calculated.[10] **FIGURE 11** shows graphical examples of force-displacement curves generated with nanoindentation with the types of parameters that can be obtained with the data.

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. The reduced

modulus accounts for the elastic displacement in both the specimen and indenter.[11]

Hysitron provided hardness and reduced modulus data for the films using a TI 950 TriboIndenter with Diamond Berkovich and 5µm Conical Probe with two main test methods: quasi-static nanoindentation and frequency sweep test.

The quasi-static nanoindentation testing procedure consisted of:

- A partial-unloading load test with a peak force of 1000µN and a single test consisting of 20 cycles of loading, holding, and unloading segments.
- A quasi-static test with a peak force of 150µN for Samples 2, 3, and 4 and 25µN for Sample 1 and a single test consisting of 5 sec. loading, 2 sec. holding, and 5 sec. unloading segments.

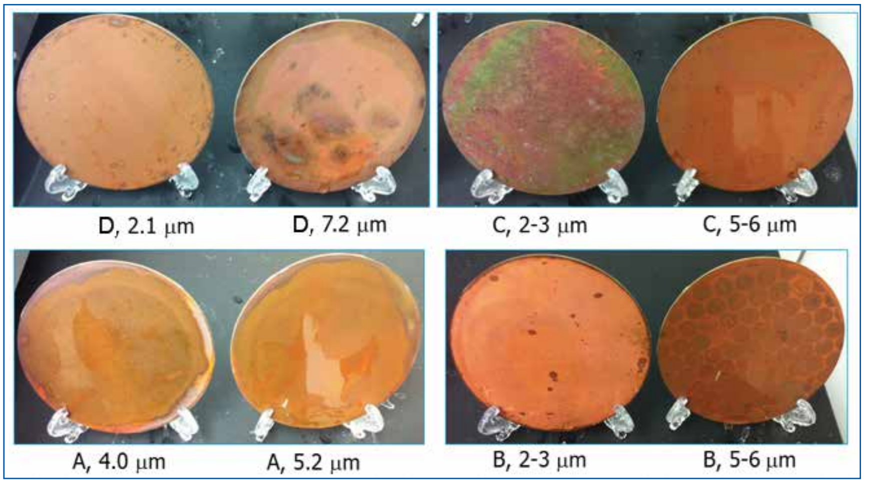

FIGURE 4. Images of the coated copper disks after being exposed to salt fog for 168 hours.

FIGURE 12 shows the reduced modulus and hardness of the samples at different contact depths. The Company C sample didn't correspond with the other samples because of substrate effects, since the coating was thin, due to the sample being coated on the opposite side than intended. The other three samples: Company A, B and D had similar results, indicating the mechanical properties were due more to the type of material than the coating provider.

FIGURE 13 shows the average hardness, reduced modulus, and the contact depth of the samples obtained from the quasi-static indentation tests. Again, the Company C sample deviates from the rest due to substrate effects from the sample being too thin. The error bars represent one standard deviation. Sample 1 appears to have higher reduced modulus and hardness, which is likely a result of the substrate effect. The samples are the same as in Figure 12.

Process control. Some of the providers didn't follow the proper instructions when depositing the coatings on the samples, which made comparisons difficult. The issues encountered included coating the wrong side of samples, coating at the wrong thickness, the use of adhesion promoters, and even when sample runs had to be repeated, a few of the issues still occurred.

Conclusions

In the salt fog test, the coatings performed well when deposited as requested and without physical damage. In the nitric acid test, the coatings performed well when deposited well. Surface roughness, contact angle, and crystallinity values for Company D's coating were different from the others, but didn't affect environmental protection performance. In mechanical testing, tensile strength, hardness, and reduced modulus, all the coatings, when deposited to an appropriate thickness, had similar results. **CA**

Ed.: Company D sample was developed by HZO.

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ELECTRONICS 2020: What Will the Industry Look Like?

We asked a number of leading electronics experts for their vision of how the design and manufacturing landscape will change. by MIKE BUETOW

Robots, DNA-based circuits, 3D printers, supply chain migration: These are just some of the challenges – and opportunities – the electronics industry is facing today. What's feasible, and what's not?

In search of what the industry thinks might happen, we asked several leading engineers and executives over the past month to share their vision. In some instances we put a deadline on the transition; in others, the question was open-ended.

We spoke with designers, fabricators, assemblers, and suppliers. Those interviewed ranged from primarily regional players to some of the biggest companies in the industry today. Input came from veterans of startups and blue chip OEMs, some who spent a lifetime in electronics, and some who only recently joined the industry. What was stressed to our esteemed panel was not so much a specific response (i.e., yes or no) but rather the reasoning behind their answers. We hope you enjoy their thoughts.

1. Will robots run SMT lines?

Phil Marcoux, founder PPM Associates; known as the "Father of SMT": Not for the vast majority of SMT lines. The cost of programming robots, as well as some of the normal SMT equipment, often exceeds the cost of manual control, especially when the builds are low to medium volume and for products that experience numerous revisions. The lines that justify a higher level of automated/robotic control are those where human error and human presence would cause potential yield loss and reliability issues. Examples of such products would be medical products and others requiring the most stringent of ESD and clean room control.

Markus Wilkens, president, ASYS Group Americas: Absolutely yes. Pick-and-place is already doing all but hand assembly. Now there's solder robots. Automotive plants have artificial intelligence. Do you trust an operator to make the decisions? The next step is, do you allow a lower qualified employee to make the decision on what needs to go next?

Cameron Shearon, lead quality engineer SCM, AT&T: Because most errors are caused by humans, and robotic technology is quickly evolving, becoming more flexible and getting less expensive, I think it is inevitable that robots will become much more pervasive in running SMT lines. Wafer fabs, automotive, and some assembly lines already have a high utilization of automation. However, I don't think robots will be running SMT lines in the next 10 years or so.

Michael Ford, marketing development manager, Mentor Graphics and former GM, Sony Europe: The challenge is putting the material on the machine. So it's looking at a new way to put materials on them. Standardization to link automated guided vehicles. Will it actually happen? I don't know, but it's not impossible.

The alternative is to make feeders more intelligent where they pick the materials and talk directly to the planning system. That's possible. If you think feeders and reels can be replaced with an alternative system … you could do that now.

If you had a mechanical changeover, you could go from a sequential to a parallel approach. That could be very interesting. Machines could change over on the fly, intelligently.

