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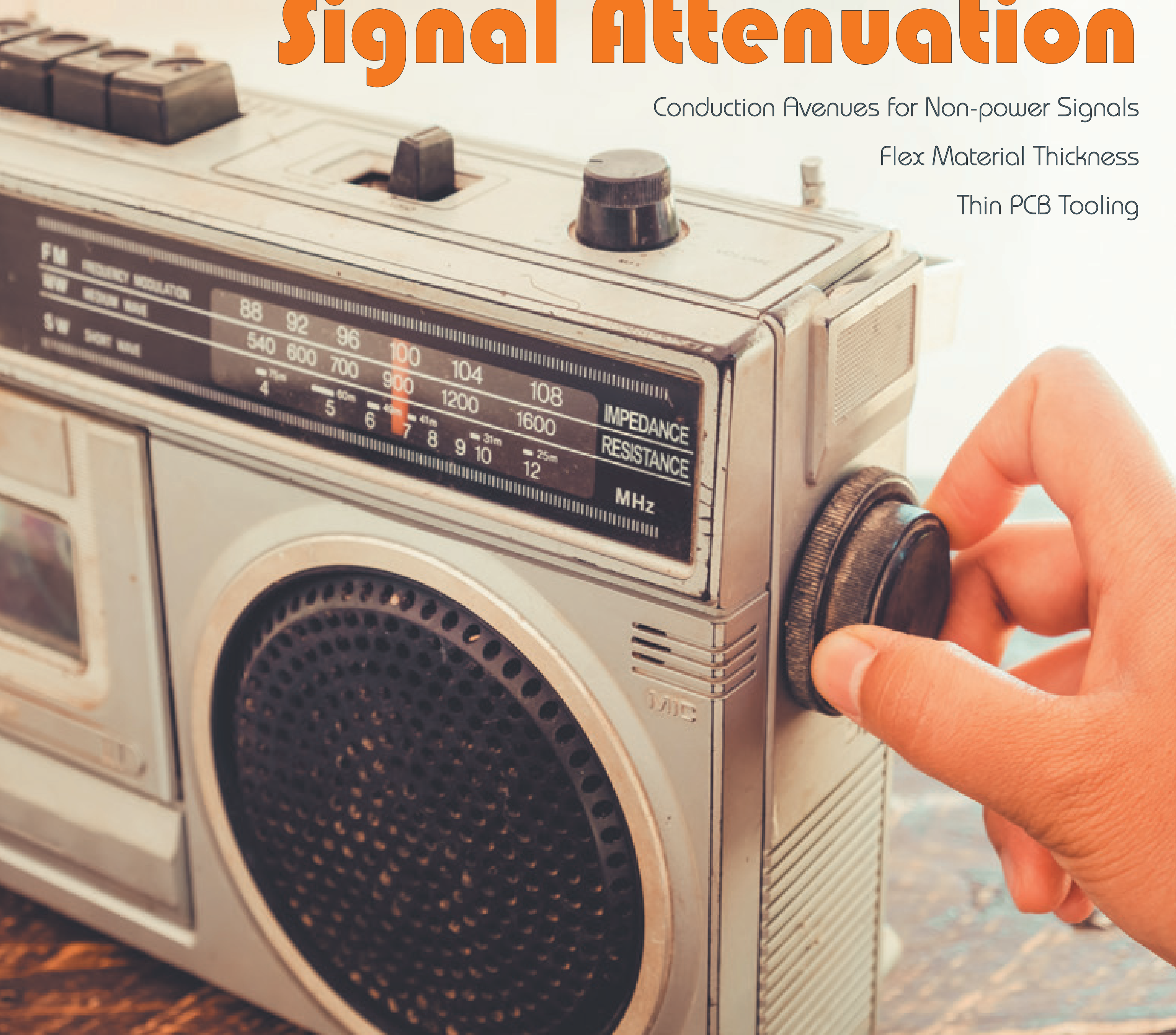
Managing for Skin Effect

Signal Attenuation

Conduction Avenues for Non-power Signals

Flex Material Thickness

Thin PCB Tooling



AUGUST 2021 • VOL. 38 • NO. 8

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FIRST PERSON

MONEY MATTERS

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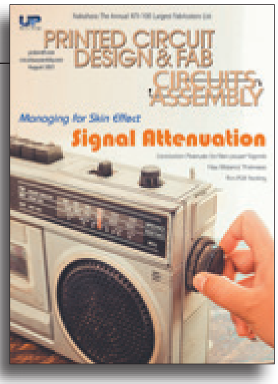
FEATURES



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MIKE BUETOW
EDITOR-IN-CHIEF

Googling Your Boards

IF THE MARKET is big enough, sooner or later Google will join it.

That much was laid bare in late June when the search giant cum OEM announced its latest venture, Visual Inspection AI, a new "purpose-built solution" designed to help businesses, including manufacturers, reduce defects and cut operational costs.

Now before you start doubting Google's temerity to dive into technology that cuts across almost every industry imaginable, remember we've been here before.

While the company today still counts on its hugely successful targeted search marketing program for the bulk of its revenue and profits, several other businesses it has launched have made serious inroads in their respective markets. These include broadband; telecommunications; autonomous vehicles; and human health gambits (marketed under the Verily Life Sciences name). Acquisitions brought it Nest Labs, the maker of smart thermostats. Less front and center, but just as integral, are Google's vast data centers, also known as server farms, which power its reach into just about every precipice known to man.

In some respects, Google is starting to look like the industry-conquering Japanese OEMs of the 1980s, or perhaps Siemens or Philips, albeit with significantly greater profits. As it closes the gap with other conglomerates, electronics was almost certainly going to become part of the mix.

Artificial intelligence is the hot buzzword. Going back a few years, we have seen many suppliers to the electronics manufacturing industry adopt the phrase for their tools, deservedly or not. Besides the major OEMs, third parties have entered the field, attempting to tackle entrenched and labor-intensive problems. But the problem all these companies run into is that, while their tools can handle simpler components or products, there's simply too many complex ones to make it a panacea.

Google doesn't come to this completely oblivious. Its AutoML product is said to enable developers, even ones with limited machine learning expertise, to train high-quality models specific to their business needs, but that solution to manufacturing quality control suits general purpose needs. Visual Inspection AI is Google's answer to manufacturers that need specific solutions.

The platform is based on Google Cloud's computer vision technology, and according to the company can build accurate models with up to 300 times fewer human-labeled images than general-purpose ML platforms. Keep in mind how relatively simple most AOIs are to operate today. For Google to attain that kind of startup speed is essential to quick, easy deployment, which is a must if it will compete with the current infrastructure of machines.

The rest of the fine print is less fine, however. Google's beta tests were run against general-purpose ML machines, which isn't the way to baseline its effectiveness in an electronics manufacturing environment. And the company touts – ironically – that its deep learning tool allows customers to train models that detect, classify, and precisely locate multiple defect types in a single image. That manual intervention is exactly what manufacturers hope to eliminate.

Through all of this, Google promotes that the AI rests in its Cloud. I suspect what Google hopes is through large numbers of users, perhaps from scores of different companies, it can build a database by which its "AI" will recognize common defects (all while Google collects fees from the subscribers). We've reached out to Google for more details, with no response as yet.

FIH Mobile, a subsidiary of Foxconn, is one of the beta sites. Foxconn is notoriously quiet, but the fact that it permitted Google to use its name in the announcement may suggest we'll get a look at their data down the road. We won't hold our breath.

There's no question AOI must continue to improve. Google's decision to try to do so is fascinating. But from what I see, this time might be a no-go.

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P.S. Those truly interested in knowing what their inspection system is saying should tune in for David Bernard's webinar on Sept. 9 (pcb2day.com). And if you are missing human connections, register for PCB West, coming October to the Santa Clara Convention Center (pcbwest.com).

PCDF People

Additive Circuits Technologies appointed **David Torp** CEO, effective Jul. 1. He has held engineering positions at Rockwell Collins and UL, and management positions at Litton, Northrop Grumman and Kester-ITW. He served six years as site director of EMD Electronics and seven years as VP of standards and technology at IPC.

Altix appointed **Maximilian Mohr** DACH regional sales director.

Apple promoted **Jonah Stephenson** to PCB manager Audio/Home/AppleTV.

Insulectro promoted **Ken Parent** to COO, a new position, **Jason Shuppert** to VP of operations, and **Felix Martinez** to national director of operations. Vice president of operations **Jeff Mason** will retire in February.

Nano Dimension hired **Sean Patterson** as president of Nano Dimension – Americas. He previously held leadership roles at Amazon and TTM Technologies.

TopLine named **Dr. Jeffrey Sokol** to its advisory team to provide guidance in aerospace and defense. He is a senior engineering specialist in hybrid microcircuits, radiation effects, and system survivability.

PCDF Briefs

Altix expanded its R&D center located at its headquarters in Normandy, France.

American Standard Circuits installed an **Orbotech** Ultra Dimension 800 AOI.

AT&S built the embedded component boards for an image sensor 1mm² in size and weighing about 1 gram.

BH, a South Korea board maker, will supply more than half of the rigid flexible PCBs used in **Apple's** new iPhones launching later this year, reports say.

Keysight Technologies has joined **Altium's** Nexar program.

Nano Dimension formed a partnership with **Hensoldt** to create J.A.M.E.S (Jetted Additively Manufactures Electronics Sources). The $6 million joint venture will advance development of 3-D-printed electronic components.

Peters and **Atotech** are developing and testing environmentally friendly technology in the field of inkjet solder masks, with the aim of providing a coordinated system of pretreatment processes and inkjet solder resists.

MKS Instruments to Buy Atotech for Over $5B

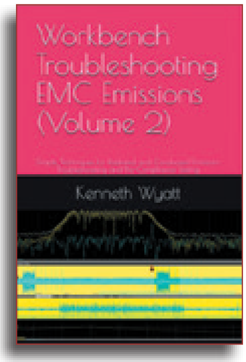
ANDOVER, MA – MKS Instruments will buy Atotech for $5.1 billion, the firm announced on Jul. 1.

The cash-and-stock deal includes $16.20 in cash and 0.0552 of an MKS common stock for each Atotech share, a per share value of around $26. The offer represents a premium of about 10% to Atotech's closing price on Jun. 10.

Carlyle Group, which owns 79% of Atotech, has agreed to the deal.

The deal is expected to close by the fourth quarter of 2021, expanding MKS' chip manufacturing capabilities with the addition of Atotech's plating chemicals. (CD)

New Book Helps Lower Risk of Compliance Test Failures



WOODLAND PARK, CO – The latest book in a series on diagnosing and troubleshooting EMC emissions written by a veteran of the electronics design industry is now available.

Ken Wyatt's latest opus, *Workbench Troubleshooting EMC Emissions (Volume 2): Simple Techniques for Radiated and Conducted Emissions Troubleshooting and Pre-Compliance Testing (EMC Troubleshooting Series)*, is a 239-page treatise on simple tests using the tools and accessories described earlier in the series to characterize and perform workbench-level pre-compliance tests for radiated and conducted emissions.

The book is the second in a three-volume set on EMC troubleshooting. Volume 1 includes examples of recommended measurement tools and probes useful for troubleshooting a myriad of EMC issues on a workbench or in-house. Volume 3 will include a deeper look at the top EMC immunity issues like ESD, radiated immunity and EFT.

The books sell for $20 to $40 each and are available on Amazon. (MB)

New Product Introduction Awards Open for Entries

ATLANTA – UP Media Group has opened its 2022 New Product Introduction Awards (NPI) for printed circuit board fabrication and printed circuit board assembly.

The NPI Awards recognize the leading new products for design, fabrication and assembly introduced in the 2021 calendar year. Awards are selected by an independent panel of judges from the industry and presented by CIRCUITS ASSEMBLY. No preferential treatment is given to customers of PCD&F, CIRCUITS ASSEMBLY or UPMG.

Awards will be presented in a variety of categories ranging from equipment to materials to software. Entries are judged on creativity and innovation; compatibility with existing technology; cost-effectiveness; design; expected reliability; flexibility; expected maintainability/reparability; performance; user-friendliness, and speed/throughput.

The deadline for entries is Oct. 22, 2021. To be eligible, entries must have been introduced to market (any region) no earlier than Jan. 1, 2021.

For more information, visit pcdandf.com/pcdesign/index.php/editorial/npi-award or www.circuitsassembly.com/ca/index.php/editorial/npi-award. (CD)

Stanford University researchers have invented a manufacturing technique that yields flexible, atomically thin transistors less than 100nm in length – several times smaller than previously possible.

Summit Interconnect's Santa Clara PCB division successfully completed certification for IPC-1791, Qualified Manufacturer's Listing (QML).

TE Connectivity has signed a definitive agreement to acquire **ERNI.**

Ultra Librarian has partnered with **Vishay** to provide free symbols, footprints, and 3-D models for download in over 30 CAD formats.

University of California, Irvine professors have been awarded a $200,000 research grant from **Microsoft** to investigate the sustainable development of materials in PCBs for next-generation electronic products.

Virginia Tech researchers created a new type of soft electronics, paving the way for devices that are self-healing, reconfigurable, and recyclable.

Xiamen Guangpu Electronics ordered multiple **Altix** Adix direct imagers.

CA People

Cicor CFO **Patric Schoch** left at the end of June.

Saki appointed **Tatsunori Muroya** chief sales officer, responsible for sales and customer relations. He has a degree in robotics from Tokyo Institute of Technology and extensive international business and management experience in over 50 countries at Mitsui.

ViscoTec named **Franz Kamhuber** managing director, replacing **Georg Senftl,** who retired.

CA Briefs

A*STAR's Institute of Microelectronics (IME) announced a collaboration with four leading industry players to form a System-in-Package (SiP) consortium.

Aegis Software expanded its reseller relationship with **Europlacer** to include China.

Apple and **Intel** will be the first adopters of **Taiwan Semiconductor Manufacturing's** 3nm chip technology ahead of its deployment, possibly next year.

Bharat Dynamics Ltd. (BDL) is upgrading its facility in New Delhi, India, with surface-mount technology lines.

Neways Spurns VDL, Opts for PE Firm

EINDHOVEN, NETHERLANDS – Neways has reached a conditional agreement to sell all shares in the EMS company to private equity group Infestos for approximately €177.5 million ($209.8 million). The offer represents a premium of 34% over the closing price of the EMS firm on Apr. 29.

The offer topped that of VDL, which previously offered about €159 million for the company. Neways' management board and supervisory board is recommending shareholders accept Infestos' bid.

Neways says it will maintain its corporate identity, values and culture and existing rights and benefits of employees. The current management board will continue to lead the company, and the members of the supervisory board will remain in place.

"Infestos is a strong and entrepreneurial investment firm that is well positioned to support us in realizing our long-term ambitions," said Eric Stodel, CEO, Neways. "We continue to develop and grow our market position as a system innovator in the EMS market by moving up the value chain and adding greater value for our customers. We're convinced Infestos is the right partner for this next phase of development. With their expertise, they can help us further accelerate the rollout of our transition and growth of our business in the years to come, while remaining an independent company."

VDL holds a 27.6% stake in Neways, but VDL has backed out of the bidding, saying Infestos is overpaying. (CD)

ACDi Acquires Enhanced Manufacturing Solutions

FREDERICK, MD – ACDi in July announced the acquisition of Enhanced Manufacturing Solutions to expand its geographical footprint, increase manufacturing capacity and complement service and product offerings. No financial terms were disclosed.

ACDi will offer printed circuit board layout and electronics manufacturing services in the New England area.

"We are looking forward to welcoming Enhanced Manufacturing Solutions' employees and clients to the ACDi family," said Bill Hornbaker, president and CEO, ACDi. "As a company we will be ideally positioned to penetrate new industries and expand into the northeastern region of the US. We are excited to add Enhanced Manufacturing Solutions, a team that shares our vision of being an agile partner with consistent high quality and customer service."

"The Branford, CT, team is looking forward to introducing our client base to ACDi's offerings," said Stephen Giardina, former president at Enhanced Manufacturing Solutions. "I am very excited for our clients and our employees to join the ACDi family, which brings us expanded design, manufacturing and testing capabilities."

ACDi's headquarters will remain in Frederick, MD, and the company will retain the Branford, CT, employees, office and manufacturing facility. (CD)

India Electronics Assn Head Calls for Renewed Investment

NEW DELHI, INDIA – The US isn't the only nation placing intense emphasis on its boosting domestic semiconductor industry. India's primary electronics association said the country must immediately start investing in semiconductor manufacturing if it plans to become a hub for electronics.

Electronic Industries Association of India director general Rajoo Goel calls electronics manufacturing "critical to Atmanirbhar (self-reliant) India." He pinpointed semiconductors and displays as critical components to ensure the domestic industry is competitive with China and other regions.

"Electronics is at the heart of most existing and emerging technologies and is widely recognized as a meta-resource. Electronic components are the building blocks of electronic equipment and contain the essence of electronics technology. India has lagged in manufacturing of components, especially the high-end PCBs, chip components, and semiconductors. Key electronics today requires these components based on cutting-edge semiconductor technology to manufacture power electronics, memory devices, sensors, and displays, which contribute the lion's share of electronic products," he said.

ELCINA was founded in 1967 and represents companies across a variety of sectors in electronics manufacturing. (MB)

IMCO Acquires EMT Electronics Manufacturing Technologies

PERRYSBURG, OH – IMCO Group in July acquired EMT Electronics Manufacturing Technologies for up to NIS 7 million (US$2.14 million). NIS 4 million will be paid at closing, with an additional NIS 3 million subject to future profit.