ATTACK OF THE ROBOTS. Could machines such as Rethink Robotics' Baxter replace humans en masse on SMT lines? (Courtesy Jabil)

2. Will solder be eliminated?

Mick Austin, sales director, Vitronics Soltec: For some applications, like low power or wearables, I think it could. What's more likely is a whole new wave of products might come along that are solderless from the start.

Karl Seelig, vice president, technology, AIM Solder; inventor: Eventually. I've been in the business since 1976. When I came in, silver epoxy was the future. Today it has less than 10% of the market because of inherent problems. Until components are embedded in boards, I doubt in my lifetime. I could see direct bonding to circuitry.

3. What's more likely: completely custom boards or 100% reference designs?

Carl Schattke, PCB design engineer, Tesla Motors: I think we will still see both board types in 2020, but would lean toward a far greater use of custom board solutions. We could also see a scenario where the Arduino model (Lego style circuits) incorporates a far greater catalog of system sub-components for various conceptual embedded systems projects. Increased cooperation is the wave of the future, and the companies that learn to do this will speed up development and leapfrog many of the leading companies today.

Gary Ferrari, director – technical support, FTG Circuits; former executive director, IPC Designers Council: Reference designs are just what they are called: reference and/or recommendations. They tend to be placed on boards along with customized, application-specific support circuitry/designs. So, my answer would be custom boards that include the use of one or more reference designs.

Rob Rowland, engineering manager, Axiom: It depends on the market segment. My company builds primarily military [electronics], and it's all custom. Military and medical are still custom.

4. By 2020, will optoelectronics be mainstream?

Gary Ferrari: Optoelectronics has been a long time coming. Drawbacks include technical fabrication difficulties that limit its general use. Current high-speed technology is just about tapped out. I believe that a major push to overcome current optoelectronics fabrication difficulties from entering the mainstream is on the horizon. By 2020, we should see more use in mainstream high-tech electronics. Optoelectronics in low-end electronics may be cost-prohibitive, and may never make it, at least not by 2020. As an example, embedded active devices have been around in Japan for the past five years or so, yet haven't taken off in North America. It will probably take another five years to migrate. Optoelectronics has been around even longer and not really taken hold.

Jim Hall, SMT process consultant and former machine designer: I would say so. The advantages of speed and processing, and the technology is maturing enough with 3D structures being more acceptable.

Jack Fisher, facilitator, HDP User Group: Optoelectronics will appear on some products by 2020, but only in selected

markets. Telecom backplanes, definitely. High-end servers, possibly. The waveguides may or may not be embedded. On a backplane with lots of room, waveguides on flex are a very real possibility. Communication between the backplane and switch cards can be flex or optical cable.

5. Will hobbyists overwhelm the traditional design/fabrication/assembly/distribution model?

Rob Rowland: Probably not, but they will have more and more of an impact. The president of our company falls into that category: He always brings in products he's created with COTS stuff. We will see more of that. Of course, what will we do if Radio Shack doesn't survive?

Duane Benson, marketing manager, Screaming Circuits: I don't see that hobbyists and DYIers will overwhelm or replace the traditional model. What I see is many more options added into the mix, and barriers to entry dropping for low-volume, high-margin businesses. It will, for the foreseeable future, be considerably less expensive to mass produce products using traditional means than it will be using personal manufacturing. However, an almost unimaginable number of low-demand or customized products will be possible. The consumer goods business will be split wide open in markets where the buyers have enough money to buy things that may seem pretty silly today, such as custom electronic coffee mugs.

Terry Heilman, president and CEO, Sunstone Circuits: No. While the hobbyist market is growing, so are the DIY tools and community collectives to support these markets to make what they need without the classic distribution sources. That phenomenon should keep a large enough percentage of them out of the traditional manufacturing distribution model.

6. Will ODMs supplant OEMs?

Phil Marcoux: No. ODM partnerships are attractive for companies (usually large OEMs), where they can outsource the more routine product designs to a company, which will perform the design as well as the build to print services for less than what the customer would pay if designed and manufactured internally. However, the forces of rapid time-to-market and control of company IP dictate that any company that wants to continue to provide leading-edge and innovative products continues to control and administer much of its research, development, and design activities.

Charlie Barnhart, analyst, founder Charlie Barnhart & Associates: Not completely, but very likely at both the bottom and top of the tech curve.

Brian D'Amico, president Mirtec USA: Maybe 20%. There are so many types of products that are made. I would think maybe on some level, but it would be very specialized.

Susan Mucha, president, Powell-Mucha Consulting: ODMs tend to drive technology in specific sectors, most often where technology is considered a commodity, and the "user experience" or capabilities of the supporting infrastructure are considered the market differentiator. Often the technology "advances" are closely tied to requirements driven by the OEM-defined user experience strategy or related to the service selling strategy infrastructure "owners" want to exploit. I think in areas where technology continues to be the market differentiator, OEMs will be the developers of new technology.

IS 3D PRINTING THE FUTURE? Prices are coming down and capability is rising on printers like this one from Makerbot.

7. Is the number of manufacturers worldwide *more likely* to halve or double by 2020?

Gene Weiner, consultant and board member, WKK: The number of manufacturers is more likely to double by 2020. The reason is that even though there is consolidation in maturing industries, there are many new opportunities arising from the needs of newly emerging technologies, such as wearable electronics, the expansion of touch and near touch sensors and controls for communications and automotive electronics, printed electronics, the expansion of automotive applications and controls, IoT, IoM, the privatization of space activities, advances in 3D printing, and more visions of future products not yet even in sight. Most innovations usually come initially from smaller ventures or startups.

Randall Sherman, analyst and president, New Venture Research: The number of manufacturers (EMS, I presume) is likely to halve. This is already happening. [My research shows the] trend is definitely toward consolidation. The weak are fading away or getting acquired, and the strong are securing or further establishing their markets. Acquisitions are either purchasing supplier capability or customers. There is no way the population will double or even grow.

Susan Mucha: I think the number will shrink. I could see segments such as Tier One EMS shrinking broadly through consolidation driven by competition, but I don't think that pattern will happen as dramatically in the lower tiers. If anything, I'm seeing a growth in sales in the lower tiers as OEMs show a preference for regionalization (putting the manufacturer closer to product development or a specific facility).

Duane Benson: Both will happen. Traditional manufacturers will be hit with consolidation and attrition losses. However, a new class of manufacturing is already in an emergent phase. These manufacturers, like Screaming Circuits, have a transactional relationship with customers, more like selling an e-commerce product than like a traditional manufacturing

ALL IN THE SOFTWARE? Will remote firmware upgrades mean IoT devices improve on the fly?

partnership. Further, this transactional model, when combined with easier-to-use, more self-contained machinery, will allow very small manufacturing businesses to be profitable. Boutique manufacturing will be viable and common.

Todd Scheerer, executive vice president, Zestron: I'd lean toward double. Electronics are becoming more a part of what everyone does every day. The number of applications in, say, automotive, is so much more now than 10 years ago.

8. Will plated through-holes be eliminated?

Terry Heilman: They will not be eliminated in the next five years. They may be down fairly significantly for new designs, but, like leaded solder, it is a tried-and-true technology that will be difficult to eliminate from the vernacular of the design engineer. Yes, there could be new technologies in the future, but nothing replacing plated through-holes anytime soon.

Andy Cameron, field application engineering manager, TTM Technologies: Fully additive (3D printing) PCB manufacturing allows for eliminating through-hole interconnects if desired (all surface mount, no press-fits, for example), but it goes well beyond that in terms of completely altering what is possible compared to subtractive manufacturing used today.

Jack Fisher: I don't think PTHs will be eliminated. There does seem to be a need for fewer PTHs, but they are not going away.

Jim Hall: No. We have to have places to solder connectors. We have to have the mechanical interface where high stresses occur. Plus the momentum of highly embedded processes; you'll find some way to use it somehow. Many economic models depend on it.

Carl Schattke: I do not think PTHs will be eliminated. What could replace them? Conductive adhesives? 3D printed wiring?

9. Will 3D printing be mainstream by 2020?

Raj Kumar, vice president technology & engineering, Specialty Products Business Unit, TTM Technologies: Unlikely. The current and very limited 3D printing technology for PCBs is not to the caliber necessary with regard to interconnects, line/space, multilayer capability, long-term reliability, survivability through multiple lead-free assembly reflow cycles, high-speed signal transmission, power carrying capability, etc., but it is evolving rapidly, particularly with the material science portion.

10. Will we more likely be disrupted by a company in our industry, or outside it?

Brian D'Amico: Inside. Most of the products we make are for companies that use them, so that would have the most drastic change for someone like us. Changes in equipment will be disrupted by new electronic end-products.

Michael Ford: I'd like it to be a new plan because there's lots of resistance to change. Someone who comes in and addresses the market the way the market needs – e.g., direct shipping from a flexible factory to a customer. Then they could do it like the old days, build close to where it's used.

Cameron Shearon: Given that someone can have an idea but not have the financial resources to set up a manufacturing line, it is equally likely that disruptions can occur from in our industry or outside it. Another example over the longer term is 3D printing – the price is coming down, the precision is increasing, and more materials are being utilized. Some organizations are even trying to develop 3D printers to make ICs. Instead of shipping to a particular market, they could build just for that market by simply printing it out. In addition, through the First Self-Replicating Synthetic Bacterial Cell project, the J. Craig Venter Institute developed a way to digitize and print DNA. Uses of this technology are to print vaccines in locations where they are needed rather than shipping them over long distances, while trying to maintain tight climate controls. If life were found in one location, it could be mapped and transmitted to another location to be studied. This is the first I have seen a blending of electronics and the biological/drug industry. It will be interesting to see if or how that continues to play out.

Gene Weiner: No one innovation from outside the industry will disrupt the entire industry. An "outsider" such as Tesla will accelerate changes to the use of standby battery power and electric cars but not "disrupt" an industry segment. I do not believe a company totally outside our industry will disrupt the electronics industry.

Todd Scheerer: It's common in a lot of industries to get blinders on. Everyone is doing incremental innovation. It's hard to step out and do game-changing innovation. It's more likely someone will take something that worked in another industry and apply it [to electronics]. Most industries tend to be disrupted from the outside.

Markus Wilkens: Definitely outside. Inside, you have blinders. You can get so focused on what you do, even in R&D. Why are we still etching boards? We should be printing boards. It's mind-boggling what these companies [outside electronics] are doing with printing ferrous materials. The really new always comes from the outside. **CA**

MIKE BUETOW is editor in chief of PCD&F/Circuits Assembly; mbuetow@upmediagroup.com.

Lean Systems Strategy for Low-Cost Countries

Linking facility systems to a standard corporate platform reduces inventory, improves response time to demand changes and enhances internal communication.

PETER SOGNEFEST is general manager and director of operations, Vietnam at SigmaTron International (sigmatronintl.com); peter.sognefest@sigmatronintl.com.

THERE WAS A time when the tradeoff that came with a low labor rate was less flexibility, less technical expertise and less automation. The theory was that since labor was often the biggest cost savings, investments in capital equipment and systems should be minimized. However, that premise is becoming an old school thought in a world where the costs of inflexibility, excess inventory and poor quality quickly trump any savings achievable by accessing low-cost labor markets. That said, what levels of automation and systems visibility make sense in low-cost markets?

SigmaTron applied Lean manufacturing principals to enhance the systems capabilities of its facility in Biên Hòa, Dong Nai province, Vietnam. Our systems strategy is focused on four key areas, detailed below. A mix of standardized system platforms are combined with a suite of internally developed software to support areas the core off-the-shelf systems don't handle as well. Systems cost is easily offset by reductions in engineering labor, excess inventory and cycle times.

1. Minimizing nonrecurring engineering (NRE) activities. The facility is in the process of migrating to a paperless factory. This reduces the potential for manually induced errors in documentation transfer and programming, plus the overall time required for new product introduction (NPI) activities. Manual entry of documentation has been eliminated for both materials and manufacturing engineering-related activities. Bills of material (BoMs) are loaded into a Macola ES ERP system to drive materials acquisition. All documentation is also released into an Agile product lifecycle management system, which automates data transfer and creation of manufacturing documentation.

2. Eliminating defect opportunities. Design for manufacturability (DfM) analysis is performed at the start of every project using Valor tools. The documentation review process uses a Valor parts library to verify all BoM component footprints against land patterns used in the layout. This helps eliminate both the opportunity for defects caused by manufacturability issues and the non-value-added time spent reprogramming machines or respinning the board layout if component packaging specified in BoM doesn't match the land patterns used in the layout.