"This expansion gives further in-house capabilities of designing and assembling electronic PCBs," said Eitan Zait, CEO, IMCO. "This move is a further step in IMCO Group's path to provide its customers with complete solutions tailored for customers' requirements, converging toward Tier-1 customers worldwide."

"We are proud and excited to join the IMCO Group, and are confident our proven excellence for the production and integration of electronic systems and assembly of electronic PCBs will enable the group to enrich its capabilities and provide its customers with state-of-the-art solutions at the highest standards and technologies," said Yaniv Hadar, CEO, EMT. (CD)

Board Shark PCB appointed **Yankee Soldering** manufacturers' representative in New England.

CalcuQuote's QuoteCQ RFQ management system has been integrated with Stackrate, a PCB fab manufacturing software.

Circuit Technology Center has issued a purchase order for two additional **RPS/Hentec** Odyssey 1325 robotic hot solder dip machines.

Cohu has completed the sale of its Printed Circuit Board Test Group business to **Mycronic.**

Deswell Industries acquired two **Panasonic** SMT placement systems for its site in China.

EMS and OEM companies interested in integrating IPC-CFX on existing assembly lines now have access to a portal listing equipment vendors and their support of IPC-CFX on specific legacy equipment models.

Foxconn is talking to Wisconsin about building electric vehicles there, according to reports.

IEC Electronics has been awarded a multiyear contract valued in excess of $45 million from a Tier 2 Department of Defense contractor.

Indium and **Unicoba** partnered for the service of their electronic and electromechanical materials in Brazil.

Karatay University in central Turkey established a new high-tech development and design center with EU funds for prototyping, validation and testing processes in the production industry's R&D projects.

Key Tronic said an audit committee concluded that inventory and cost of goods sold was improperly recorded at its Oakdale, MN, production facility during the fourth quarter of fiscal 2020 and during the first six months of fiscal 2021.

Kyzen installed an **Austin American Technology** (AAT) Mega Ion SA cleaning system.

Lacroix Electronics deployed **Keysight's** i7090 board test system in their automotive printed circuit board manufacturing facility.

Lumasmart, a contract manufacturer specializing in lighting, will invest $4 million to expand its electronics factory operations outside Detroit.

Micross Components acquired the assets of the microelectronics business from **Ultra CEMS.**

MRSI Systems (Mycronic Group) opened a product demo center in Shenzhen.

NexLogic Technologies has implemented soldering to aluminum using **Averatek's** Mina chemistry.

Note signed an agreement to manufacture a new generation of a programming module for a large international customer. It also signed an agreement with **Mölnlycke** to manufacture the company's new generation of wound care products.

Quantic Electronics acquired **Union Technology Corp.** for an undisclosed sum.

Saigon Hi-Tech Park, a Vietnamese electronics factory complex, was forced to shut down in mid July and workers required to live onsite after more than 750 employees tested positive for Covid-19. The park is home to many high-tech companies – including an **Intel** chip assembly and test plant and a **Samsung** factory.

The heads of **Sanichi Technology** and **PNE PCB's** proposed takeover of **BSL** will strengthen their precision metal parts and PCB operations, according to the offer sheet.

TT Electronics will close facilities in Corpus Christi, TX; Barbados and Lutterworth, England, and lay off scores of workers.

VDL Groep has opted to pull its previously announced public offer for all issued and outstanding shares of **Neways,** the company said on its website.

ViTrox Americas has received purchase orders of 22 units of V810i AXI systems this year through May 31.

Vizinex RFID installed a **Datacon** flip-chip bonder line, its second, and a **Schunk Intec** router/saw for PCB cutting at its Bethlehem, PA, facility.

Wavelength Electronics purchased a **Hentec/RPS** Vector 460 selective soldering system.

Wheatstone plans to add a second SMT line at its factory in New Bern, NC.

Wiwynn will build a server assembly plant in Malaysia.

XDry announced an exclusive representative agreement with **MaRC Technologies** in Northern California and Northern Nevada.

Z-Axis added a **Universal Instruments** Radial 88HT automated through-hole insertion machine.

Hot Takes

- **Revenue of listed Taiwanese PCB companies** grew at an annual rate of 16.8% year-over-year in May, up 1.1% sequentially. Total revenue of listed PCB material-related companies grew over 70% in the same month. (TPCA)
- **Shipments of tablets** are expected to grow 1.8% in 2021. Global tablet volume is expected to reach 166.5 million units over the course of this year. (IDC)
- **Semiconductor manufacturers worldwide** will have started construction on 19 new high-volume fabs by the end of this year and break ground on another 10 in 2022 to meet accelerating demand for chips in communications, computing, healthcare, online services and automotive. (SEMI)
- **The worldwide IC market** is forecast to grow 24% in 2021, exceeding $500 billion for the first time. (IC Insights)
- **Global smartphone sales** to end-users grew 26% in the first quarter of 2021. (Gartner)
- **Worldwide contract manufacturing revenue** increased 7.1% in 2020. (New Venture Research)
- **Total North American EMS orders in May** rose 10.5% year-over-year and decreased 19% sequentially. EMS shipments for the month were up 1.9% year-over-year and down 3.9% sequentially. (IPC)
- **Consumer electronics revenue** will cross $1.5 trillion by 2027. (Global Market Insights)
- **The global government Internet of Things** endpoint electronics and communications market will total $21.3 billion in 2022. (Gartner)
- **The head-mounted display market** is expected to grow to $36.5 billion by 2026, a CAGR of 46% between 2021 and 2026. (Research and Markets)
- **Server ODMs** saw shipments fall short of customer orders by 10 to 30% in the first half of 2021, with the shipment shortfall likely to widen in the second half of the year because of chip shortages. (DigiTimes)
- **Worldwide shipments of traditional PCs,** including desktops, notebooks and workstations, reached 83.6 million units in the June quarter, up 13.2% from the second quarter 2020. (IDC)

US MANUFACTURING INDICES

	FEB.	MAR.	APR.	MAY	JUN.
PMI	60.8	64.7	60.7	61.2	60.6
New orders	64.8	68.0	64.3	67.0	66.0
Production	63.2	68.1	62.5	58.5	60.8
Inventories	49.7	50.8	46.5	50.8	51.1
Customer inventories	32.5	29.9	28.4	28.0	30.8
Backlogs	64.0	67.5	68.2	70.6	64.5

Source: Institute for Supply Management, July 1, 2021

KEY COMPONENTS

	JAN.	FEB.	MAR.	APR.	MAY
Semiconductor equipment billings[1]	29.8%	32.4%	47.9%	50.3%[r]	53.1%[p]
Semiconductors[2]	13.2%	14.7%	17.8%	21.8%[r]	26.2%[p]
PCBs[3] (North America)	1.14	1.29	1.22	1.16	1.11
Computers/electronic products[4]	5.12	5.20	5.18	5.18[r]	5.22[p]

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

COVID REBOUND

Trends in the US electronics equipment market (shipments only)	% CHANGE MAR.	APR.	MAY	YTD%
Computers and electronics products	0.9	0.7	-0.3	8.3
Computers	-3.1	0.7	0.8	4.5
Storage devices	0.9	9.0	3.6	29.2
Other peripheral equipment	-5.1	11.6	-8.3	14.1
Nondefense communications equipment	0.9	-2.3	0.7	14.1
Defense communications equipment	-1.3	-3.6	4.6	3.4
A/V equipment	-1.8	2.3	6.4	1.3
Components[1]	0.7	-0.6	-0.8	7.8
Nondefense search and navigation equipment	-1.3	4.4	-2.6	1.7
Defense search and navigation equipment	0.2	1.2	-1.4	2.9
Medical, measurement and control	1.2	0.4	-0.3	9.1

[r]Revised. *Preliminary. [1]Includes semiconductors. Seasonally adjusted.
Source: U.S. Department of Commerce Census Bureau, July 2, 2021

PCB ECAD Sales Continue Growth Streak

MILPITAS, CA – Printed circuit board and multichip module design software revenue increased 15.3% to $289.2 million compared to the first quarter of 2020, said the ESD Alliance in July, continuing a long run of growth. The four-quarter moving average, which compares the most recent four quarters to the prior four, increased 5.3%.

Electronic system design industry revenue increased 17% year-over-year to $3.16 billion in the first quarter, the strongest first-quarter growth ever. The four-quarter moving average rose 15%, the highest annual growth since 2011.

"The industry reported substantial double-digit year-over-year revenue growth for the first quarter 2021," said Wally Rhines, spokesperson for the SEMI Electronic Design Market Data report. "All product categories significantly contributed, with double-digit growth in the computer-aided engineering, IC physical design and verification, printed circuit board and multichip module, and semiconductor IP segments.

"EDA license and maintenance, which includes PCB, is at an all-time record," Rhines said to PCD&F in an interview recorded for the PCB Chat (pcbchat.com) podcast.

"Geographically, the Americas; Europe, Middle East, and Africa; and Asia Pacific also reported double-digit growth. First quarter 2021 marked a new high for quarterly growth of total license and maintenance revenue, as well as IC physical design and verification."

The companies tracked employed 49,024 people during the quarter, up 6.7% year-over-year and 1.1% sequentially. EDA continued to growth during 2020, Rhines told PCD&F, because "design is something you can interact with people online. They didn't reduce their personnel during Covid. They kept their people and continued to hire.

"This has historically gone on for decades.… Design continues pretty steadily, I believe because companies know someday the problem will be over, and they have to have new products." (MB)

New Tech Needs Standard Solutions

The trend toward keeping ideas under wraps may slow adoption.

EARLY IN MY career cutting-edge technology was personified in hardware, such as a wire EDM machine for cutting metal used in dies for wire-to-wire terminals: for instance, forks, rings and spades. No one in those days associated software with technology. It was simply some magic the IT department created to generate reports.

Decades later, most people immediately think of software, firmware and apps as technology, while the devices themselves, regardless of how advanced, are more or less just hosts for the apps. In our industry, there is far more recognition of the technology that goes into hardware and an appreciation that the two are codependent to provide the desired end-application. In fact, many in our industry may well believe the real magic is in hardware that can withstand a variety of operating environments, while providing a stable and robust platform for software to operate.

Today, in some ways, technology is wearing two faces: one that enables and one that confounds!

The face that enables can be seen in how software has in many ways displaced hardware as the gate to continually upgradable equipment. In the electromechanical past, machinery could do only so much within the physical limitations of tolerances, motor speeds, etc. When purchasing a piece of capital equipment then, the limitations or built-in obsolescence could be identified and planned for. While creative mechanics might stretch the life or technological capability of some equipment, the end of useful life was definitive. The software on some (most?) equipment was more like firmware, providing commands to operate rather than offering any real intelligence to manipulate.

Over time, however, software has taken on increasingly intelligent operations. With ever-more sophisticated sensors, utilization of camera optics, and architecture that permits ongoing upgrades to software, the technology of a piece of capital machinery has shifted from its electromechanical constraints to platforms capable of ongoing technological expansion quickly and relatively cheaply. In large part due to the software, machines are seeing flexibility, lifespan and value significantly extended.

How this may impact capital spending in manufacturing will play out over the next few years. Many touting Industry 4.0 have hyped the increased productivity of all equipment on a shop floor communicating and engaged with each other. I question if that is the real value, however. If humans don't or can't interact and share data on a shop floor, I suspect that, over time, machinery and computers will follow suit. That said, the real value may be that replacing a computer instead of an entire machine achieves significant improvement in capability, stretching capital investment and permitting a business to buy more equipment on the same capex budget.

The confounding aspect of technology is that Moore's law has reached a point where any new tech may have a short peak value. When technologies are advancing and being displaced so frequently, those who create and produce them often become overly protective and don't want to share their "secret sauce" for fear a competitor will leapfrog them.

Often in the past, the bleeding-edge technology would undergo some level of proprietary secrecy, in part so the mystique could attract customers. More often, however, companies would race to patent an emerging technology. Then, the normal lifecycle of the technology would take years to evolve, and the invention would go from new one year to commodity as the world (competitors included) would learn how to compete with it.

Early in the printed circuit board industry, when it was new technology, manufacturers banded together to develop standards so they and their customers could market that their product was produced properly and would meet user requirements. Today's fast-paced development cycle has upset that trend, leaving many cloaking their inventions in secrecy.

This can be seen in some electronics technologies such as interposers. With so few in the business scrambling to improve and refine what they believe is (or their company's marketing hypes to be) their "secret sauce," those technologies most likely will never reach maturity. Only when technology reaches some level of maturity is it feasible, or even possible, to create standards that customers can specify. Closely held IP, trade secrets, and the like do not lend themselves to standardization, nor do they invoke the confidence necessary for the technology to find its way into mainstream products.

Regardless as to how much it changes, what's clear is technology can both enable and confound. Which direction will the accelerating pace of development, refinement and societal adoption go? Will protecting a technology in the cloak of secrecy become the new norm, or will rapid and open adaptation persevere? Time will tell. Either way, our industry will be in the front row. ❑

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Changing Attitudes in the Post-Covid World

It's time to consider more in-person visits.

ARE WE IN the post-Covid world yet? That simple question will ignite both outrage and debate in many parts of the world. Yet in other places people are ripping off their masks and starting to resume normal life. This disconnect has significant implications for electronics manufacturing services (EMS) companies and their marketing strategies. It also has implications for people not wishing to transition from temporary work-at-home settings.

I live in Texas, and our governor has made mask mandates illegal, so I have had a preview of the psychological changes that hit when people who have been masking up and hunkering down for over a year suddenly don't have to do that anymore. I'm fully vaccinated and am choosing not to wear a mask. Once the mask mandate was lifted, stores switched to encouraging those not vaccinated to continue to wear masks, but that choice is left to patrons. The first week I went shopping without a mask, I was in the minority. Three weeks later, the aisles are full of maskless people. Even store employees are ripping off their masks. In short, attitudes on masking shift quickly once unmasking starts and case numbers continue to drop.

"FROM A SALES STANDPOINT, **HOME OFFICES AREN'T A NEW THING.** HOWEVER, IF THE WORK-AT-HOME SCENARIO WAS RELATED TO COVID-DRIVEN POLICIES, **CONSIDER RETURNING TO THE OFFICE** AS SOON AS ALLOWED."

In the EMS industry today, business travel is still limited. OEMs continue scheduling virtual tours. Salespeople are selling via Zoom or Teams calls. Trade shows are happening, but many companies are reluctant to exhibit, fearing low traffic. That creates both a challenge and an opportunity. The challenge is low traffic at shows is likely to be a reality as long as varying levels of restrictions (and vaccination levels) are in place. However, we are approaching a time when trade shows will return to normal, and exhibitors at those shows will get better than usual value. Early 2022 will definitely be in that zone. Shows in Fall 2021 may be as well. Shows that have moved into unattractive time slots late in the year may not do as well, as people are likely to focus on holiday activities and gatherings they couldn't have last year.

One of the big drivers of trade show attendance in normal times is market uncertainty. Material constraints and shifts in demand typically increase attendance as people go to shows to network and see what others think about market challenges. We have materials constraints, demand spikes, logistics challenges and potentially an infusion of government money into infrastructure that will drive even more demand across a broad range of industries. And just as the trickle of maskless folks in my local stores shifted to a surge as people got comfortable with a return to normal, I think the business travel shift will be equally fast. From my observations, people who have traveled in the past for their jobs seem to be getting vaccinated. So, the beginnings of a return to discretionary business travel are in place. Since vacation travel doesn't seem to be causing super spreader events, it's likely that corporate travel policies will start to relax fairly quickly.

Consequently, start picking the shows that will likely have the best networking attendees. Shows with strong conferences or that have been target industry networking hotspots in the past are good options. An interim strategy with low risk is walking industry shows to view traffic patterns. Another way to gauge potential attendee mindset is to have sales team members ask prospects about their company's trade show attendance plans.

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On the sales side, consider more in-person visits. This timing needs to be customer-driven, since their policies will dictate when face-to-face meetings start. However, it is time to ask about customer preferences for telecom or in-person meetings. In-person meetings build better relationships, and once people accept the idea of a return to normal, there seems to be an affinity for like-minded people. Consequently, if your team is setting up Zoom calls and your competitor's team is buying a prospect lunch or dinner, they may have the inside track on that fear-free interaction. That said, if a prospect prefers teleconferences, don't push. People with a shelter-in-place mindset won't like pressure to change.

The final area I see as concerning is employment. Many sales and marketing teams have been working from home. From a sales standpoint, home offices aren't a new thing. Many salespeople worked remotely pre-Covid because a large part of the job involved travel to a regional customer base. If that was the case pre-Covid, there is no downside to continuing to work from home. However, if the work-at-home scenario was related to Covid-driven policies, consider returning to the office as soon as allowed. There is discussion about a "great resignation" period as people who like working at home switch to employers that will enable that lifestyle, but I honestly think those who make a job change this summer to continue to work from home will be blindsided by the speed at which the market shifts back to normal expectations for work environments. Work-at-home employees are easier to lay off because they aren't getting the same level of face time as those in the office. In some cases, those jobs will also be easier to shift to automation as artificial intelligence (AI) tools improve. In short, make career decisions after the return to normal, not to avoid the return to normal.

In today's changing world, the best tool is common sense. I masked up and social distanced when there were few protections from Covid and my age group was high risk. I rolled the dice on vaccination (and it is not without risk) because I saw that as the best way to protect myself and get back to normal. Everyone will make these adjustments differently. Some will do it independently; others will wait until a majority of people they interact with make the change. The one element of certainty is that shift is underway. Start thinking about what a return to normal looks like for your business now and you'll be adequately prepared. ❑

Is it Time to Design Printed Circuit Boards around the Bill of Materials?

Make every chip a layout unto itself.

BEING A PRINTED circuit board designer is not easy. Parts we used to take for granted have become really hard to come by. Geopolitical trade wars and a pandemic were serious triggers for the undersupply. We really didn't need a Japanese chip factory to burn down to make things worse. A giant cargo hauler clogging up a vital shipping artery for a week was no help either.

The fear, uncertainty and doubt sown into the supply chain put the squeeze on purchasing managers who, in turn, did their best to secure as much material as possible. Ordering more inventory than their forecasted requirements is a typical kneejerk reaction for the big players. Some purchase orders may be defensive measures, an effort to block competitors that are caught shorthanded themselves.

Automakers are a vital sector of the US, German and Japanese economies. They have been busy lobbying their respective governments to pressure chipmakers, with the goal to create a sufficient supply of devices for the vehicles they want to build. Propping up that industry with their ruggedized devices leaves even less bandwidth for other industries.

The mainstream chips that remain have become a strategic and tactical pawn to be overbought to ensure a supply down the road. Scarcity breeds scarcity as the big players use their clout to absorb as many chips as possible. Things will remain messy and uncertain for the PCB design engineer who must accommodate the supply chain crisis.

Lead times are one of the key elements in forecasting **(TABLE 1)**. What I've heard from contacts in the chip houses is they are facing a lot of uncertainty in this environment. If everyone is trying to get a larger allocation than they require, what is the true demand? It's not like they can announce a new fab and, presto, more chips. It takes chips to make chips, and the companies that make equipment for the chipmakers are in the same boat we are. It's a vicious cycle.

It's not only lead times but also the confidence in those numbers as they continue to grow. We don't see light at the end of the tunnel yet. When you don't know what cards you hold, or even how many cards are in the deck, planning with any certainty is difficult. Do you commit to a higher price to ensure a supply six or even three months out? These are tactical problems, but they become technical problems of the highest urgency once we find a viable path forward.

Hurry up and wait? We need something better than that. Getting away from traditional program management in favor of agile program management might be a better solution for uncertain times like these. Maybe you've heard of agile methodology. It's more of a software development thing but can be applied to hardware as well. Instead of projects that have concrete start and end dates, "agile" relies on getting everyone together, setting a goal around a set of parameters and executing on that plan in a sprint. Learn and repeat.

Design pre-use. In this case, the parameters are the line items that make it into the bill of materials. The full set of items has a lot of redundancy, and only those most likely to be available go into the product. Every chip is a layout unto itself, and a library of chip layouts are generated as you go. Some circuit elements may never be incorporated at the board level but are on hand if you need them.

Instead of cataloging design reuse modules, you're designing sub-circuits for everything. Even if it is a one-off on the board, it can be created as a module to free it from the constraints of the reference designators. The idea is to keep your options open by having a sub-layout for everything you might need.

Modular schematics may not be as ecofriendly since each chip will use a full page or pages, leaving you with some white space. Some of us still work from paper schematics, especially during placement and as prop for the final design reviews. In the interim, people are proving out the sub-circuits to reduce the technical risk while the tactical risks are sorted out.

This is more about simulation than actual bench work, but it is possible to generate PCBs for the

TABLE 1. Material Lead Times, in Weeks

Material Type	Current Lead Time	Typical Lead Time
Power management	24-52	4-8
Microcontrollers	24-52	4-8
CPUs	12-16	4-8
Memory	14-15	4-8
Wi-fi	24-30	4-8
Consumer LCD screens	16-20	12
Substrate materials	52	20
Chip packaging services	12	2-4

Source: Nikkei Asia

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

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4-DAY CONFERENCE	1-DAY CONFERENCE	EXHIBITS ONLY
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Conference attendees will receive certificates that reflect the number of hours spent in classes during PCB West. These certificates can be used as evidence of continuing education and training in accordance with ISO 9001 and other corporate quality assurance and quality management requirements.

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PRICING OPTIONS	4-DAY CONFERENCE	1-DAY CONFERENCE	EXHIBITS ONLY
Early Bird (ends September 6, 2021)	$1395	$795	FREE
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ACCESS TO:			
Tuesday Oct. 5 Technical Sessions	✓	✓ (inclusive if selecting Tuesday)	
Wednesday Oct. 6 Technical Sessions	✓	✓ (inclusive if selecting Wednesday)	
Thursday Oct. 7 Technical Sessions	✓	✓ (inclusive if selecting Thursday)	
Friday Oct. 8 Technical Sessions	✓	✓ (inclusive if selecting Friday)	
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Evening Reception (Wed. Oct. 6)	✓	✓	✓
Exhibits (Wed. Oct. 6)	✓	✓	✓

sub-circuits where more data are required. (Assuming you can get your hands on sample quantities of your projected components, that is.) Various functional pieces can be cobbled together on the test bench to get a better characterization prior to the final form-factor.

What you want is a collection of circuits you are confident will perform as required. Then, pick and choose the sub-circuits so you can complete the BoM and deliver the board within the budget and on schedule. The single breakout board becomes an interchangeable system of multiple printed circuit boards.

Multiple footprints for an at-risk component. To alleviate uncertainty, it may be possible to have a single footprint that supports two different components **(FIGURE 1)**. It is not ideal, and it will want to be distilled to a single footprint on the next iteration. This is the key. You're working with a dynamic universe of components and need to be able to pull a board together quickly.

Interposers are another way to keep your options open. The concept is simple: one footprint on the bottom of the substrate and a different one on the top. The two are connected such that an old board can learn a new trick or at least accommodate a second-source component with a different footprint.

Rushing a board may not be an optimal solution, but rest assured, an agile methodology means doing one iteration after another. Fail quickly and move forward with what you know for the next time. Managing this risk is a team sport that requires solid communication. Interesting times call for more evolved solutions. □

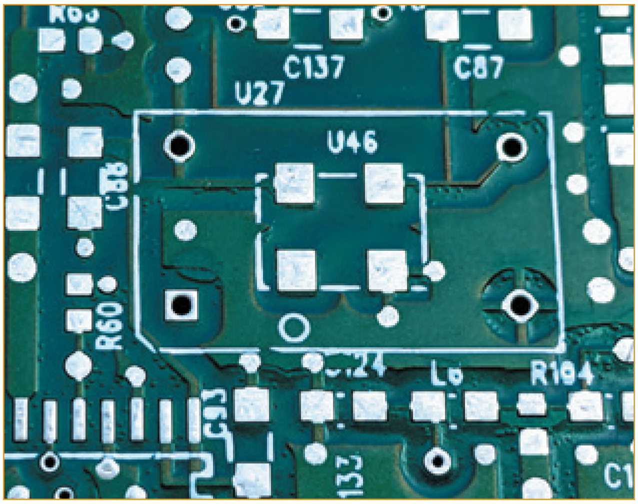

FIGURE 1. U27 and U46 are crystals of the same frequency but with different types of packaging. They are mutually exclusive assembly options, depending on the component available.

Learning from the Quality Auditors

Those who buy and specify everyday have much to teach us about the industry.

ARE YOU FINDING your place in the PCB industry? Are you feeling a bit disconnected from the rest of the world as you perform your PCB engineering job? Maybe you should consider joining a trade organization. Aligning and participating with a trade org that is well matched to your areas of expertise can be a monumental benefit to your career. It can put you in touch with others who can help you discover what you don't know, but perhaps you've needed to know!

Our industry has many PCB engineering development groups and trade organizations. Finding the right ones to join may not be as easy as you think. Following some of the criteria PCB engineering quality assurance stakeholders use to find good products and services for their company makes it easier to narrow the list.

Many in the PCB engineering industry do not specify or qualify materials directly. But we might work closely with those who take part in qualifying the materials and manufacturers that are responsible for checking out and making important decisions regarding the quality of the materials or processes offered. It could be valuable to understand how these industry stakeholders of ours set up business relationships and roadmaps for moving forward.

All these folks – sometimes referred to as quality auditors – have something in common when they search for resources and providers: They often belong to industry organizations whose quality standards they use to determine conformance.

Let's reflect on our own resource requirements for a moment. As mentioned, our day-to-day jobs might not require sourcing the next supercomputer chip or specially formulated material to route its circuitry on. Regardless of our professional part in the printed circuit engineering industry, however, we can benefit from some of the same criteria quality auditors use to qualify any professional organization we associate with.

Quality auditors look for several important things when evaluating a new supplier to engage in mutually beneficial, long-term business relationships. Think for a few moments about how these criteria can be applied to evaluating an industry trade organization. When searching for a trade organization to join, wouldn't you want to "audit" and check for some of the following?

- A culture of operational compliance. Are their standards and operating procedures documented? Do they say what they do and do what they say? Do they provide open book operations with clearly defined stakeholders and areas of responsibility and traceability?
- Social compliance. Are the management personnel or board of directors well-known members of the community or industry? Are they diversely represented? Are they transparent and communicative, free of any potential conflicts of interest? Are their business dealings and the organization mission clear and consistent?
- Does the organization offer education and training for the goods they provide? If they charge for training, is it of justifiable value?
- Can the organization readily provide documentation and explanation of their business ethics and value to the stakeholders they serve?

Maybe you have criteria of your own. The organizations you contact should be responsive to your interests and reciprocate with a speedy response detailing how they can help connect you with information to help your career and demonstrate ways you can become vested in the organization's membership. At the very least, a trade organization should offer a tangible description of what they stand for. Their purpose and mission must be aligned with your needs for understanding and desire for engagement.

Message from the Chairman

by Stephen Chavez, MIT, CID+

It's hard to believe the year is half over and summer is in full swing. Here in Arizona, with our monsoon season just starting and those triple-digit temperatures in full swing, summer is definitely here! As the days and months fly by, it seems there is never enough time, and the never-ending workloads keep piling up. (Don't even get me started on those "Honey do lists.")

As PCEA continues to evolve and grow, the original vision that begat our mission statement – Collaborate, Educate, and Inspire – has become reality. For me personally, it has always been about making a positive difference in our industry by helping others be successful, at work and in life. Doing this by networking, sharing experiences (good and bad), passing on knowledge, and inspiring others. That's PCEA at our core!

Our individual chapter activities continue to gain momentum and our chapter growth flourishes. As new members join the PCEA, along with our sponsorships and affiliations, the synergy is spreading as we envisioned it. It's amazing to see positive energy spread as we see true collaboration take place from chapter to chapter, and from member to member globally.

Now that we are coming out of the pandemic darkness and Covid-19 restrictions loosen, we are finally

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getting back to face-to-face interactions, without those face masks! I think our hands have aged faster than the rest of our bodies thanks to the constant washing and sanitizing. Industry trade shows and conferences are coming back to life. Hooray!

Because we are back to face-to-face interactions, the second half of this year will be awesome, regarding industry events such as DesignCon, SMTAI, PCB Carolina and PCB WEST, to name a few. I cannot wait to attend my first face-to-face industry event. Long overdue, in my opinion. Friends and colleagues who have already attended a live industry event come across as excited and euphoric, yet exhausted from being "out of conference shape," if that makes sense.

So, I look forward to the hustle and bustle of traversing crowded airports and congested rental car parking lots or even taking Ubers and taxis just to get to my first in-person conference. Be assured you will see a PCEA presence at many of these conferences and shows, either at a booth on the show floor or at an informal meeting with other fellow members. Look for us, and feel free to join the conversations. We love to engage and interact with you face-to-face.

I continue to wish everyone and their families health and safety. Best of success to all as 2021 unfolds.

Warmest regards,
Steph

Chapter Activity

by Scott McCurdy
PCEA-Orange County chapter president

The PCEA-Orange County chapter in southern California held a successful virtual "Lunch 'n Learn" event on May 19. Hosted by EMA Design Automation, senior field applications engineer Orlen Bates gave an educational presentation on Designing for RF – Tips and Tricks from the PCB Pros.

The topic of RF design must have struck a nerve, as this meeting drew an audience of 98 printed circuit professionals, making it one of the largest events in our chapter history.

Orlen's many decades of manufacturing and design experience fueled his talk and the images and examples he presented provided a valuable learning opportunity of the best practices and how to avoid design pitfalls to those in the audience. A lengthy question and answer period at the end added great value and audience participation in this webinar format.

As California starts to open as the pandemic is waning, we hope that later this year our chapter will be able to have in-person events again. We all miss that great feeling of being in a large group of our fellow colleagues interacting in these educational and interesting events.

Next Month

August is sure to be a time for "doing what we say" as far as the PCEA's commitments for engaging in activities to collaborate, educate and inspire those both inside and outside our organization. We hope to bring you more information regarding PCEA's role in certifying those who have completed the Printed Circuit Engineering Professional program, authored by several renowned members of the PCEA.

Upcoming Events

Below is our list of upcoming events. Hope to see you at any of these!

- **PCB West**
  Oct. 5-8, 2021
  Santa Clara Convention Center
  Santa Clara, CA
  www.pcbwest.com

- **SMTA International**
  Nov. 1-4, 2021
  Minneapolis, MN

- **Productronica**
  Nov. 16-19, 2021
  Munich, Germany

Spread the Word

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

Conclusion

We hope you will look at all the information and resources the PCEA has published on our website, broadcast via many of our online chapter presentations and what we have printed right here in this column and see what our organization is doing to collaborate, educate and inspire. We indeed say what we do and do what we say when it comes to being a trade organization that will pass your audit for value, integrity and making difference in your PCB engineering career.

See you next month or sooner! □

Your PDN's Other Job: Closing the Loop with the Return Path

Conduction avenues for the non-power signals.

WE'VE DISCUSSED THE importance and care required when routing the power delivery network (PDN) of modern printed circuit boards. From how to support current supply needs, loop inductance, and defining layer stack-ups, it may seem we've addressed all the power concerns one could have. This is just a fraction of the considerations a designer needs to keep in mind, however. The PDN has an important secondary role that has nothing to do with power delivery. Often forgotten, the PDN is responsible for roughly 50% of the conduction avenues for the non-power signals.

Commonly referred to as return path, this routing "completes the loop," enabling current to flow. It can be as influential (and problematic) to signal quality as the transmission lines we study in detail. In fact, failure to address the return path is a leading cause of signal integrity issues. Perhaps more troubling, they frequently go undetected even in the setting of comprehensive simulation.

The perfect plane promise. Historically, we've approached the transmission line (formed each time two ICs are connected with PCB etch) from a two-dimensional perspective. We typically place and route boards from the top view utilizing the visualization capabilities of our layout software to move up or down the layer stack (the third dimension or Z-axis). It's common to have power plane layers not visible, frequently unrouted, or even empty until well into the layout timeline. Both PCB layout practice and the simulation techniques that follow it rely on a simple assumption:

> Both power and ground will be supplied to each chip, will continue, uninterrupted between them, be added in later, and will be beautiful. So, let's all just assume "perfect planes."

For a long time, what reads as sarcasm was in fact true. For the frequencies we were interested in, PCB designers have done a remarkable job routing boards such that both the power and ground planes have in fact been "electrically perfect." This is because the many perforations from drill and via anti-pads remained small enough to go electrically unnoticed. So, what has changed? Volumes of studies, articles and even textbooks have been written to address this very question, but they generally fall into two categories: The planes are much less "continuous," and the signals are much less forgiving.

Not so perfect anymore. Let's look at the power planes themselves first. High-density packaging, fine-pitch devices, and tightly packed vias have combined to reduce the amount of copper that remains when a plane layer is manufactured. Further complicating this, the copper that does remain is often partitioned so several voltages can share a single physical layer, creating additional voids. Complications from this layer sharing can also sabotage the "continuous plane" goal as factors such as current demand, safety clearances and filtered power further influence the chopping of the plane. Known among industry veterans as the "Swiss cheese effect," it is most noticeable for the power planes but also affects ground (FIGURE 1). The same miniaturization effort for which we chop up the power planes has led to layer reduction as well. Typically, as designs have evolved, the ground layers suffer due to the substantial reduction in conducting copper.

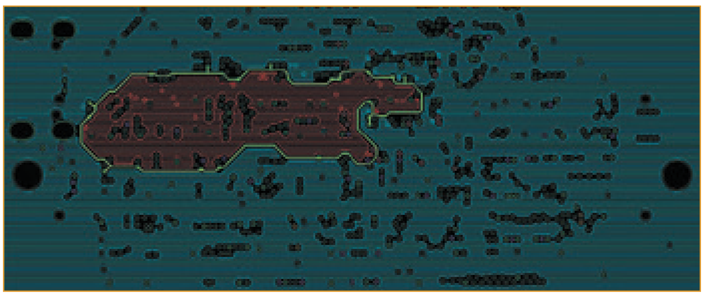

FIGURE 1. The Swiss cheese effect impacts power and ground planes.

Collectively, these perforations and separations create at best bottlenecks and at worst flat-out obstructions to the very current flow we've historically assumed uninterrupted and ignored. (Remember the "perfect plane promise.")