Test and inspection strategy includes AOI and electrical and functional testing. Functional test systems include a machine vision test that verifies products with LED control panels have adequate light levels and colors.

Systems strategy is also applied here, as internally developed MES software called Tango is used to integrate shop floor control, quality data collection and traceability activities. All material is barcoded at incoming inspection, and kitting priorities are set based on demand trends. Products are tracked through all production processes associated with that work order. Placement and insertion equipment self-checks any feeders based on the work order. If a production process set is missed, operators cannot scan the barcode until the missing step is completed. Additionally, it tracks the actual operators associated with each production step, the revision level of any software loaded in the unit and the number of units completed.

At the end of the process, a Customer Advocacy Audit (CAA) is performed via a sample plan and inspection strategy designed to ensure at a 99.9% confidence level no defects are present. If the sample fails inspection, the entire shipment is inspected. While there is a cost associated with both sampling and any required inspections, it is far less than the cost incurred if the shipment was rejected at the customer.

From a defect prevention standpoint, the lockout mechanism makes it impossible to skip production steps or load incorrect components into placement equipment. From a traceability standpoint, the system maintains a device history record which includes components used, production processes completed, operators associated with assembly activities and test results. This level of data supports quick resolution of any quality issues that could potentially develop.

3. Shared systems for maximized visibility. While functionally specific suites of software are helpful in eliminating non-value-added activity or *muda*, having a system capable of linking this information across the internal staff, supply chain and customers is critical to reaping maximum benefits from a strong systems strategy. SigmaTron uses an industry standard ERP system enhanced with an internally developed tool suite across all facilities, accessible by suppliers via an iScore interface. Through this tool suite, the Vietnam facility and the IPO have visibility into forecasted demand, actual demand, inventory in each facility and inventory on order. Materials systems are linked globally to provide company-wide visibility into inventory levels and materials status. Data from Tango are also linked to the ERP system through iScore, but not available yet externally through Score. Customers can access Score 24/7 via the

FIGURE 1. A robust inspection and test strategy, which includes AOI, is used to ensure any quality issues are identified as early in the production process as possible.

internet for project status visibility, and program management uses iScore to stay abreast of key project metrics.

This system strategy also provides country-specific benefits. Under Vietnam customs regulations, manufacturers must be able to provide proof that incoming material is appropriately consumed in the manufacturing process and shipped out, to minimize the potential for black market material sales to the local market. The material tracking data stored by Tango are used to document material import, transformation and shipment for customs purposes, which eliminates the need for manual tracking.

Similarly, iScore and the ERP system support program management activities by making easy-to-run "what if" analyses when demand trends are changing or an engineering change order needs to be implemented. These types of "what if" analyses reduce the time to gather the necessary information on available inventory, cost and lead-time from days to fewer than 24 hr.

4. Maximizing economies of scale. Centers of expertise for engineering and procurement share these resources throughout the company. While every facility has an engineering staff, DfM is performed by an engineering team located at the company's Suzhou facility, and test engineering development is supported by a test

FIGURE 2. An operator barcodes a product prior to packaging for shipment. The shop floor control system will not permit the barcode to log in if all prior steps are not complete.

engineer at our subsidiary Spitfire Controls' design facility in Elgin, IL. Similarly, while there is a local purchasing team within the Vietnam facility, the bulk of purchasing is handled through the company's International Purchasing Office (IPO) in Taiwan. The IPO and distribution partners in each region act as

continued on pg. 43

Down the Drain

Starved solder joints? Here's how to compensate.

ROY AKBER is chief executive office of Rush PCB, a printed circuit design, fabrication and assembly company (rushpcb.com); roy@rushpcb.com.

FIGURE 1 SHOWS a close-up photo of a PCB assembly. It seems as though solder has flowed "down the drain" and away from the solder joint where it's needed.

In fact it has, because the customer inconveniently located a via right through the center of one of the two topside SMT pads for a surface mount component. When the assembled PCB is run through reflow, the molten solder drains away through the barrel of the via and out the other side of the PCB. There isn't enough solder remaining post-reflow to create an acceptable solder joint per IPC-A-610. The joint is "starved"; this is unacceptable. What to do?

The via is there to stay by virtue of the customer design. So, no matter how many times solder is added to the joint, every time the PCB is run through the reflow oven, the solder will drain away because the PCB, including the via, is at reflow temperature.

Obviously, more than one run through the oven makes no sense. The only practical solution is to manually add solder to the individual solder joint, post-reflow, without running the entire PCB through another thermal cycle. It's a touchup procedure that's required to create a robust SMT solder joint that meets acceptability criteria. This is a manual PCB assembly soldering process that should be performed by a skilled hand-soldering or rework operator. Solder is added only to the joint, via cored wire solder or solid wire with flux, in order to build up the volume of solder at the solder joint to provide strength, connectivity, and an acceptable meniscus per IPC standards, covering the via drain-hole. The solder won't flow through the via because only the surface joint area is heated.

It may seem tedious, but a skilled operator can touch up the joint in a few seconds, and if there is only one instance per assembly, it won't appreciably delay production. CA

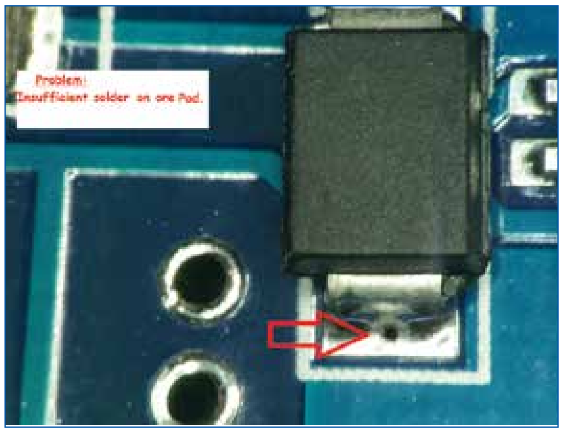

FIGURE 1. Insufficient solder, i.e., "starved" solder joint on an SMD pad.