As our planes get less perfect for the reasons above, we must revisit the determination that they can be assumed "electrically perfect" for the purposes of signal integrity simulation. What we find is the signals themselves are also becoming less forgiving of these return path imperfections. It's the least desirable situation: The returns are becoming less perfect as the signals are becoming more susceptible to the imperfections. Simply put, as signals get faster (the natural progression of hardware development), smaller interruptions become more significant. This is like how a 30-second stoplight becomes more significant on our drive from First Street to Fifth Street than from First

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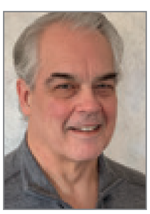

Street to, say, Boston. As signals get faster, even if the return path imperfections haven't worsened (they have), their relative size and significance has increased significantly.

Addressing the return path dilemma. The most challenging component of the return path dilemma is "awareness." Even those convinced to make routing power and ground a priority often do so with a focus only on power delivery. Many forget the critical "return path" function that same copper is responsible for. No board would be considered for production with a signal routed on two layers *without* a via or pin to complete the conductive path, yet the same type of interruptions in the conductive loop go unquestioned daily when they occur on the return path.

To understand this, we need to review a bit of transmission line physics. As digital data are transmitted from driver to receiver, each transition creates an electrical "edge," which propagates along the transmission lines' length. It is this edge, and the effects they cause, that we study in signal integrity. The return current energy travels with this edge on the nearest conductor it can find (**FIGURE 2**). The steeper the edge, the more that return path energy stays closely concentrated near it, following it from driver to receiver. Much like lanes on a highway, signals are transmitted over the routed conductors from source to destination and return on conductors (lanes) in close proximity, often parallel. Not considered, however, is the way energy moves. We mistakenly visualize each bit from traveling source to load and its return energy reversing that, running load to source.

Extending our highway analogy, we would be more accurate if each car traveled only a single exit, passing its "energy" to the next in line and returning on the parallel lanes immediately. We would see traffic (current flow) on the homebound lanes well before the message even made it to the destination. Consider the case where somewhere on the path those return-bound lanes were interrupted, failed to connect, or were otherwise disrupted; the resulting congestion would quickly impact each exit and ultimately the highway in both directions. This model better represents the energy movement in a transmission, and from it we can make some PCB comparisons.

If routing a signal trace, and its first several inches are adjacent to a ground layer, voids in that layer are the electrical equivalent of missing sections of highway. Travelers will eventually make the connection, but may use several inefficient, indirect pathways to do it. Likewise, ground slots, via voids and plane partitions can cause enough disturbance in the return path conduction to create "issues" as the signal seeks its own path. Frequently these "gaps" in adjacent return copper are easily addressed, but often go unchecked.

A similar, but even more dangerous, situation occurs when the copper on either side of the void is not connected electrically, as in the case where a trace is routed over a void separating one power domain from another. The multiple power rails that have become the hallmark of PCB design today almost guarantee these will need watching. Again, the highway can help visualize that. Here, we would replace a single section of the return lanes with the lanes of a different highway. Like the original, travelers could use those lane sections in their path, but would need to navigate getting on, getting off, *and* switching from one highway to another. Relating this to our transmission line problem, the concerns are the same. Although there is nothing inherently problematic when a 3-volt signal returns on a 1.8V plane, many avoid this condition, and several tools are available to identify the "reference changes." Like the road, provided the entrance, exit and plane change have good conductive paths between them, there is no issue with the differing levels.

Power is the new bus. This simple change in the way we visualize the conduction helps us devise a routing methodology that can avoid the most common return path pitfalls. Many are finding success reaching back to methods driven by the wide busses associated with parallel data transmission. Because a bus frequently involves many nets following a similar path to the same chips, they are typically routed (or at least floor-planned) first. Recognizing the large swaths of real-estate they need, an initial plan or partial route almost always occurs while placement is still in flux. With a single interface now requiring numerous voltages, power is the new bus on nearly every board. To ensure your PDN is sufficient both in delivery and its ability to provide adequate returns, consideration must start early and be a part of the routing process, even in placement and fanout. Route power first; use it as a canvas for the remainder of your routing. This as well as the proper tools can help prevent the two things that get us in trouble: reference changes and routing over splits. Avoiding these where we can (and containing them where we can't) enables us to maintain our claim to "electrically perfect" planes for the frequencies we're concerned about and enhances our ability to find problems with a board before we build it. □

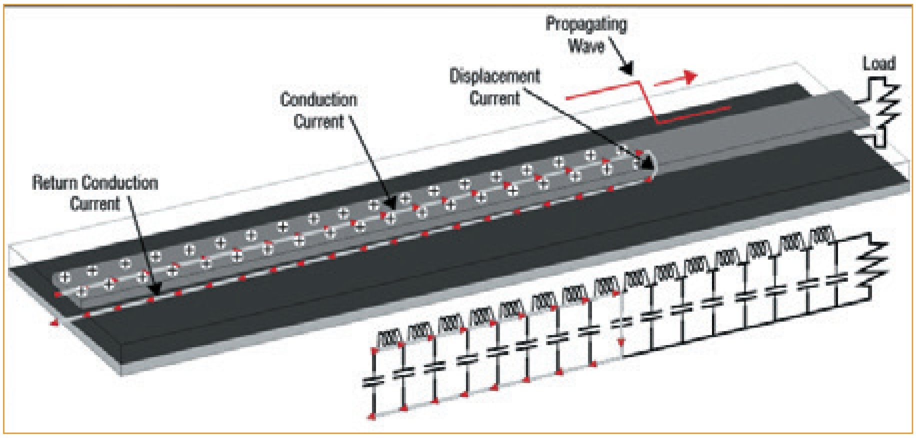

FIGURE 2. The digital data transmission path creates an electrical "edge" along the length of the line.

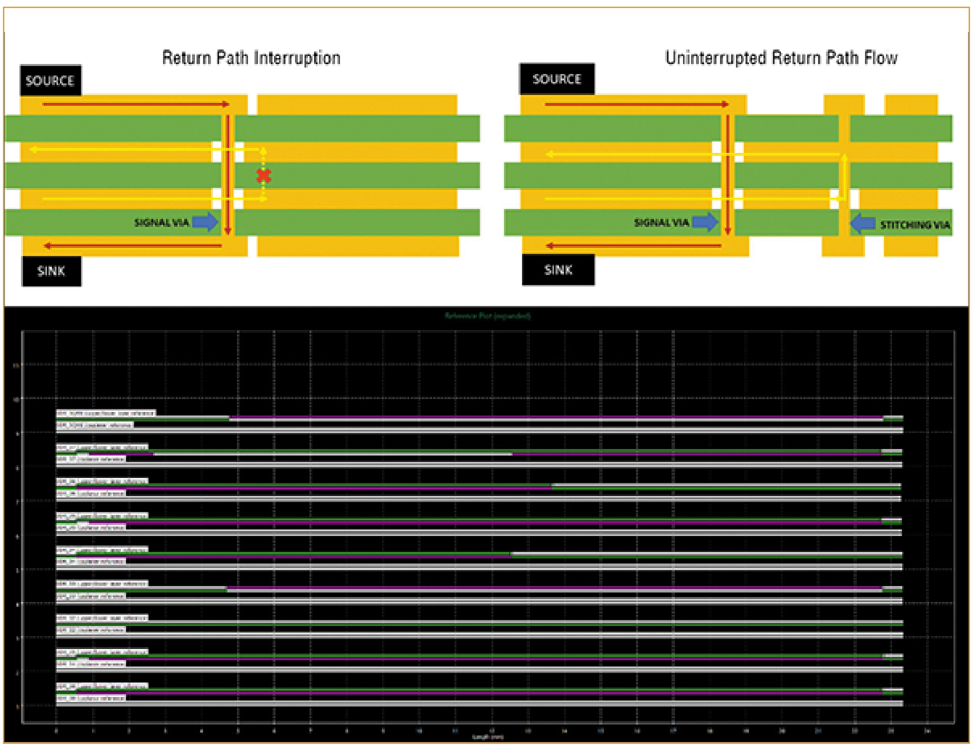

FIGURE 3. Route power planes prior to other planes and pads.

Cryptocurrency Mining is Energy-Intensive. Is It Also an Energy Solution?

The controversial technology could help cut the carbon footprint of daily living.

WE KNOW THE pandemic has forced many to work from home (WFH) and as a result driven up demand for products like PCs and home IT equipment. There has also been a large reduction in commuting to and from workplaces, which many have enjoyed and vowed to continue even after lockdowns are lifted.

These changes ought to benefit the planet by reducing greenhouse gas emissions and other pollution. We should consider the impact of the extra demands placed on data infrastructures to handle this upsurge in remote working, however. It takes energy to move all that data back and forth, although arguably this would happen whether workers are at the office or at home.

Data center businesses have blossomed during the pandemic, with an uptick in demand for their services. These include work-related services as well as home entertainment. Netflix has reported record consumption, although the rise has flattened recently, perhaps as content has become exhausted.

With or without the pandemic, the number of subscribers is growing, and the diversity of workloads, particularly IoT applications, data analytics, AI training, video streaming and social media, is increasing.

Cryptocurrency mining, the number crunching needed to maintain the digital ledger (blockchain) and create new cryptocurrency, has been growing too and is likely to continue as acceptance of cryptocurrency becomes more widespread. Despite the concerns governments and financial regulators have expressed regarding cryptocurrencies such as Bitcoin and independent exchanges, El Salvador recently became the first sovereign state to recognize Bitcoin as legal tender.

Perhaps even more important, the Chinese government has recently created its own digital currency, the Digital Yuan, although there are important differences compared with a traditional cryptocurrency, one being that it is centralized and government-controlled.

The political, practical and technical aspects of cryptocurrencies are fascinating. The digital ledger technology eliminates any need for a coordinator or intermediary and hence could dramatically reduce the cost of transactions. Investopedia noted the Digital Yuan could enable China's unbanked population – the world's largest – to take part in the mainstream economy without expensive banking products and infrastructure.

This observation contrasts with concerns over the energy-intensive nature of cryptocurrency mining. The Cambridge Bitcoin Electricity Consumption Index continuously monitors the energy consumed by mining and estimates it to be 26 to 175TWh per annum, the median being 72TWh. To put this in perspective, it's about half the energy estimated to be consumed in the US alone by consumer devices sitting in standby modes and not being used.

Cryptocurrency creators know energy consumption is an issue. Ethereum is trying to tackle it by changing its underlying principle from proof of work, which requires energy-intensive mining, to a proof-of-stake basis that could consume 1/10,000th of the energy currently needed.

Another way to reduce crypto's carbon footprint is to power data centers using renewable energy sources. Plans were announced recently to set up a dedicated crypto-mining data center in Texas, powered by a gigawatt of renewable energy.

Miners are also blamed for the supply difficulties conventional data centers and gamers have experienced in accessing high-performing graphics accelerator cards. Of course, the disruption to IC supplies caused by the pandemic is another factor. The situation could ease as chip supplies recover and as new cryptocurrency mining processor (CMP) cards reach the market. These deliver the performance of a graphics card while removing display outputs and image-rendering capabilities, which, obviously, are unneeded.

As well as chip-supply shortages, supplies of basic materials like FR-4 substrates have become compromised of late. Some Asian suppliers have extended lead times for FR-4 substrates to several months, leading some markets to consider higher-value substrates as replacements. The shift could ultimately end demand for low-end FR-4 materials, particularly in Europe.

There is some justification for moving to higher-value substrates. The demand for high-performance computing engines to host all types of data-intensive workloads is forcing system architects to contemplate how to reduce energy consumption and improve thermal management. Low-loss substrates, in particular, are a part of the solution to these challenges, and there will also be demand for more diverse and differentiated portfolios of thermal management substrates.

Ultimately, we must find ways to accomplish our tasks using less energy and, in fact, with less environmental impact generally. Other examples include moves toward using less-aggressive chemistries in PCB production.

WFH and digital currencies (whether centralized or decentralized – the arguments will continue) are trends that could help us work toward parity between our demand for energy and the total environmentally sustainable supply. ◻

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Flex Material Thickness

A little information goes a long way – but can carry added cost.

MARK FINSTAD

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"MY COMPANY HAS traditionally specified the finished thickness for each flex printed circuit (FPC) layer, and total thickness. This is because it's understood some material layer thicknesses (i.e., adhesives) change during the manufacturing process due to compression and curing. As a purchaser of FPCs, we are less concerned with the initial raw material thickness than the finished thickness.

"We have received feedback, however, that the FPC market in general specifies the raw material thickness used in FPC fabrication, and not finished thickness. The assertion was nearly all customers purchasing FPCs follow this rule to minimize miscommunication. Is this common practice?"

Answer: The level of detail we see on customer drawings is all over the map, but the majority of customers that do specify individual materials will indicate the raw material thicknesses and then the overall finished circuit thickness.

I typically recommend you only specify what is truly critical to the electrical and mechanical function of the circuit. This usually includes minimum *finished* copper thickness, overall circuit thickness (in each area with unique stack-up), and dielectric spacing between layers (when there is controlled impedance). Any additional material stack-up requirements that are specified will only add cost and possibly reduce the supplier base that is willing to build your parts. Following are the different variables in play:

***Finished* copper thickness.** You will notice the emphasis on *finished* copper thickness. Many factors during processing can affect finished copper thickness on each layer, and these factors can increase or decrease the final result. For this reason, never assume the starting copper weight is exactly what you will have on the finished circuit on any given layer. Fabricators use multiple copper cleaning steps during processing, and each will slightly reduce the copper thickness. Conversely, copper plating will typically increase the copper thickness. To further complicate the situation, if panel plating vs. button plating is not specified on the drawing, the fabricator has some liberty to use whatever method works best for them. So, if you assumed they were going to panel plate, and they instead button plated, your presumed finished copper thickness could be significantly less than expected. For any application where finished copper thickness is critical to the function of the circuit, it is always best to specify *finished* copper thickness. On the other hand, if you do not have impedance, high current, or voltage drop requirements, copper thickness is not critical to the function and you can just specify starting thickness.

Flexible adhesive films. You are correct that adhesive layers do change thickness as the material flows to fill between conductors. The exact amount of change will vary between manufacturers and the methods they use for lamination. But in reality, if your conductors are fully encapsulated, and the circuit meets overall thickness requirements, why do you care? It is much better to only specify what really matters, and give the vendor some freedom to meet those requirements in the most cost-effective way.

FIGURE 1. This cross-section specifies the material manufacturer's P/N, which indicates "before processing" material thicknesses. It also indicates total thickness over stiffener area, rather than a specific stiffener thickness.

Flexible dielectric films. Thermosetting polymer dielectric films like polyimide (most common) are very stable during lamination and other processing and will change little, if any, from the starting thickness. Thermoplastic polymer dielectrics (much less common) can change considerably during lamination. If a final dielectric layer thickness for a thermoplastic polymer is critical, note the final value on the drawing.

Stiffeners. Specifying stiffener and/or stiffener adhesive thickness can cause real heartburn for your fabricator. The same issues that apply to dielectric adhesives also apply to stiffener adhesive. Also, raw FR-4 laminate tolerances increase as the overall thickness of the FR-4 increases. The fabricator will know the typical tolerances and how to deal with them. You are best specifying overall circuit thickness, including the stiffeners, and let the fabricator determine the best stiffener and stiffener adhesive thicknesses to meet your requirements.

In reality, if the overall circuit thicknesses are within the specified range, and the circuit functions as it should electrically and mechanically, do you really care what *any* of the individual layer thicknesses are? It is important to ensure you are not over-specifying your flex design to where you are adding cost without adding value. If a particular thickness or feature will have a noticeable impact on the function of the circuit in its application, by all means specify that on the drawing or procurement documentation. If not, leave it off.

Any specific features you add to the drawing must be verified by the manufacturer and will carry a price tag. Review your drawings prior to release, and for each dimension and feature specified ask, "Does this *really* need to be on the drawing? ▫

Ed.: The authors will speak on flex circuits at PCB West in October.

Dooson to Focus on Laminate Sales for Future Growth

SEOUL – Doosan Group is selling off non-core businesses to focus on its electronics unit, according to reports.

The conglomerate's printed circuit materials business projects 2021 operating profits will rise 17% from a year ago to 114.6 billion won ($99.9 million) on higher demand. It reported sales of 816.1 billion won last year.

Doosan forecasts electronics unit sales will rise to 2 trillion won by 2025, about 1.15 trillion won from laminates and 950 billion won in sales from new growth from displays, electric vehicle (EV) components and energy materials.

As part of a debt reduction plan, Doosan has sold its industrial and construction equipment units, which were responsible for a combined 44% of its operating profits, leaving the electronics, retail and hydrogen businesses.

Electronics now brings in 69% of the company's overall operating profit, up from 39% before the divestitures. (MB)

'BIG GETS BIGGER and Faster'

The largest circuit board fabricators are pulling away from the rest of the market. by DR. HAYAO NAKAHARA

This is the 25th NTI-100 report. The author cannot believe he has done NTI-100 such a long time. As years go by, it becomes more difficult to accurately record revenue data of privately owned PCB fabricators, and there are many. As a result, the data of about one-fifth of the top PCB companies are questionable. Nevertheless, it is interesting to see the revenue trend.

As usual, data compiled by trade organizations and with the assistance of many of the author's friends around the globe were vital to completing this report. He expresses his gratitude to all who helped. Any errors are strictly his responsibility.

The 2020 average exchange rate conversion of revenue from local currencies to the US dollar was made using the exchange rates listed in TABLE 1. Since various organizations and individuals seem to use slightly different rates, the results may differ but only slightly.