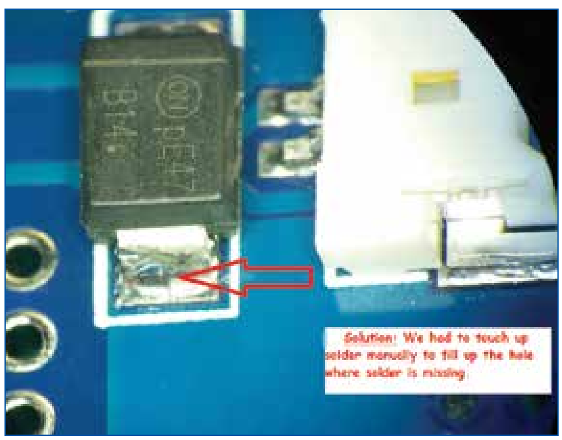

FIGURE 2. The solution: Add solder to the joint manually via a touchup procedure.

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Ms. May Chen / Ms. Kathy He
Tel : (86-20) 133-6057-7973
E-mail : may.chen@baobab-tree-event.com / kathy.he@baobab-tree-event.com

2015 HKPCA & IPC Show

Organizers

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IPC Association Connecting Electronics Industries

CCPIT

Supporting Organizations

SZETITC

SZCEA

Event Manager

BAOBAB TREE 柏堡

'Fixed' to Be Tied

Navigating the Big Corporation supplier partner program is a test in itself.

WELCOME TO THE *supply chain portal of Big Behemoth Aerospace Technologies (BBAT). The fact that you have gained access to this portal means you are vetted as not posing a credible threat and, therefore, considered a worthy and valued supplier partner to BBAT. It also means you have acknowledged and accepted BBAT's corporate-mandated net 180 payment terms, without which you would have been expelled and permanently denied access to this portal, with no follow-up right of appeal. With willing and compliant partners like you, BBAT can be successful in its ongoing mission of supporting the US defense and worldwide aerospace community. After all, it is partnerships like ours that built this country and continue to keep it strong and vigilant against all enemies, both foreign and domestic. Be proud as we are proud.*

They wanted a test fixture. One simple ICT fixture and accompanying program. They approached us in July 2013. Unhappy with their current supply chain. Wonder why. Locked into 30-year-old technology, not to mention 60-year-old mindsets. We dutifully quoted it, expecting nothing, which for a while is exactly what we got. (Blessed is the one who expects nothing, for they shall never be disappointed.) We waited over a year. Fourteen months to be exact. Not a word. Suddenly, out of the blue, an electronic notification appears. No prior warning. An order is pending. Of course they want it next month. Your country needs you, Prospective Supplier Partner, so snap to it!

First we have to navigate the damn portal to retrieve the purchase order and set ourselves up as a vendor, the latter before the former. For a $5,000 order.

But first a few preliminaries.

As a valued supplier partner to BBAT, and to familiarize your company with BBAT's business practices, you are invited to participate in a supply chain portal training session, to be held in the following high-technology centers in the coming weeks: Waco, Texas; Harrisburg, Pennsylvania; Tallahassee, Florida; Duluth, Minnesota; Rapid City, South Dakota; and Bannockburn, Illinois. Cost to participate is $250, plus travel expenses. All costs will be borne by the supplier partner and are not the responsibility of BBAT. Additionally, please be advised participation in BBAT supply chain portal proficiency training (SCHAPPOT) comes with no assurance of award of future BBAT business. Please be further advised BBAT updates its portal at a minimum annually. Updates require mandatory SCHAPPOT on the part of the entire registered BBAT supply base.

Can't justify the training for one order. Gonna try to do this intuitively. Figure it out on our own. Improvise if necessary. Additional gray hairs a small price to pay for avoiding a trip to one of those garden spots. First circle of hell. Where greed overcomes common sense. Why are we doing this?

Greetings! You have been assigned a temporary login name and password. Please access the portal to retrieve your temporary credentials, following which you may change your password and login.

Sigh. Here goes. Deep breath.

You neglected to acknowledge and agree to BBAT's standard 180-day payment terms. Please acknowledge payment terms in order to proceed with retrieving temporary login and password.

Suck it up and press the "acknowledge and agree" button. Hopefully we can talk some sense into them later. Try the "Big Business depends on small business, and small business depends on other small businesses" argument. Not exactly heartstrings, but it's logical as arguments go. Worst case, we can put the project on ship hold when ready and play some good old American hardball. Where do they think the real innovation and business initiative in this country comes from anyway? 180 days? Do they ever stop to consider that *our* suppliers and employees can't possibly wait 180 days? Don't they have bright young MBAs who can explain cash flow?

Congratulations! You have successfully accessed the BBAT Supplier Portal. You may now change your password to a robust combination of alphanumeric characters. Robustness is ultimately judged by BBAT, but password should consist, at a minimum, of six letters (at least one of them upper- and one of them lower-case), six numbers, and six characters, such as $, %, or !. There are no length restrictions to passwords.

Fair enough. How about this:
Ih8tEp@$$w0000RD$!1!!!!

Thank you. Your (highly robust) password has been accepted by the BBAT Supplier Portal.

Another hurdle:

You are required to maintain current registration in our system, by means of our portal, on an annual basis. This requirement shall remain in force irrespective of whether you receive actual orders from BBAT during the calendar year or not. Responsible vendor parties shall be electronically reminded of re-registration and update requirements 30 calendar days prior to end of calendar year. Failure to provide timely updates shall be grounds for automatic disqualification and ineligibility to receive future orders, with no right of further appeal.

What? Is BBAT prepared to pay all or part of the salary of our person designated to maintain these records? (The question was rhetorical. Most definitely not. It's a

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

cost of doing business, bub, and we at BBAT enforce the rule because we can. We don't need any other reason. It's good to be big.) I suppose we are expected once again to absorb the hassle and consider doing business with them an honor and a privilege while we contribute to our nation's security. Regardless of cost, which is clearly no concern of theirs.

Yet another hurdle:

As an Approved Supplier and Vendor Partner to BBAT, you are required upon request to provide objective evidence of ongoing certification, maintenance, and internal and external audit of your company's quality management system (QMS). Evidence may take the form of QMS documents requested for review, such as quality manuals, written procedures, work instructions, training records, as well as preventive and corrective actions; third-party audit reports (e.g., AS9100C certification or surveillance audits); or customer audit reports. BBAT also reserves the right to conduct onsite inspections and QMS audits at the time and place of its choosing, given adequate notice. BBAT reserves the right to determine adequate notice. Failure to comply with these requirements shall be grounds for automatic disqualification as a BBAT supplier with no right of appeal.

Please complete the attached 47-page Vendor Qualification form prior to proceeding further in this portal. Upon completion, kindly attach current copies of all pertinent certifications, such as ISO 9001, DTSC (ITAR), AS9100, ISO 13485, and ISO 14001. Note carefully that all pages of the form must be completed and that ISO 9001 or AS9100 certification does not excuse this requirement. Provide as much case-specific evidence (as opposed to generic replies) to support your answers to these 535 questions as you are able.

Please provide a list of your company's 10 largest customers, with business concentration levels and areas of industry sector specialization. Also provide length of each business relationship, as well as detailed descriptions of any quality-related problems that have occurred in the past five years. Failure to disclose business relationships governed by nondisclosure agreements (NDAs) shall not be acceptable.

In addition, please sign the enclosed affidavit that states you will report any change in process, personnel, domicile, management, corporate entity, ownership, or customer base and customer concentration ratios to cognizant BBAT personnel immediately. Failure to report such changes shall be cause for immediate disqualification as a BBAT Supplier Partner.

Please also enclose a W-9 form and two years' audited financial statements. Additionally, please sign the attached NDA. It will be returned in due time once review of all documents is completed by BBAT Legal Department. Expected turnaround time for legal review is 3-6 months. Expect lengthier delays during summer months and major religious festivals.

Other than that, they're the very model of user-friendliness. Funny, all we want is to retrieve a lousy purchase order to build a test fixture. We should have quoted more money. Enough to fill a Nimitz-class aircraft carrier.

Good lord, it took hours to read this and complete these forms. And they still want this test fixture in one month. The clock is ticking.

You have been timed out of the BBAT Supplier Portal. Please log in and repeat the initiation process. For security reasons you will be asked to change your password.

*&)**&()8%M(&`5V)_)*(&FI4&!!!! (Editor's note: Not a password.)

Extra costs and cost overruns on individual projects, once quoted and reflected in a BBAT purchase order, shall be sole responsibility of the BBAT Supplier Partner and not BBAT. Revised quotations reflecting these changes are not acceptable and will not be approved and could lead to order cancellation.

Like costs of learning to navigate supplier portals?

Well, at least it's done and we're all set up. Won't have to do this again. Which is good because when we started we were single, and now we have grandchildren. All that's left to do is press "submit."

We regret to inform you that the BBAT supply chain portal is currently disabled and inaccessible due to quarterly maintenance. All prior data entered to the portal will not be saved. Please attempt access again when the supply chain portal is reactivated for service in fifteen working days. We apologize for any inconvenience, and thank you for your patience.

Before logging out, we kindly request that you go to the Comments Section of the BBAT Supplier Portal and offer any suggestion you have for improvement of service. Failure to fill out the Comments Section could result in supplier/partner disqualification.

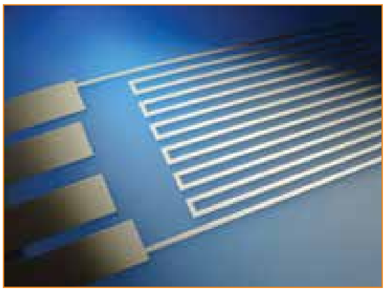
My helpful suggestion involves explosives.

Thank you for your concern and for being a valued Supplier Partner to BBAT. **CA**

Getting Lean, continued from pg. 39

"single" suppliers for most materials, increasing efficiency by consolidating orders. Program managers reside in the US to be in closer proximity to end-customers. Customer service representatives in Vietnam coordinate with US-based program managers. In addition to maximizing economies of scale, leveraging centers of expertise provides more flexibility in supporting tight deadlines or unusually heavy engineering workloads. It also improves customer service by placing resources in close time zone proximity to their counterparts at the customer. This standardized systems strategy ensures remote team members have the same tools and visibility into project requirements as the Vietnam facility team.

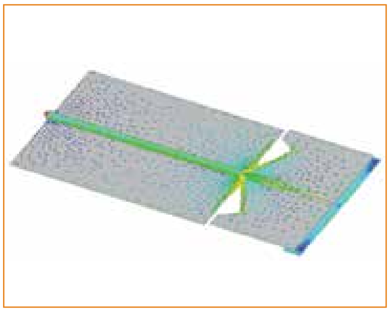
Vietnam offers a highly educated and dedicated workforce, and the systems strategy ensures employees receive real-time feedback on the quality of their efforts. The compensation program includes a quarterly pay-for-performance element that is eliminated if even one shipment is rejected anywhere in the world. The facility has had zero rejected shipments since its inception in 2005. On-time delivery is 100%, and there have been zero late shipments since 2005. The bar is set high because rejected product not only creates potential inventory shortages at the customer. It also represents wasted logistics cost and wasted time expended in transit and repair. The facility's inventory turns are averaging slightly over seven turns annually. **CA**



LOW-TEMP CURING INKS

PE827 and PE828 electronic inks cure at as low as 60°C. Potential applications include printed antennas, sensor applications, heated surfaces and smart packaging applications. Viable substrate options for printed electronics include PVC, polystyrene, high-density polyethylene, and acrylic polymers.

DuPont
dupont.com



CONDUCTOR MODELING

Studio Suite 2016 now comes with Characteristic Mode Analysis integral equation solver. Provides physical insight into the behavior of a conducting surface. Calculates set of orthogonal current-modes supported on a conducting surface – for example, current modes of a metal plate. Tunes antenna to correct resonant frequencies and aids in placing the feed to couple into a particular radiating mode.

Computer Simulation Technology (CST)
cst.com

PCB POWER CONNECTOR

SMT Radsert compact, high current connector enables power delivery of 35A to 200A. Reportedly can accommodate any dimensional constraint and stack height. Comes in tape-and-reel packaging. Brings power to a board from busbars suspended above or below the board and its components. Comes in press-fit and solder versions. Novel pin and socket technology is high-reliability, durable, high current, and has low mating force.

Amphenol Industrial Products
amphenol-industrial.com

OTHERS OF NOTE

STENCIL/PASTE GENERATION

VisualCAM Stencils v. 16.7 design tool streamlines and automates stencil/paste design generation. New release defines paste shapes using pitch rules. Features enhanced library management, improved identification and shape assignments, and improved paste generation and reporting. Many new macro commands and a powerful macro developer to aid in automation, data preparation and stencil generation.