It is impossible for one person (the author) to get an accurate number of PCB fabricators and factories worldwide. TABLE 2 is the best he could come up with. European figures are based on his old industry friend, Michael Gasch.

China is home to approximately 55% of the world's PCB makers. That figure includes about 150 foreign transplants, however. For example, there are about 100 Taiwan-owned fabricators, some of which do not have plants in Taiwan. Japan has about 20 fabricators in China. The US has three; Europe has several; and Southeast Asian countries have several.

In mid-1980, Europe had over 1,400 fabricators, according to Gasch. The US had 780 and Japan about 250 in 2000. The numbers in the US and Japan decreased through closures and

TABLE 1. Average Exchange Rates vs. US$1, 2014-20

Currency	2014	2015	2016	2017	2018	2019	2020
China Yuan (RMB)	6.16	6.28	6.63	6.76	6.62	6.91	6.90
Japan Yen	105.86	121.06	107.84	112.93	110.44	109.01	106.77
Taiwan NTD	31.86	31.78	32.25	30.44	30.16	30.93	29.47
Korea Won	1,054	1,132	1,161	1,131	1,101	1,166	1,180
Thai Baht	32.48	34.25	35.29	33.92	32.32	31.03	31.27
Singapore Dollar	1.28	1.38	1.44	1.33	1.35	1.36	1.38
Malaysia Ringgit	3.27	4.12	4.10	4.32	4.04	4.12	4.20
Vietnam Dong	21,137	21,921	22,763	22,721	23,001	23,202	23,201
Philippines Peso	44.40	44.52	47.30	50.44	52.70	50.82	4.96
Indonesia Rupiah	12,671	13,749	13,320	13,440	14,236	13,799	14,559
Canada Dollar	1.104	1.279	0.997	1.297	1.296	1.327	1.34
Indian Rupee	61.01	64.24	67.80	64.87	68.43	70.39	71.12
Mexico Peso	13.31	15.79	19.05	18.95	19.00	19.25	21.50
Russia Ruble	38.51	61.20	57.40	58.31	62.78	64.69	72.41
Swiss Franc	0.92	0.96	1.00	0.98	1.02	0.99	1.38
UK Pound	0.61	0.66	0.74	0.81	0.75	0.78	0.78
Euro	0.75	0.90	0.90	0.89	0.84	0.89	0.87

Source: NTI summary from exchangerates.com

TABLE 2. Global Number of PCB Fabricators and Factories (Estimated in March 2020)

	China**	N. America	Europe	Japan	Taiwan	S. Korea	S.E.A.	India	S. America	ROW*	World
No. Companies	1,250	190	170	110	80	70	80	130	37	130	2,247
No. Factories	1,480	230	190	190	120	90	90	130	37	130	2,687

Source: N.T. Information Ltd. *Includes Africa, Middle East and Russia (rough estimate) **As of May 2021, about 70 new plants are under construction and under plan

M&As. Assuming 150 foreign fabs operating in China, it is necessary to subtract 150 from the world total of 2,247. That brings the total number of fabricators in the world to about 2,100. Chinese "nationals" make up 1,100 (1,250 minus 150). Since many large fabricators have multiple factories, the total number of factories worldwide is estimated to be about 2,700.

These figures may provide interesting insight later.

The capital investment payoff. In compiling the annual NTI-100, the author found 128 fabricators had revenue of $100 million or more in 2020. In 2019, there were 122 such companies, with a total output of $62.3 billion. In 2020, the total revenue of that cohort was $68.8 billion, an increase of 10.3%, although the number of fabricators in these two years is different.

One trend of note is big gets bigger and faster. Like semiconductor production, PCBs are a capital-intensive industry. As a fabricator grows, its ability to invest more makes it bigger and faster. You may see this trend from the upper echelon of these firms.

By region, China's revenue grew 14.5% year-over-year, while its number of entries in the NTI-100 increased by four companies to 56 in 2020 (TABLE 3). The output of Chinese nationals is rapidly approaching that of Taiwan. South Korea's strong growth came from IC substrates and flex printed circuits (FPCs), largely in Vietnam. Japan grew but only by a small amount compared to the Chinese and Koreans. Starting in 2021, Japan's output is expected to grow rapidly on the back of several billion dollars ($4+ billion) in investment over the next few years to expand IC substrate production there.

The US saw negative growth because TTM Technologies sold its mobility business to AMK Meadville in 2020 (for $550 million). Europe's gains come mainly from the growth of AT&S. Southeast Asian fabricators grew on the strength of KCE, MFS and Gul Technology. Taiwan fabs were mixed. IC substrate makers did well, but those engaged mainly in automotive PCB did poorly in general. Motherboard makers for PCs, tablets, wearables and smartphones did well.

TABLE 3. NTI-100 2020 Summary by Country

Country	# Entries	2019	2020	Growth
Taiwan	25	21,796	23,076	5.9%
China	56	17,319	19,912	14.5%
Japan	21	11,692	12,153	3.9%
S. Korea	14	7,029	8,070	14.8%
US	4	2,778	2,680	-3.6%
Europe	5	1,795	1,980	10.3%
SE Asia	3	930	1,048	12.7%
Total	**128**	**63,339**	**68,919**	**8.8%**

In US$ millions

TABLE 4. 2020 Top Fabricator Analysis

Rank	2019	2020	Growth	2020 Share
Top 1-25	36,176	40,695	12.5%	59.3%
Top 26-50	13,114	13,369	1.9%	19.5%
Top 51-75	6,992	7,316	4.6%	10.7%
Top 76-100	3,773	4,017	6.5%	5.8%
Top 101-128	3,092	3,204	3.6%	4.7%
Top 128 Total	**63,147**	**68,601**	**8.6%**	**100%**

In US$ millions

The $1B club. If we break the 128 fabricators in the NTI-100 into segments, the top 25 saw the largest aggregate percentage growth, and have an almost 60% share of NTI-100 (TABLE 4). Remember the previous observation: Big gets bigger and faster.

In 2019, 17 fabricators had revenue of $1 billion or more, and their total output was $29.8 billion (TABLE 5). Despite the poor outlook a year ago as the Covid-19 pandemic kicked into high gear, six more topped the $1 billion mark in 2020, and the cumulative revenue was $38.9 billion. Need we say it again? Big gets bigger and faster.

The Taiwanese fabricators in Table 5 accounted for 30 to 31% of the world output. Of 23 companies, eight are Taiwan nationals, or 35% of the total. They are investing heavily, and the author will not be surprised if the Taiwanese remain in the top position for some years to come. The two top Taiwanese fabricators, Zhen Ding Tech and Unimicron, produced more than the total 2020 output in North America.

The rankings. NTI-100-listed fabricators with an asterisk (*) are engaged heavily in FPC: ZD Tech, DSBJ, Nippon Mektron, Young Poong Group (Young Poong Electronics and Interflex), Fujikura and Flexium. All are major suppliers of FPC to Apple.

As noted, the big gainers were the IC package substrate makers ("PKG substrate"): Unimicron, Ibiden, Samsung Electro-Mechanics, AT&S, Shinko Denki, LG Innotek, Simmtech, and Kinsus. In fact, the overall best performers in 2020 were PKG makers. Their investment in capacity increases through enlarging existing facilities and building new plants is phenomenal. Ibiden spent $1.2 billion from 2019 to 2021 and announced another $1.6 billion to scrap an old plant and build a new one for high-end PKG substrates. AT&S is spending €1.1 billion for Plant III in its Chongqing plant and an additional €1.7 billion to build a new PKG plant in Kedah, Malaysia, probably in financial partnership with Intel. Unimicron built three new PKG plants in China, which cost the company $800 million, and is building a $1 billion plant for PKG substrates in Yangmei, Taiwan. Rumor is Intel is supporting Unimicron. Shinko is spending about $800 million for PKG. Kyocera (#37) is the world's largest PKG substrate maker if ceramic substrates are included, with about $2.5 billion PKG substrate revenue. Kyocera is filling up its Ayabe (Kyoto) Plant 3, which was empty the past few years.

Shennan Circuit finished construction of two new PKG plants in Wuxi. Kinsus is converting one of its plants in Taiwan to PKG substrate manufacturing. Daeduck is concentrating on PKG substrates. Kinwong, Victory Giant, Suntak Technology and CEE made deals with the government to invest in PKG substrate manufacture. They may be getting government subsidies.

China's consumption of semiconductor devices is about 40% of the world total, yet its domestic production of the total consumption was only 16% in 2020 (FIGURE 1). Pressure from the US government is accelerating China's huge investment into semiconductor technology in an attempt to be self-reliant. In view of this future development, many Chinese PCB fabricators are taking aim at the PKG substrate market, although it will take time to catch their peers in Japan, Taiwan and South Korea. According to IC Insights, the Chinese semiconductor "deficiency" in 2024 is expected to be 80%.

Thanks to remote work and study brought on by the pandemic, demand for PCs, particularly laptops, tablets and game consoles, has skyrocketed since April 2020. Motherboard makers for these products benefited from this demand. Compeq, HannStar, Gold Circuit, Tripod, etc., mainly Taiwanese fabricators, did well.

Although recovering quickly, automotive PCB makers performed poorly in 2020. Meiko (not so bad because of other products), CMK, Chin Poon, Dynamic, Ellington, Kyoden, Shirai Denshi, etc., each had poor showings last year. Moving forward, however, the automotive PCB business is expected to grow steadily despite the chip shortage. Electrification of automobiles creates a market – with substantial demand – for new types of PCBs. KCE did exceptionally well, although its major revenue comes from automotive PCBs. TTM's automotive business was not strong in 2020.

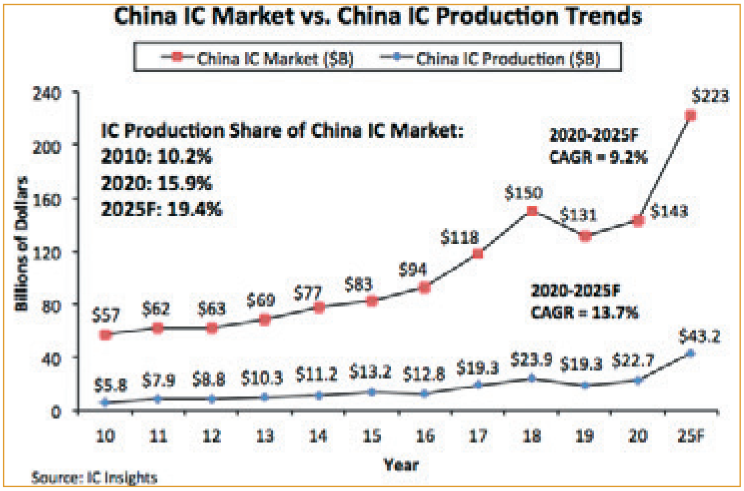


FIGURE 1. China IC Production, 2009-24 (estimated). Source: IC Insights.

TABLE 5. Fabricators in 2020 with Revenue of $1B+

Rank	Company	Nationality	2019	2020	Growth
1	Zhen Ding Tech	Taiwan	4,080	4,454	9.2%
2	Unimicron	Taiwan	2,801	2,982	6.5%
3	DSBJ (Mflex+Multek)	China	2,150	2,719	26.5%
4	Nippon Mektron	Japan	2,652	2,639	-0.5%
5	TTM Technologies	US	2,238	2,105	-5.9%
6	Compeq	Taiwan	1,906	2,054	7.8%
7	Tripod	Taiwan	1,851	1,885	1.8%
8	Shennan Circuits	China	1,525	1,680	10.2%
9	Ibiden	Japan	1,238	1,556	25.7%
10	HannStar Board	Taiwan	1,464	1,551	5.9%
11	SEMCO	S. Korea	1,043	1,493	43.1%
12	Kingboard PCB Group	China	1,253	1,370	9.3%
13	AT&S	Austria	1,153	1,360	18.0%
14	Nanya PCB	Taiwan	1,055	1,243	17.8%
15	Wus Group	Taiwan	1,205	1,243	3.2%
16	Young Poong Group	S. Korea	1,134	1,206	6.3%
17	Meiko	Japan	1,082	1,117	3.2%
18	Fujikura	Japan	977	1,073	9.8%
19	Shinko	Japan	764	1,061	38.9%
20	LG Innotek	S. Korea	624	1,054	68.9%
21	Kinwong	China	917	1,023	11.6%
22	Simmtech	S. Korea	858	1,018	18.6%
23	Flexium	Taiwan	885	1,014	14.6%
Top 23 Total			**34,855**	**38,900**	**11.6%**

In US$ millions

High-layer-count multilayer board fabricators for 5G infrastructure did well: TTM Technologies, Shennan Circuit, Wus Electronics, Shengyi Electronics, Gold Circuit, etc.

Sumitomo Denko sold its Shenzhen Songgang FPC plant last year to a Chinese fabricator, Guangdong Junya. Showa Denko is the former Hitachi Chemical. However, Showa Denko sold its PCB division to Polaris Capital Group, a Japanese private equity firm, after the table was made. IKT, with three plants in Japan and one in Singapore, used to be known as Hitachi Chemical Singapore, or HCS.

When it comes to PCB fabricators ranked below 50, the author's knowledge gets fuzzy, unless they are publicly held. Many Chinese fabs, which are privately held, are problematic because they do not publish financial reports. The author depends on private communications to obtain their revenues.

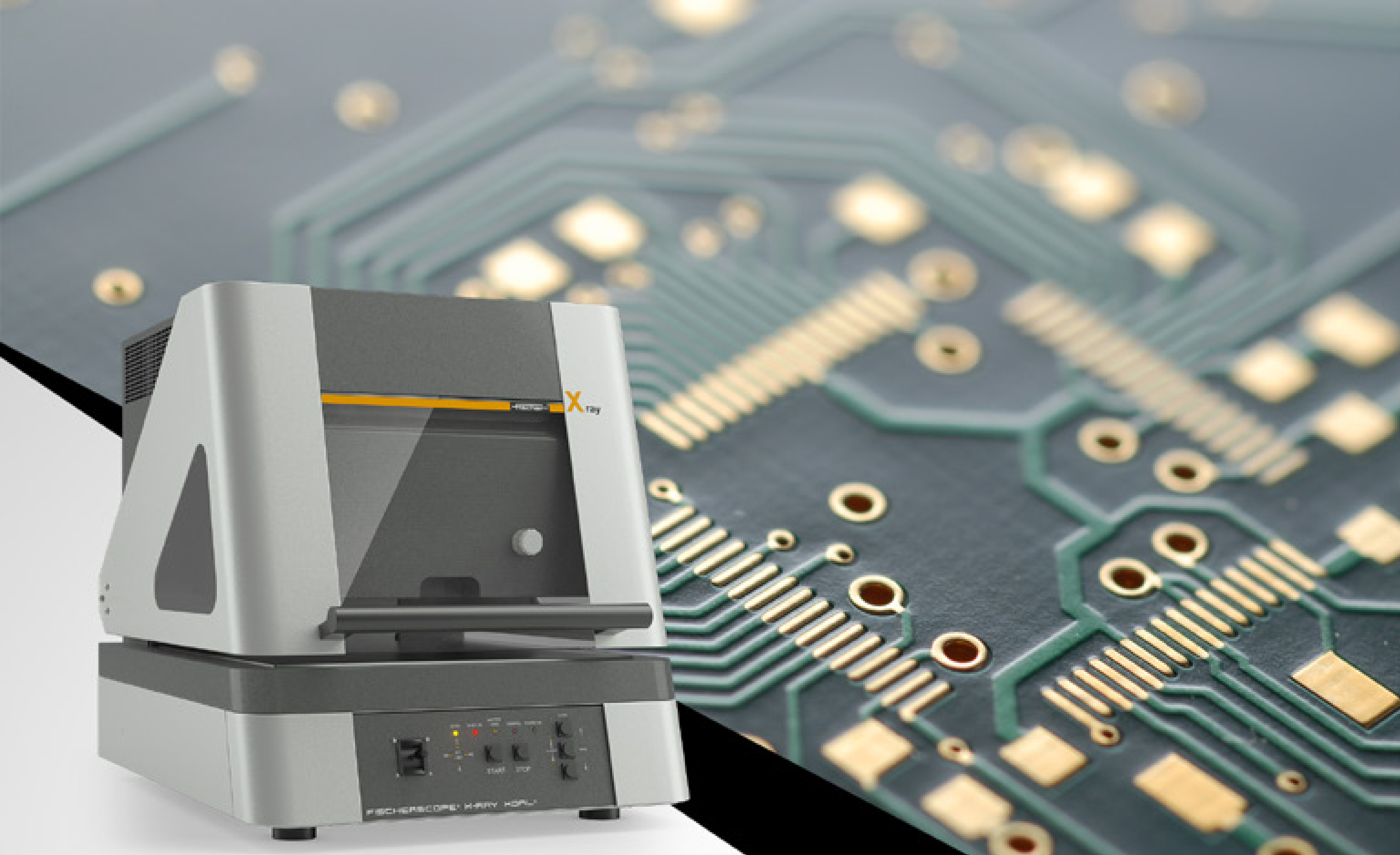
Many mergers and acquisition activities are taking place in China, and it is difficult to keep up with ownership changes. One big problem is the acquired companies continue to be called by their original names. Although the author understands written Chinese fairly well, when it comes to the nitty-gritty of ownerships, he is hopelessly in trouble. Once in a while he gets a lucky break to learn complex ownerships after spending hours, and sometimes days, digging.