Wise Software Solutions
wssi.com

3D MULTI-BOARD DESIGN

CR-8000 2015.1 single- and multi-board design software's true 3D checks of multi-board designs can be carried out against all aspects of a product, including the enclosure. Includes improved accuracy in layer configuration design work through transfer of layer configuration data with Polar Instruments Speedstack. Design Force creates any design from quick prototype boards to complex, multi-board systems using a single tool. Uses true 3D component model with a precisely matched 3D shape, rather than a shape defined by a boundary box.

Zuken
zuken.com/cr-8000

QUICKTURN PCB PROTOTYPES

IsoPro 3.2 software produces isolation data in G-Code format, permitting the manufacture of PCBs on Quick Circuit in an hour from the time schematic and layout are completed. Calibrates depth of cut with the tool, touching off the surface of material in an average of 5 sec. from the time tool has changed. Enhanced real-time milling progress allows automatic alignment of multilayer PCBs in the lab.

T-Tech
t-tech.com

HIGH-FREQUENCY IMPEDANCE TOOL

Microwave Impedance Calculator includes additional dielectric materials, thermal model capabilities, and bug fixes. Predicts impedance of a circuit made with high-frequency materials, as well as transmission line losses. Loss calculation divided into conductor loss and dielectric loss. Predicts wavelength, skin depth and thermal rise above ambient.

Rogers Corp.
rogerscorp.com

HIGH-SPEED DIRECT IMAGING

Three Wavelength series Ledia systems are for high-speed exposure of solder mask and innerlayer and outer-layer resists. These five and six exposure head systems combine 365, 385 and 405nm wavelength LED emissions. Reportedly deliver 15μm lines and spaces with well-defined edges, with improvements in throughput.

Ucamco
ucamco.com

DIY LAYOUT TOOL

Eagle Make PCB CAD software includes Eagle Make Personal and Eagle Make Pro. Offer separate license types based on usability (noncommercial vs. commercial) and board size. Make Pro provides full functionality. Upgradable. Targeted at hobbyists.

CadSoft Computer
newark.com/cadsoft

REFLOW OVEN RECIPE GENERATION

Recipe Generator software is a starting point for in-spec process and development of final recipe. Prompts selection of reflow oven type, board thickness, component density and solder paste type. Automatically produces reflow recipe zone temperature set points and conveyor speed. Drop-down menu; Windows 10 compatible. Use with V-MOLE, SuperMOLE Gold 2 and MegaMOLE 20 thermal profilers.

ECD

ecd.com

'EASY CLEAN' DISPENSER

NexJet NJ-8 features ReadiSet two-piece jet cartridge which is quickly and easily removed, cleaned, inspected and reinstalled without tools. Is said to be long-lasting, durable and has been tested on many fluids, from high-viscosity silicones to low-viscosity reagents, in board-level underfill, CSP, BGA, PoP underfill, precise coating, silicone jetting, and adhesive dispensing applications. Only parts that come in contact with fluid have to be removed from system for cleaning and maintenance.

Nordson Asymtek

nordsonasymtek.com/nexjet

WAFER LEVEL BONDTESTER

4800 was developed for testing wafers from 200mm up to 450mm. Paragon software provides flexibility for the creation and mapping of wafers, enabling setup of test patterns. Virtual images for each test pattern reportedly enable easy editing.

Nordson Dage

nordsondage.com

OTHERS OF NOTE

LED ENCAPSULANT

Dow Corning EI-1184 clear encapsulant for outdoor LED lighting applications features high-transparency and weatherability. Two-part silicone encapsulant delivers protection of LED electronics in environments containing moisture, UV light, thermal cycling, and extreme temperatures. Conforms to UL F1. Requires a 1:1 mix ratio.

Dow Corning

dowcorning.com

HALOGEN-FREE SOLDER PASTE

PF606-P26 no-clean, halogen-free solder paste is said to prevent BGA non-wet opens and head-on-pillow defects. Is printable, wets and solders well even if BGA components are warped.

Shenmao

shenmao.com

POLYESTER PSA

Pressure-Sensitive Cover Tape 2698 transparent polyester film tape has synthetic, room-temperature, pressure-sensitive adhesive zones at its sides. Helps eliminate pick-and-place errors, minimize downtime and increase productivity. Is said to enable near-flawless placement of chips without sticking, static charge or contamination. Comes in standard widths and 600m reels designed to reduce changeover time and enable productivity improvements. Compatible with existing industry-standard equipment.

3M

3m.com/transport

LASER SOLDERING SPOT AIDS

Laser shape rings aid selection of optimal laser spot shape to fit components and land shapes to reduce circuit board problems. Come in twin-spot, circle, square, ring and oval ring. Help avoid inadvertent burning of PCBs. Twin-spot enables simultaneous soldering of two joints.

Japan Unix

japanunix.com/en/products/laser/shapes.php

SI BONDING MATERIAL

Master Bond MasterSil 912Med, a vulcanizing silicone system, is a one-part material that offers noncorrosive cure with a tack-free time of 15-30 min. at room temperature. Translucent color; serviceable over temperature range of -75°F to +400°F. Tensile strength 700-1,100 psi. Elongation 250-350%. Volume resistivity of >10^{15} ohm-cm. Comes in 80g tubes and has 6 mo. shelf life.

Master Bond

masterbond.com/tds/mastersil-912med

WAFER VACUUM TWEEZER

Adjust-a-Vac is for handling very thin/delicate substrates, wafers, MEMS devices and other fragile components. Can adjust vacuum level from 1-10" of mercury. Integrated 10-segment bar graph display shows vacuum level present during operation. Bar graph shows minimum vacuum pressure until part is grasped, then displays vacuum level presented to the part being handled. Vacuum port integrates a user-replaceable inlet filter.