Recently, the author did a study on new plant construction in China. He identified about 70 projects, some huge, some modest. He recognized at least one or two additional projects per week. To some eyes, this may lead to disastrous overcapacity in China. However, none of the fabricators seem to go belly up. The PCB industry is a strange business. PCB fabricators are often resilient. Even when they may be on the bankruptcy list, they continue to exist for some reason. One thing for sure is that with all this coming capacity, more Chinese fabricators will enter the NTI-100 list over the next several years. After 25 years compiling the NTI-100, it is about time for the author to quit. He gets tied up with this project for six months. He hopes someone will take

TABLE 6. Top PCB Fabricators, 2020

Rank	Company	Local Name	Country	2019	2020	Growth
1	ZD Tech*	瑧鼎科技	Taiwan	4,080	4,454	9.2%
2	Unimicron	欣興電子	Taiwan	2,801	2,982	6.5%
3	DSBJ (Mflex*+Multek)	東山精密	China	2,150	2,719	26.5%
4	Nippon Mektron*	メクトロン	Japan	2,652	2,639	-0.5%
5	TTM Technologies	TTM Tech	US	2,238	2,105	-5.9%
6	Compeq	華通電脳	Taiwan	1,906	2,054	7.8%
7	Tripod	健鼎科技	Taiwan	1,851	1,885	1.8%
8	Shennan Circuit	深南電路	China	1,525	1,680	10.2%
9	Ibiden	イビデン	Japan	1,238	1,556	25.7%
10	HannStar Board	瀚宇博徳	Taiwan	1,464	1,551	5.9%
11	Samsung E-M	삼성전기	S.Korea	1,043	1,493	43.1%
12	KBC PCB Group	建滔集団	China	1,253	1,370	9.3%
13	AT&S	AT&S	Austria	1,153	1,360	18.0%
14	Nanya PCB	南亜電路	Taiwan	1,055	1,307	23.9%
15	Wus Group	滬士電路	Taiwan	1,205	1,243	3.2%
16	Young Poong Group*	영풍그룹	S. Korea	1,134	1,206	6.3%
17	Meiko	メイコー	Japan	1,082	1,117	3.2%
18	Fujikura*	フジクラ	Japan	977	1,073	9.8%
19	Shinko Denki	新光電気	Japan	764	1,061	40.2%
20	LG Innotek	LG이노텍	S. Korea	624	1,054	68.9%
21	Kinwong	景旺電子	China	917	1,023	11.6%
22	Simmtech	심텍	S. Korea	858	1,018	18.6%
23	Flexium*	台群科技	Taiwan	885	1,014	14.6%
24	Kinsus	景碩科技	Taiwan	758	920	21.4%
25	Victory Giant	勝宏科技	China	563	811	44.0%
Top 25 Total				**36,176**	**40,695**	**12.5%**

In US$ millions. *Flex circuit fabricator.



over this tedious and not-so-rewarding work. Curiosity drove him the past 25 years.

Two South Korean makers should have been in the past NTI-100 lists. One is TLB (no. 94), a spinoff from Daeduck more than 10 years ago. TLB is engaged mainly in module circuits manufacture. Another is Haesung DS (no. 113). This fabricator is a spinoff from Samsung Techwin and came under Haesung Group. In 2020, 31% of its revenue of $386 million came from PKG substrates.

Aiko Kiki (no. 108) is providing core circuits to AT&S Chongqing and other Japanese PKG substrate makers. With strong demand for high-end flip-chip BGAs, Aiko Kiki doubled its core circuit capacity in Japan. Shin-Asahi Denshi (no. 122) made it. It purchased Panasonic's PCB plant in central Japan, which specializes in buildup multilayer boards. Like most makers in North

TABLE 6. Top PCB Fabricators (Continued), 2020

Rank	Company	Local Name	Country	2019	2020	Growth
26	Gold Circuit	金像電子	Taiwan	645	794	23.1%
27	Daeduck Group	대덕전자	S. Korea	931	785	-15.7%
28	T.P.T.	志強科技	Taiwan	736	775	5.3%
29	AKM*+AKM Meadville	安捷利美維	China	450	756	68.0%
30	CMK	シーエムケイ	Japan	826	700	-15.2%
31	Shenzhen Suntak	深圳崇達	China	540	633	17.2%
32	BH Flex*	베에이치플렉스	S. Korea	569	611	7.4%
33	Shenzhen Fast Print	深圳興森快捷	China	551	585	6.2%
34	Career*	嘉聯益科技	Taiwan	558	544	-2.5%
35	DG Shengyi Electronics	東莞生益電子	China	448	526	17.4%
36	Chin Poon	敬鵬工業	Taiwan	607	520	-14.3%
37	Kyocera PCB	京セラ	Japan	500	515	3.0%
38	Unitech	燿華電子	Taiwan	761	488	-35.9%
39	Sumitomo Denko*	住友電工	Japan	574	473	-17.6%
40	Murata*	村田製作所	Japan	450	450	0.0%
41	KCE Electronics	KCE	Thailand	374	446	19.3%
42	Isu-Petasys	이수페타시스	S. Korea	444	436	-1.8%
43	Wuzhu	五株科技	China	358	432	20.7%
44	Nitto Denko*	日東電工	Japan	433	429	-0.9%
45	Dynamic	定穎電子	Taiwan	465	428	-8.0%
46	Founder Tech	方正科技	China	440	424	-3.6%
47	Aoshikan	奥士康	China	330	422	33.7%
48	Bomin	博敏電子	China	300	403	34.3%
49	APEX International	泰鼎科技	Taiwan	356	402	12.9%
50	SI Flex*	에스아이플렉스	S. Korea	468	391	-16.4%
Top 26-50 Total				**13,114**	**13,368**	**1.9%**

In US$ millions. *Flex circuit fabricator.

TABLE 6. Top PCB Fabricators (Continued), 2020

Rank	Company	Local Name	Country	2019	2020	Growth
51	Xiamen Hongxin*	厦門弘信	China	356	382	7.3%
52	Olympic	世運電路	China	345	382	10.7%
53	CCTC	超声電子	China	336	361	7.4%
54	Gul Technologies	高徳科技	Singapore	316	361	14.2%
55	Ellington	依頓電子	China	436	355	-18.6%
56	Sun & Lynn	深聯電子	China	297	342	15.1%
57	Kyoden	キョウデン	Japan	385	340	-11.7%
58	CEE PCB	中京電子	China	304	339	11.5%
59	Showa Denko Materials	昭和電工	Japan	346	330	-4.6%
61	GZ Junya (Champion Asia)	広州駿亜	China	213	299	40.4%
62	Redboard	紅板	China	311	296	-4.8%
63	STEMCO*	스템코	S. Korea	234	289	23.5%
64	Sanmina	Sanmina	US	280	285	1.8%
65	ASE	日月光	Taiwan	262	282	7.6%
66	APCB	競国	Taiwan	269	282	4.8%
67	Jiangsu Chuanyi (Transtech)	江蘇伝�White	China	222	256	15.3%
68	DAP	디에이피	S. Korea	232	255	9.9%
69	Fujitsu	富士通	Japan	243	244	0.4%
70	MFS*	MFS	Singapore	240	241	0.4%
71	Delton Technology (Guanhe)	広合科技	China	193	235	21.8%
72	Guangdong Kingshine	科翔股份	China	192	232	20.8%
73	Kunshan Huaxing	昆山華新	China	200	212	6.0%
74	Shirai Denshi	シライ電子	Japan	245	209	-14.7%
75	Palwonn Group	競華集団	Taiwan	240	207	-13.8%
Top 51-75 Total				**6,992**	**7,316**	**4.6%**

In US$ millions. *Flex circuit fabricator.

America and Europe, Japanese fabricators that do not have overseas plants survive and grow a bit by providing quickturn assembly and prototyping services, and with specialty PCBs including defense products.

The top 128 fabricators of the estimated 2,100 worldwide produced about $69 billion in revenue (output) in 2020. That represents 6.6% of the total companies. What was the output of the other nearly 2,000 firms?

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TABLE 6. Top PCB Fabricators (Continued), 2020

Rank	Company	Local Name	Country	2019	2020	Growth
76	Daisho Denshi	大昌電子	Japan	192	197	2.6%
77	Würth Elektronik	Würth	Germany	184	196	6.5%
78	Tai Hong Ind	台豐工業	Taiwan	157	192	22.3%
79	Circuitronics	世科創力	China	180	190	5.6%
80	Ichia*	毅嘉科技	Taiwan	211	187	-11.4%
81	Shenzhen Sunshine	深圳明陽電子	China	167	187	12.0%
82	Somacis	Somacis	Italy	180	180	0.0%
83	Onpress	安柏電路	China	181	178	-1.7%
84	Ji'An Mankun	吉安満坤	China	156	178	5.5%
85	Huading Group	華鼎集团	China	162	176	8.6%
86	Leader-Tech*	上達電子	China	159	174	9.4%
87	Tigerbuilder	悦虎電子	China	160	170	6.2%
88	OKI PCB Group	沖PCB	Japan	155	168	8.4%
89	Liang Dar	良達電子	Taiwan	171	165	-3.5%
90	BYD*	比亜迪股份	China	163	163	0.0%
91	Kyosha	京写	Japan	178	162	-9.0%
92	Jiangxi ZLE Circuits	江西中絡電子	China	143	157	9.8%
93	SZ Jove Enterprise (Zhongfu)	深圳中富電路	China	162	157	-3.1%
94	TLB	티엘비는	S.Korea	126	156	28.8%
95	Guangzhou Jiesai GCI Sci Tech	杰賽科技	China	138	152	10.1%
96	Toppan	凸版印刷	Japan	130	150	7.3%
97	Brain Power	欣強電子	Taiwan	136	146	7.4%
98	Amphenol PCB Div	Amphenol	US	140	145	3.6%
99	Summit Interconnect	Summit Summit	US	120	145	20.9%
100	CHPT	中華精測	Taiwan	114	143	25.4%
Top 76-100 Total				**3,965**	**4,214**	**6.3%**

In US$ millions. *Flex circuit fabricator.

TABLE 6. Top PCB Fabricators (Continued), 2020

Rank	Company	Local Name	Country	2019	2020	Growth
101	Kunshan Wanzhen PCB	昆山万正	China	138	143	3.6%
102	SZ Xinyu Tengyue Elec.	新宇騰跌電子	China	103	135	31.1%
103	ACCESS	越亜半導体	China	68	133	95.6%
104	Suzhou Forein FPC	福莱盈電子	China	98	132	34.7%
105	Hyunwoo	현우	S. Korea	147	130	-11.6%
106	Jiangsu Suhan	江蘇蘇杭	China	128	130	1.6%
107	SZ Sandeguan Prec. Circuit	三德冠	China	103	128	24.3%
108	Aiko Kiki	愛工機器	Japan	114	126	10.5%
109	New Flex*	뉴플렉스	S. Korea	119	126	-5.9%
110	Schweizer Electronics AG	Schweizer AG	Germany	146	4.5	-13.7%
111	Zhuhai Kingsun PCB	珠海金順電子	China	125	125	0.0%
112	Changzhou Haihong & Aohong	常州澳弘	China	122	123	0.8%
113	Haesung DS	해성디에스	S. Korea	100	120	20.0%
114	Yihao Circuit Technology	益豪電路科技	China	120	120	0.0%
115	KSG	KSG	Germany	132	118	-10.6%
116	Kunshan Hua Zhu	昆山華涛電子	China	116	116	0.0%
117	Dongguang Hongyuen子	東莞康源電子	China	106	116	9.4%
118	Jiangsu Difeida	迪飛達電子	China	95	116	22.1%
119	Jiangxi Liangyi Elec. (Union Gain)	聯益電子	China	110	115	4.5%
120	Plotech	柏承科技	Taiwan	103	111	7.8%
121	Huizhou Glorysky	特創電子	China	95	109	14.7%
122	Shin Asashi Denshi	新旭電子	Japan	105	108	2.9%
123	Yamamoto Mfg	山本製作所	Japan	103	106	2.9%
124	Camelot Elecronic Tech	金禄電子	China	107	106	-0.9%
125	Shichuan Intronics IQE	英創力電子	China	94	103	9.6%
126	HT (HeTon) Electronics	河通電子	China	103	103	0.0%
127	StaRiver (Galaxy)	星河電子	China	98	102	4.1%
128	Belinda PCB	奔力達	China	94	100	6.5%
Top 101-128 Total				**3,092**	**3,204**	**3.6%**

In US$ millions. *Flex circuit fabricator.

RESISTIVE LOSS is Only Skin Deep

Mitigating skin effect's impact on high-speed signals.

by BILL HARGIN

I've spent much of the past seven years dealing with insertion loss as it relates to PCB dielectrics, as well as losses due to copper roughness. During that period, there's been comparatively little discussion regarding "skin effect," a significant contributor to signal attenuation that in my view gets less attention than it should. While discussing the phenomenon in-depth, we'll also discuss what, if anything, can be done to mitigate its impact on high-speed signals.

While writing this article, I've been thinking of places that skin appears in nature and pop culture. When I started writing, I flipped on *Skinwalker Ranch* on the History Channel for the first time as background noise, and they were talking about magnetic fields, current flow, and Tesla coils.

Skin is said to be the largest organ in the human body. It has multiple layers and some amazing properties. Galvanic skin response, used in lie detectors, measures changes in skin conductance caused by sweat-gland activity. I suppose you could call that a "skin effect" too.

It's perfectly reasonable for engineers and PCB designers to ask, "Where should I focus my attention?" insofar as loss is concerned. In *Signal and Power Integrity – Simplified,*[1] Dr. Eric Bogatin points out five ways energy can be lost to the receiver while the signal is propagating down a transmission line:

1. Radiative loss
2. Coupling to adjacent traces
3. Impedance mismatches and glass-weave skew (the latter being my addition)
4. Conductor loss
5. Dielectric loss.

Each of these mechanisms reduces or affects the received signal, but they have significantly different causes and remedies. Plenty of articles over the years have discussed managing impedance and crosstalk, including ones I've written. I've also written about managing loss through dielectric-material selection and copper roughness, one of the two components of conductor loss. The other contributor to conductor loss is commonly known as skin effect.

Skin Effect Definition

From DC to about 100MHz, the bulk resistivity and, by extension, the series resistance of copper transmission lines are constant, and current flow is uniform across the entire cross-section. AC currents, on the other hand, take the path of lowest impedance at higher frequencies – traveling in a thin shell on the conductor's surface toward the outside of the conductor.

The result is an effective reduction in the trace cross-section. At high frequencies, the cross-section through which current will flow in a copper conductor is referred to as the skin depth, δ:

$$\delta = 2.1\sqrt{\frac{1}{f}}$$

where

δ = skin depth, in μm
f = frequency, in GHz.

In copper, at 1GHz, the current in a transmission-line cross-section, for example, is concentrated in a layer about 2.1μm thick, on the perimeter or "skin" of the trace, shown graphically in **FIGURE 1.** At 10GHz, current flow concentrates in a layer of 0.66μm thick. Note: This relationship has nothing to do with trace width or any other parameter but frequency.

Signal resistance depends on the actual cross-section the current is flowing through. So, at higher frequencies, like the 10GHz frequency point where the skin depth is 0.66μm in Figure 1, resistance will increase with frequency. It's important to note the only thing that's changing to cause this increase in resistance is the cross-section through which the current is flowing.

FIGURE 2 illustrates the skin effect phenomenon for a 0.5-oz. symmetrical stripline trace at various frequencies. The top cross-section shows that at 70MHz current will flow through the entire cross-sectional area, as the skin depth still reaches the midpoint of the trace in the vertical. Skin depth, δ, is 7.9μm, half the thickness of half-ounce copper after processing. Resistance will be unaffected for half-ounce copper at this frequency, and currents will follow the path of least resistance.

The second image shows the same trace cross-section at 1GHz. Following the graph in Figure 1, the skin depth, δ, is 2.1μm. This is shown by the orange "skin" around the perimeter. At 1GHz, the blue area represents the remaining area where there is no current flow. Note the "current crowding" of high-frequency signal components on the top and bottom of the trace cross-section. Above the frequency at which skin effect kicks in – the "skin-effect onset frequency," as some call it – signals follow the path of least inductance. (An entire article could be written on this subject alone.)

The third cross-section shows the skin depth at 10GHz for the same half-ounce trace. Note δ is reduced to 0.66μm, as is seen in the plot in Figure 1.

It's instructive to perform the same exercise for 1-oz. copper. As **FIGURE 3** shows, 1-oz. copper, with a post-processing thickness of 30.5μm, utilizes the entire cross-section at a skin depth of 15.7μm up to 5MHz. Above this skin-effect onset frequency, resistance will increase, and this is shown in the other two cross-sections at 1 and 10GHz.

A few things are worth noting now that we've looked at both 0.5 and 1-oz. copper. The first thing to consider is the skin depth is the same for both copper weights. That means that for the same trace width, the current will have roughly the same cross-sectional area to flow through. What's different is how the skin depth compares to the remaining cross-section due to its size, but above the skin-effect onset frequency, we don't really care about the blue regions in Figures 2 and 3.

So far, all we have pointed out is the series resistance of the conductors in a transmission line will increase with the square root of frequency. The question of how this frequency-dependent resistance affects *loss* follows.

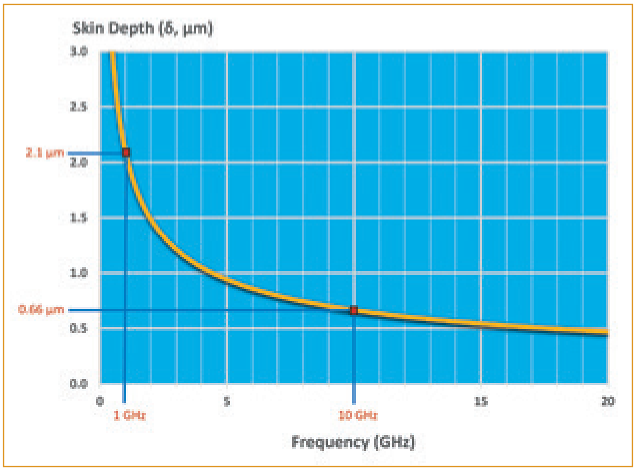

FIGURE 1. Skin depth, δ (μm) vs. frequency (GHz).

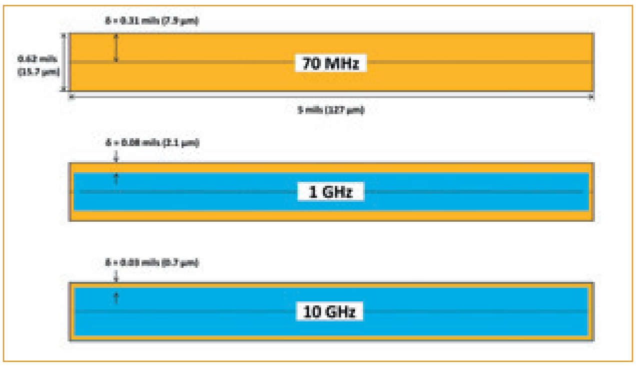

FIGURE 2. Skin depth, δ (μm) for a half-ounce symmetrical stripline trace at three different frequencies.

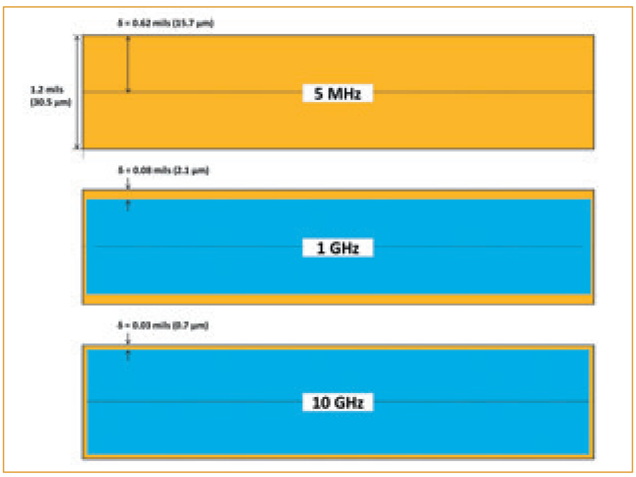

FIGURE 3. Skin depth, δ (μm) for a 1-oz. symmetrical stripline trace at three different frequencies.

Skin Effect and Loss

The reduced current-flow area and increased resistance discussed up to this point will cause high-frequency signals to attenuate in proportion to the square root of frequency, a significant mechanism for decreasing the bandwidth of signals when propagating down a lossy line. An approximate, first-order relationship for this is shown in equation form below:

$$Loss_{resistive} = Length \frac{36}{w \cdot Z_0}\sqrt{f}$$

where

$Loss_{resistive}$ = is resistive loss (attenuation),
Length = trace length in inches
w = trace width in mils
Z_0 = the single-ended impedance (ohms)
f = frequency (GHz).

Note that trace length, frequency and impedance are the biggest factors in this equation. Frequency and length increase loss, as you would expect, and impedance reduces it. Trace width pulls resistive loss down too, but both trace width and trace thickness in the vertical are factors in the denominator of the impedance relationship, reducing trace width's impact on resistive loss. Thickness, which is a small value for signal layers whether 0.5 or 1.0-oz. copper is used, is a small factor compared to the others. As Figures 2 and 3 show, currents and electromagnetic fields crowd toward adjacent reference planes in the vertical, whether 0.5 or 1.0-oz. copper is used.

Let's plug in some numbers for a 36" backplane as an example. At 10GHz, a 50Ω stripline with a width of 4.9 mils will have an attenuation from the conductor of $Loss_{resistive}$ equaling approximately $(36)(10)^{1/2}/(4.9 \times 50) = 0.46$dB/in. Across the 36" run length, it would be 16.7dB from resistive loss.

Reducing Loss by Increasing Trace Width

Reducing loss by increasing trace width is a commonly considered option for reducing resistive loss. Several years ago, I sat in on Lee Ritchey's "Getting to 32GHz" workshop, and he had a few things to say on this subject that bear repeating.

Ritchey[2] mentioned that increasing trace width reduces impedance. Fair enough. He went on to say that to maintain the 50Ω single-ended impedance required for each line in a differential pair, the dielectric thickness needs to increase, increasing the overall thickness of the PCB, along with the cost due to the additional dielectric material. He pointed out dielectric loss dominates the loss problem for common laminates, and selecting a lower-loss dielectric provides more leverage than using wider traces to reduce skin-effect losses.

It's pretty easy to show this with a good 2-D field solver, which we'll do next, reusing our 36", asymmetrical stripline backplane example above. For a 4.9-mil line width and 0.5-oz. copper, the insertion loss due to the skin effect (aka: resistive loss) is 0.35dB/in., as shown in **FIGURE 4.** While the results are in the same ballpark, the *simulated* resistive loss is a good bit lower than the *calculated* value above (0.46dB/in.). I have more trust for a field solver over the equation-based approximation, partially because the field solver represents a detailed model of Maxwell's equations, but also due to its flexibility. A good 2-D field solver allows inclusion of dielectric loss and copper roughness in the same simulation. Adjustments between microstrip and both symmetrical and asymmetrical stripline configurations are automated in field-solver software as well.

Next, we'll use a 2-D simulator to test Ritchey's statement regarding wider traces. In this case, we'll double the trace width and adjust the dielectric height to maintain 50Ω. **FIGURE 5** shows that doubling the trace width does reduce resistive loss to 0.21dB/in. To achieve this, however, we had to adjust the dielectric height to 9.4 mils to preserve the 50Ω single-ended impedance. A lower-loss laminate or using pre-emphasis or equalization (the latter two are beyond the scope of this article) are generally better options.

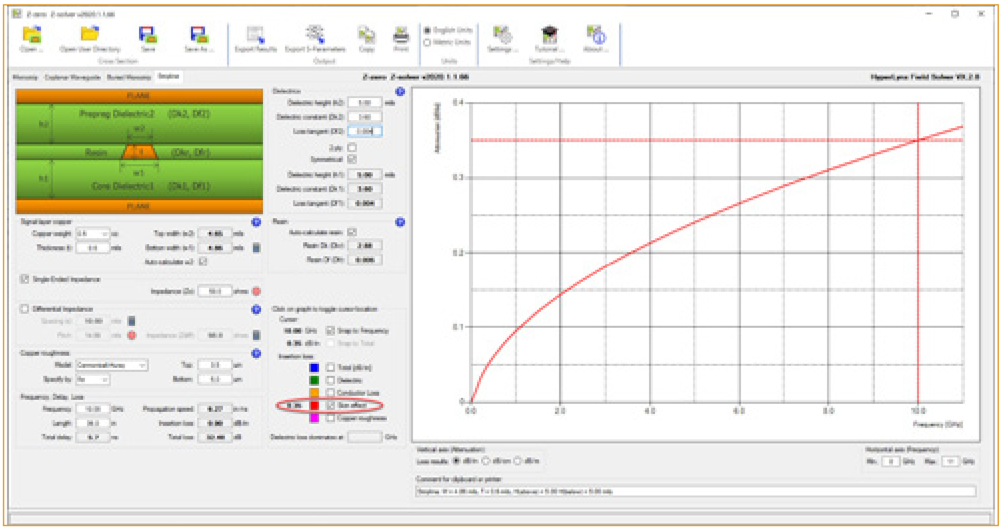

FIGURE 4. Resistive insertion loss for a 4.9-mil-wide 50Ω symmetrical stripline at 10GHz. Simulated with Z-zero Z-solver software using Siemens HyperLynx 2-D field solver.

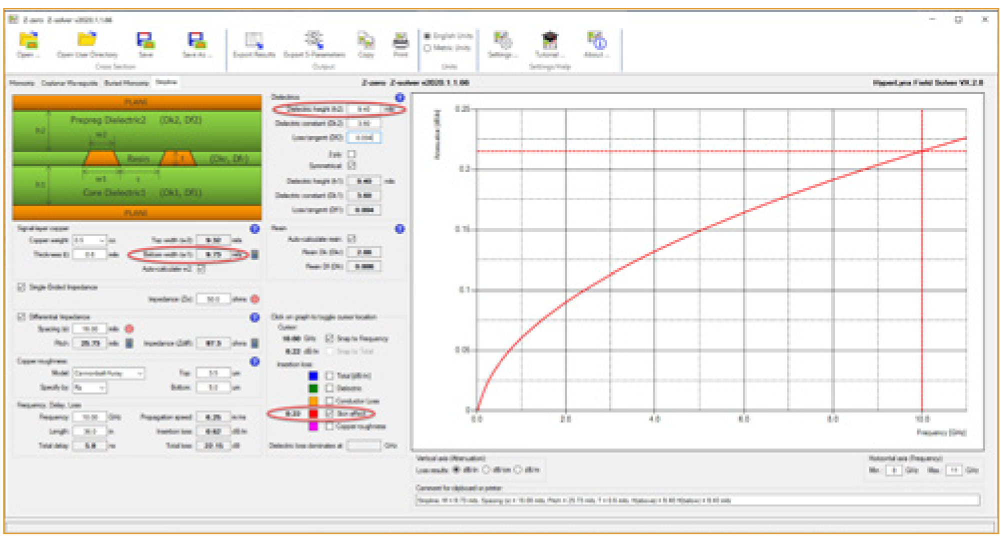

FIGURE 5. Resistive insertion loss for a 9.73-mil-wide 50Ω symmetrical stripline at 10GHz. Simulated with Z-zero Z-solver software using Siemens HyperLynx 2-D field solver.

Skin Effect and Dielectric Loss

Some may be confused into thinking an interrelationship exists between different types of loss – for example, between resistive loss and dielectric loss. Dielectric loss is tied to a dielectric material's loss tangent, which is represented by tan(δ). No connection exists between the δ in tan(δ) and the δ in skin depth. And, if you look at the resistive loss equation above, there's no connection between $Loss_{resistive}$ and loss tangent or dissipation factor (Df).

Scanning the resistive loss equation cited above, we can see factors that relate to everything surrounding the trace, including Dk, which ties to Z_0, but not copper roughness or Df, as noted above. Contributions from each of these can be calculated or simulated separately and then summed together, as we'll do in the example below.

Managing Interconnect Loss at 10GHz

Let's say we're starting from scratch on the backplane interconnect outlined above. We'll assume all we know is it needs to be 50Ω, single-ended, 36" in length, and we want to keep total loss at 20dB or lower (0.55dB/in.) to prevent excessive power consumption from transmitter pre-emphasis and the receiver's equalization circuitry. Ignoring vias for this particular example, we'll start with a symmetrical stripline with an initial dielectric height of 4 mils, a Dk of 3.6 and a Df of 0.005 at 10GHz. Ideally, we'd like the Dk to be even lower because it helps keep the board thickness and cost down and helps with loss. (Dk is in the denominator of the Z_0 relationship, and Z_0 is in the denominator of the loss relationship. As a result, there's a direct connection between Dk and loss.) We'll also say we would prefer 0.5-oz. copper because it's less expensive, but we're willing to consider 1-oz. copper. Copper roughness will start at R_z=5.0µm. (Note: Many equations regarding copper roughness use RMS roughness, which is a hard number to obtain from laminate and PCB fabricators, so I tend to use R_z, the peak-to-peak measurement, which is a rather easy number to obtain with a profilometer.)

FIGURE 6 shows the result, but in our initial swing at hitting 0.55dB/in. we are pretty far off. The copper roughness contribution alone is consuming most of our interconnect loss budget, and at 0.54dB/in. it's more than twice the dielectric loss. We'll start here first.

A good backplane fabricator can build PCBs with a roughness of 1.5µm on the "process" or prepreg side. Most hardware designers working on long, high-frequency backplanes are aware smooth copper comes at a price premium, so we'll try R_z=2µm and R_z=1µm, respectively. An R_z roughness of 2µm brings us to a copper roughness loss of 0.11dB/in. and a total loss of 0.77dB/in. This is much better, of course, but we still have a good bit of loss to trim from our design, so it's worth trying R_z=1µm copper. This brings us to 0.07dB/in. for copper roughness and a total loss of 0.73dB/in., as shown in FIGURE 7. Note the resistive

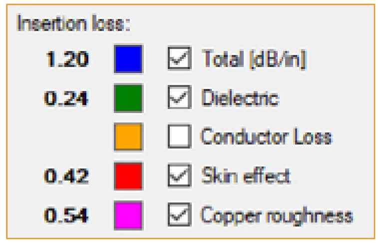

FIGURE 6. Simulation of insertion loss box, showing the comparative contributions of dielectric loss, skin effect, and copper roughness. (Source: Z-zero Z-solver software.)

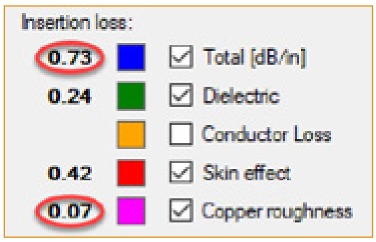

FIGURE 7. Simulation of insertion loss box, showing the comparative contributions of dielectric loss, skin effect, and copper roughness, after switching to R_z=1µm copper. (Source: Z-zero Z-solver software.)

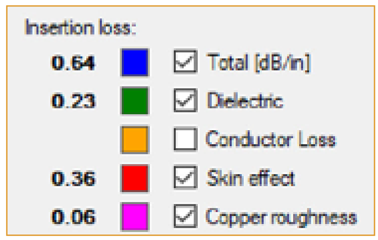

FIGURE 8. Widening the trace by 1 mil reduced resistive loss by 0.06dB/in., and we had to move to a thicker dielectric, 4.5 mils, to maintain our impedance target. (Simulated with Z-zero Z-solver software.)

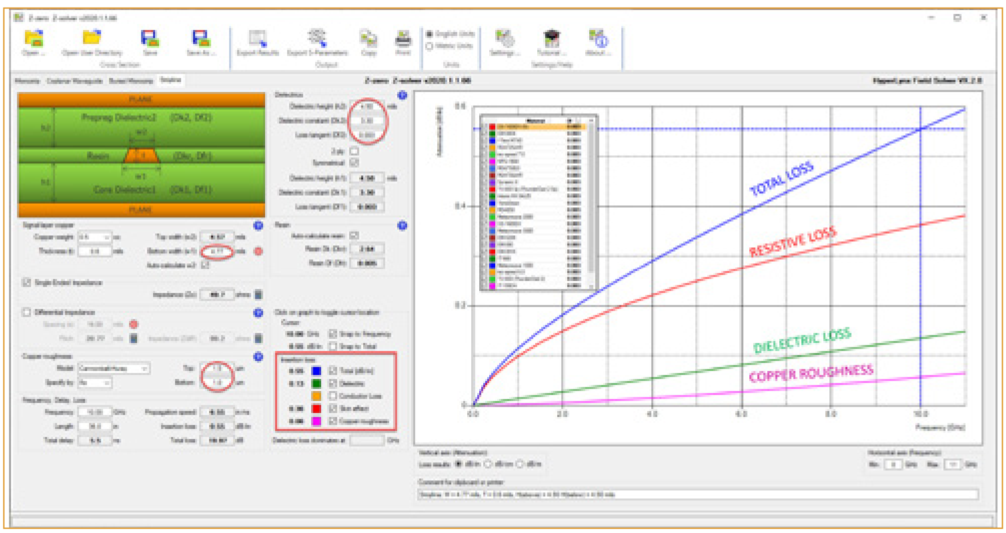

FIGURE 9. The final configuration for our backplane, including dielectric selection based on Dk and Df at 10GHz, dielectric height, trace width, and copper roughness, resulting in 0.55dB/in. (Simulated with Z-zero's Z-solver software.)

loss from the skin effect didn't change at all. As noted above, there's no interrelationship between these two parameters.

Now we need to look at where we're going to get the last 0.18dB/in. The resistive loss or skin effect looks like the biggest remaining contributor, so against my own best judgment from experience, I'll go there next in this example. To hit 50Ω with this example required a trace width of 3.77 mils. That's doable, but a bit on the aggressive side from a manufacturing standpoint and possibly from a resistive loss standpoint. Let's bump that up by a mil and see if we can find a laminate construction with a lower Dk to help us hit our impedance target. A good number of materials have Dks in the 3.3 range with Df values at or below 0.005. **FIGURE 8** shows that widening the trace by 1 mil only reduced resistive loss by 0.06dB/in., and we had to move to a thicker dielectric, 4.5 mils, to maintain our impedance target. As Ritchey mentions, this seems a less-than-optimal tradeoff.

Let's see where we end up if we reduce the Df from 0.005 to 0.004. This change reduces loss to 0.060dB/in. We still have some work to do. **FIGURE 9** shows a good number of materials with Df values reported as low as 0.003 at 10GHz. The final configuration is shown in this view with all design decisions represented.