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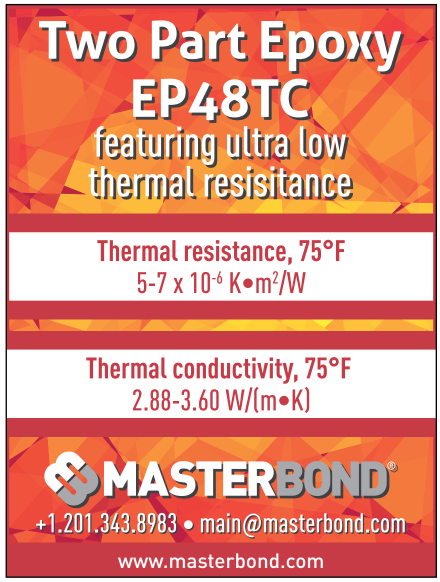

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Company	Page No.
Alpha, alpha.alent.com	15
ASYS Group, asys-group.com	29
Bergquist, a Henkel Co., bergquistcompany.com	18
BEST, Inc., soldertools.net	47
CST, cst.com/pcb	21
EMA, ema-eda.com/OrCAD2015	C4
Glenbrook Technologies, GlenbrookTech.com	7
HKPCA & IPC Show, hkpca-ipc-show.org	41
Imagineering, PCBnet.com	1, 46
Kyzen, kyzen.com	11
Master Bond, masterbond.com	47
Mentor Graphics/Valor, mentor.com/drive	19
Miller Stephenson, millerstephenson.com/vertrel	46
MIRTEC, mirtec.com	3
Online Electronics, pcb4less.com	46
Overnite Protos, pcborder.com	46
PentaLogix, pentalogix.com	26
Precision Technologies, Eprotos.com	13
Prototron Circuits, prototron.com	4
Rogers, rogerscorp.com/rogmobile	C3
Rush PCB, rushpcb.com	5
SCHMID, schmid-group.com	27
Seika Machinery, seikausa.com	39
Seika Machinery, mcdry.us; mcdry.eu	35
Shenmao, shenmao.com	31
Sierra Circuits, flexpcbdesign.com	C2
SMTA Pan Pac, smta.org/panpac	33
Speedline, speedlinetech.com	9
TMP, frenchoil.com	25
Uyemura, uyemura.com	23
VJ Electronix, vjelectronix.com	17

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In Case You Missed It

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

Quantum Physics

"Quantum Photonic Interconnect"

Authors: Jianwei Wang, et al; mark.thompson@bristol.ac.uk.

Abstract: Integrated photonics has enabled much progress toward quantum technologies. Many applications, including quantum communication, sensing, and distributed and cloud quantum computing, will require coherent photonic interconnection between separate chip-based sub-systems. Large-scale quantum computing systems and architectures may ultimately require quantum interconnects to enable scaling beyond the limits of a single wafer and toward "multi-chip" systems. However, coherently interconnecting separate chips is challenging due to the fragility of these quantum states and the demanding challenges of transmitting photons in at least two media within a single coherent system. Distribution and manipulation of qubit entanglement between multiple devices is one of the most stringent requirements of the interconnected system. Here, the authors report a quantum photonic interconnect demonstrating high-fidelity entanglement distribution and manipulation between two separate chips, implemented using state-of-the-art silicon photonics. Path-entangled states are generated and manipulated on-chip, and distributed between the chips by interconverting between path-encoding and polarization-encoding. The authors use integrated state analyzers to confirm a Bell-type violation of S=2.638+-0.039 between two chips. With improvements in loss, this quantum interconnect will provide new levels of flexible systems and architectures for quantum technologies. (arXiv, September 2015; arxiv.org/abs/1508.03214)

Reliability

"Relative Effect of Solder Flux Chemistry on the Humidity Related Failures in Electronics"

Authors: Vadimas Verdingovas, Ph.D., Morten Stendahl Jellesen and Rajan Ambat, Ph.D.; vaver@mek.dtu.dk.

Abstract: This paper aims to investigate the effect of no-clean flux chemistry with various weak organic acids (WOAs) as activators on the corrosion reliability of electronics, with emphasis on the hygroscopic nature of the residue. Flux residue hygroscopicity was studied by quartz crystal microbalance, while corrosive effects were studied by leakage current and impedance measurements on standard test boards. Measurements were performed as a function of relative humidity in the range from 60% to ~99% at 25°C. Solder flux system corrosiveness was visualized by the *ex situ* analysis using a gel with tin ion indicator. Results showed the solder flux residues are characterized by different threshold RH, above which a sudden increase in direct current leakage by 2 to 4 orders of magnitude and a significant reduction in surface resistance in the impedance measurements were observed. (*Soldering & Surface Mount Technology,* vol. 27, no. 4, 2015)

"Board, Package and Die Thickness Effects under Thermal Cycling Conditions"

Authors: Jean-Paul Clech, Ph.D.; jpclech@aol.com.

Abstract: Network and computationally intensive applications make use of thick board assemblies, with board thickness spanning the range from 62 mils to possibly as high as 200 mils. Depending on the package type, the effect of board thickness on solder joint reliability goes from being insignificant to half an order of magnitude reduction in life, or even an increase in life under specific conditions. Some of these observed trends, as confirmed by finite element analysis (FEM), are seemingly counterintuitive. Thus, empirical power law models that give an inverse relationship between solder joint life and board thickness (raised to a power that varies from one source to another) can be misleading, if generalized. This leaves physical designers with significant product life uncertainties and reliability risks. This paper presents a simple strength of materials model that explains and quantifies the observed trends. The model also captures die thickness effects in bare die assemblies, substrate thickness effects in ceramic BGA assemblies, and is validated under a wide range of thermal cycling conditions. The strength of materials approach provides physical insight into the apparent counterintuitive trend of solder joint life increasing with board thickness. (SMTA International, September 2015)

Tin Whiskers

"Platelet Composite Coatings for Tin Whisker Mitigation"

Authors: Lauren E. S. Rohwer and James E. Martin; leshea@sandia.gov.

Abstract: The mechanisms of tin whisker growth are unclear, and this makes lifetime predictions of critical components uncertain. The development of robust methods for tin whisker mitigation is currently the best approach to eliminating the risk of shorting. Current mitigation methods are based on unfilled polymer coatings that are not impenetrable to tin whiskers. The authors report tin-whisker mitigation results for several filled polymer coatings. The whisker-penetration resistance of the coatings was evaluated at elevated temperature and high humidity and under temperature cycling conditions. The composite coatings comprised Ni and MgF_2-coated AlNiAl platelets in epoxy resin or silicone rubber. In addition to improved whisker mitigation, these platelet composites have enhanced thermal conductivity and dielectric constant compared with unfilled polymers. (*Journal of Electronic Materials,* November 2015, vol. 44, no. 11)


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