Wrapping Up

This process may seem tedious, but no one said designing 36" backplanes is easy. Nevertheless, spending a little time with a handy software tool can give you a feel for the tradeoffs. One advantage is you can try things almost as fast as you can think of them.

We've seen the physics of skin effect make it hard to affect. But before we rule out changing copper weight or trace width completely, I thought I'd pass along a tip I've learned through many hours of experimentation with the tradeoffs. As fine-tuning knobs for impedance and resistive loss, these two parameters are great, especially when working with a sharp pencil.

If you can make material and routing decisions like this early in the design process, you'll avoid prototype surprises down the road or paying more than you need to for laminate systems that are overkill for a design. Making these choices early also allows you to avoid initial laminate lead times that can delay prototypes or early production. Because of prepreg shelf lives, fabricators only carry the laminates they know they can use within six months or less, so a just-in-time approach is usually followed. As with many other aspects of life, planning gives more options and fewer surprises. You can feed that expensive signal-integrity solution Dk and Df data from the actual laminate system you're planning to use. Moreover, it may allow you to hold to NPI (new product introduction) schedules more consistently, while relieving some of the pressure you've been putting on PCB suppliers to make up for poor planning. Everyone wins!

I appreciate hearing from readers. Drop me an email if you read this far and found this article helpful! ❑

REFERENCES

1. Eric Bogatin, *Signal and Power Integrity – Simplified,* Pearson Education, 2010.
2. Lee Ritchey, "Getting to 32 Gb/s," DesignCon Proceedings, 2018.

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1. Brian Young, *Digital Signal Integrity: Modeling and Simulation with Interconnects and Packages,* Prentice Hall, 2000.

BILL HARGIN has more than 25 years' experience with signal integrity software and PCB materials. He is director of everything at Z-zero (z-zero.com); billh@z-zero.com. Hargin will present on PCB Stackup Design and Materials Selection at PCB West (pcbwest.com) in October. (Ed. note: Lee Ritchey will present on Getting to 56Gb/s at PCB West.)

A Different Take on Tooling

Reconfigurable with dedicated-like support.

AS BOARD COMPLEXITY has increased with decreasing pitches, thicknesses and component sizes, ensuring support for thin, high-density substrates – essential to cost-effective, pinpoint accuracy stencil printing – continues to pose challenges. Using vacuum to secure miniaturized assemblies is, for the most part, a successful technique but requires the use of dedicated tooling plates, which can be costly. Considering the quantities of dedicated tooling blocks needed in a high-volume manufacturing environment, finding a suitable, lower-cost alternative has been a longstanding ambition. And, while commercialized automatic pin-based tooling systems are a good option for some applications, they are not as effective for high-density, thin boards.

How, then, do we bridge the gap and provide similar quality substrate support without requiring a dedicated tooling plate for each product and each SMT line? One solution lies in a high-flow vacuum system that supports the PCB – no matter how densely populated – through an almost counterintuitive use of airflow, low-pressure vacuum and reconfigurable metal plates. **(FIGURE 1)**. The plates – which are tooling height, approximately 2.0mm thick and constructed of different lengths – can be configured and overlapped to form a box, the top of which is constructed slightly smaller than the PCB perimeter so the edges of the substrate sit on the frame. The rising table contains a vent, and support pins are placed for stability. Once positioned, the tooling cube creates a semi-sealed environment where the vacuum pulls air through the table vent to create substrate stability during the print cycle. Unlike a conventional vacuum connected to a tooling plate, which uses a sealed technique to generate incredible pull (trust me, don't get your finger anywhere near the vacuum pipe!), this new approach floods the area with tremendous amounts of air, allows for leakage (unlike dedicated plates) and securely holds the PCB with low vacuum. While there is upfront time to set the plates in the desired location, this system provides the support needed for thin, high-density, heavily routed PCBs without the expense of dedicated plates, and it can be reconfigured for an infinite number of board sizes.

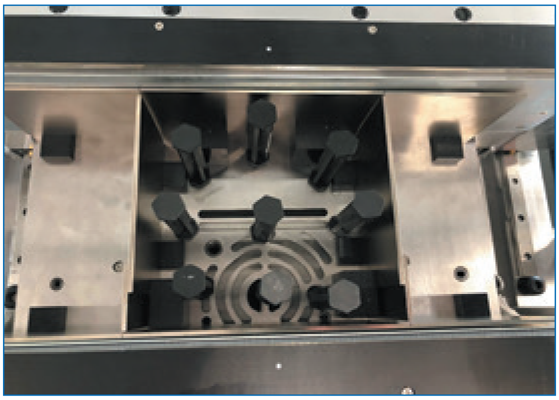


FIGURE 1. High-flow vacuum tooling provides a reconfigurable, lower-cost solution than dedicated tooling plates.

Using this setup with pallets is also effective. For high-volume assembly of smaller PCBs for mobile phones and wearables, many manufacturers have moved toward use of pallets and secure boards in the pallet using tape or clips. Typically, with pallets, no vacuum is employed for substrate stability during the print cycle. As many of the PCBs for mobile products are so intricate, pallets have emerged as a more cost-effective and viable option than dedicated tooling and enable the alignment critical to high yield. One drawback is that without any vacuum securing the pallet, when the stencil separates from the PCB, the board tends to follow the stencil, and the lack of clean separation can negatively affect material transfer efficiency. This situation can be resolved with the new tooling approach. Employing the high-flow vacuum tooling cube, the pallet is framed by the edges of the plates and secured with low vacuum force, which helps encourage clean stencil separation.

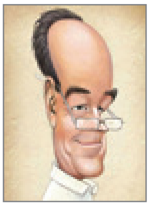
To analyze print quality and repeatability of PCBs produced with high-flow vacuum tooling, our company conducted internal testing to evaluate solder paste deposit height, area and volume, the standard stencil printing process KPIs. Means and standard deviations were examined from a C_p/C_{pk} point of view, with C_{pk}s over 1.33 (4 Sigma) being the baseline acceptable benchmark minimum. Our test board contains an array of technology including 01005s, 0.4mm-pitch CSPs, 0805s and 0.4mm-pitch QFPs, and has 0.55 area ratios that push the boundaries of acceptable limits. To be considered a viable process tool, all tested boards must pass the C_{pk} threshold. With the novel solution, every board passed and illustrated that the system delivers results comparable to dedicated tooling. ❑

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

It’s Reliable, But Didn’t Fill the Hole

Is the board preheat process optimized?

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



THIS MONTH WE look at incomplete fill of plated through-holes. During any soldering operation a balance of flux and solder/paste chemistry and soldering temperatures creates good and reliable joints. In FIGURE 1 the solder has not filled the hole completely but still exceeds the requirements of IPC-A-610, class 2 of 50%; measured, it may be 75% filled.

Possible reasons for solder not filling the hole in wave or selective soldering is the amount of flux or heat, limiting good penetration and wetting. More likely, however, board preheat is inadequate, causing solder to solidify early.

In the case of manual soldering, the temperature and dwell time of the soldering iron need to be considered. With a good quality circuit board, a joint like this is *not* very likely to fail.

We have presented live process defect clinics at exhibitions all over the world. Many of our Defect of the Month videos are available online at youtube.com/user/mrbobwillis. Find out how you can share our new series of Defect of the Month videos to explain some of the dos and don’ts with your customers via CIRCUITS ASSEMBLY: https://bit.ly/3mfunlF. ❑

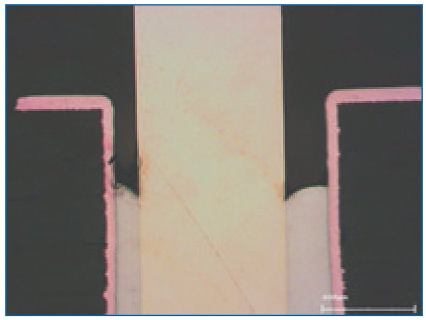
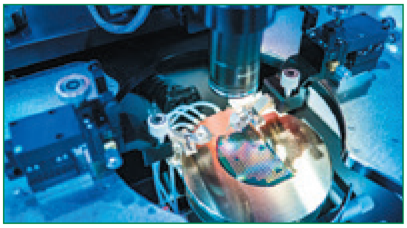


FIGURE 1. Incomplete hole fill.

NORDSON MARCH MEGAVIA

MegaVIA plasma treatment system has 15-cell configuration for panel sizes up to 30" x 52". Overall dimensions are 1652mm x 1782mm x 2326mm. Provides plasma treatment at 40kHz and accommodates common gases – CF4, O_2, N_2, and argon – with process reproducibility and uniformity. EPC controller with Windows 10 PC-based touchscreen HMI permits data collection and control capabilities. Reportedly achieves higher than 80% uniformity for desmear and etch-back applications to both sides of PCB panels.

Nordson March
nordsonmarch.com



SEICA PILOTV8XL HR NEXT

PilotV8XL HR Next flying probe offers probe card test. Brings together three tools to perform complete test: bare board test for single MLO and PCB test; ICT and functional test for assembled PCB test; probe card test for PCB+MLO. Ensures ICCT (integrity connection certification testing). Features vertical platform; eight independent axes; two standard probes plus two high-res probes on front side; four standard probes on rear side. Test area is 800 x 650mm. Has laser sensor(s) for warpage control. Automatically generates specific tests considering resistance of each single path that can be different from one to another.

Seica
seica.com

ZUKEN CR-8000 2021

CR-8000 2021 software features more than 150 enhancements ranging from architectural planning, system-level schematic design and verification, 3-D multi-board and advanced packing layout, through to manufacturing output generation. New place by area, template and reuse functionality that enables application of existing placement and routing patterns on new designs. Supports simulation of PCB parasitic effects in circuit design stage.

Zuken
zuken.com/us zuken.com/us

OTHERS OF NOTE

CADENCE ALLEGRO X

Allegro X Design Platform unifies schematic, layout, analysis, design collaboration and data management. Built on Allegro and OrCAD core technology, is said to streamline system design process by providing access to logical and physical domains simultaneously with concurrent collaboration capabilities across schematic, layout and analysis activities. Leverages hybrid cloud that provides scalable compute resources and full technology access, while reducing deployment footprints and complexity.

Cadence
cadence.com/go/allegrox

NANO DIMENSION DRAGONFLY LDM 2.0

DragonFly LDM 2.0 update introduces improved print quality, optimized ink utilization and smarter management for printer uptime. Uses digital files and simultaneous 3-D printing of dielectric and conductive materials to produce high-performance multilayered electronic devices. Consists of hardware and embedded software upgrades that optimize ink utilization, improve print quality with print-head calibration and nozzle cancellation wizards, and improve printer uptime.

Nano Dimension
nano-di.com

AVX TCQ

TCQ series conductive polymer chip capacitors are AEC-Q200-qualified for automotive, industrial, and telecommunications applications. For space-constrained, harsh-environment applications, including body electronics, cabin controls, comfort and infotainment systems, aftermarket automotive electronics, DC/DC converters, and coupling/decoupling. Conductive polymer electrodes enable benign failure mode under recommended use conditions.

AVX
avx.com

CAD DESIGN SOFTWARE EPD SUITES

Electronics Packaging Designer suites are powered by AutoCAD OEM. Used for complete PCB design or specific tasks such as bond wire exporting or translation of Gerber or GDS files. Basic Suite for Windows is for PCB, RF, and flex with bidirectional Gerber translator, GDS translator. Includes schematic capture and 3-D, advanced routing, automatic documentation, and module of commands that allow designers to clean file.

CAD Design Software
cad-design.com

CADENCE AWR DESIGN ENVIRONMENT V.16

AWR Design Environment v. 16 has cross-platform interoperability to support RF to millimeter wave (mmWave) intellectual property integration for heterogeneous technology development across the Cadence Virtuoso design platform, as well as the Allegro PCB and IC package design platforms. Seamlessly integrates with Clarity 3D Solver and Celsius Thermal Solver for electrothermal performance analysis of large-scale and complex RF systems.

Cadence
cadence.com/go/awrv16

AVX LCCI

LCCI series ultraminiature MLCC inductors are for high-frequency RF applications. Come in 0201, 0402 and 0603 sizes. Sn-plated surface-mount terminations. Compatible with high-density PCBs and reflow soldering.

AVX
avx.com

YAMAHA YRI-V

YRi-V 3-D hybrid AOI features a newly developed inspection head equipped with a high-speed camera with a new 5µm resolution lens. High-precision 8-direction 3-D projector offers greater component inspection compatibility. New coaxial lighting improves measurement accuracy and range by 100% compared to current models. High-precision measurement up to 25mm high.

Yamaha SMT Section
yamaha-motor-im.eu

TAKAYA APT-1600FD-SL

APT-1600FD-SL dual-sided flying probe test system is for large PCBAs for 5G communications and battery management system applications. Provides 48% larger test area. Deploys flying probes to both sides of UUT. Provides average head speed increases of up to 50% with throughput improvements of 30-50% over existing models.

Takaya
takaya-itochu.com

LASERSSEL RLSR

rLSR Mini LED rework system enables industry to solder temperature-sensitive, warpage-prone, fine-pitch, odd form, big die, SiP, wearables, flex to flex, and other applications. Beam shaping optical module takes energy of spot laser and turns it into uniformly distributed area laser. Uniformity of energy is reportedly greater than 95%.

Laserssel
laserssel.com

OTHERS OF NOTE

MICROTRONIC D&L AUTOMATOR

Automated and PC-controlled D&L Automator for dip and look meets IPC-J-STD-002 and 003 standards. Provides repeatable dipping of specimen. Has built-in PC with Windows 10 and touch screen for settings and operation. Comes with tool to automatically measure bath level and light curtain to automatically measure length of test coupon.

microtronic
microtronic.de

INSPECTIS WELDINSPECT DIM

WeldInspect DIM optical inspection system inspects welds and other shiny surfaces. Uses digital inverted microscope for optics alignment. Used for advanced visual inspection tasks using 4K imaging of hybrid microcircuits, ceramic PCBs and other substrates.

Inspectis
inspect-is.com

REHM PROMETRICS THERMAL PROFILE MONITORING

ProMetrics monitors thermal profiles during soldering. For single- and dual-lane systems and suitable for vacuums. Checks how previously created profile corresponds to required, predefined specifications. Process window index quantifies quality of thermal process; determined by specification of solder paste and most heat-sensitive component.

Rehm Thermal Systems
rehm-group.com/en/index.html

SHENMAO PF918-P250

PF918-P250 SnAgBi3 alloy offers high thermal impact reliability. Reportedly increases thermal reliability performance by 30%. Is said to provide better mechanical shock performance than SAC 305 and SAC 405. For use in consumer electronics, servers and automotive applications. Similar melting point to SAC 305.

Shenmao
shenmao.com

METCAL GT90, GT120 SOLDERING SOFTWARE

GT90 and GT120 soldering systems have software upgrades that offer combination of inductive heating technology with adjustable temperature control. Allow setting of temp. profiles for various components or solder joints. Can set profiles with preheat ramp rates that prevent damage from thermal shock caused by rapid heating.

Metcal
metcal.com

KOLB FR100

FR100 flux remover is intensive spray detergent for manual cleaning of assemblies. Is applied from spray bottle to surface to be cleaned. Is ESD-safe; evaporates residue-free. Dissolved flux residues can be removed using bottle's brush head, which is gentle on components.

Kolb
kolb-ct.com

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.

Connectors

"Impact of Thermal Cycling on Cu Press-Fit Connector Pin Interconnect Mechanical Stability"

Authors: Yeon-Jin Baek, *et al.*

Abstract: Press-fit technology provides an electrical and mechanical connection by inserting a press-fit pin into a through-hole of a printed circuit board. Recently, there has been wide interest in the long-term reliability of the press-fit pin interconnect of electric systems under various thermo-mechanical conditions due to the integration and minimization of electric devices. Compared to a ball grid array interconnection, press-fit pin connector interconnects are expected to have a different degradation mechanism. In this study, the impact factors affecting the reliability and degradation mechanism of press-fit connector pins were investigated. The bonding strength of inserted pins was measured before and after thermal cycling at room temperature and elevated temperature conditions. The bonding strength of the press-fit pins to the PCB copper wall was observed to increase after thermal cycling. The development of an intermetallic compound between the Cu pin and the Cu wall was observed. The microstructure of the press-fit connector pin and the Cu wall and localized stress and strain levels were analyzed by electron backscattered diffraction, including inverse pole figure maps, grain reference orientation deviation maps, and strain contouring maps. Along with the increase of pull strength after thermal cycling, an increase in residual stresses was observed, while strain contouring maps exhibited a decrease in localized strains at the interface between a press-fit pin and copper wall of a PCB. (*Journal of Electronic Materials,* Jun. 8, 2021, https://link.springer.com/article/10.1007/s11664-021-09045-w)

Failure Analysis

"First-Principles Prediction of Electronic Transport in Fabricated Semiconductor Heterostructures via Physics-Aware Machine Learning"

Authors: Artem K. Pimachev and Sanghamitra Neogi

Abstract: First-principles techniques for electronic transport property prediction have seen rapid progress in recent years. However, it remains a challenge to predict properties of heterostructures incorporating fabrication-dependent variability. Machine-learning (ML) approaches are increasingly being used to accelerate design and discovery of new materials with targeted properties and extend the applicability of first-principles techniques to larger systems. However, few studies exploited ML techniques to characterize relationships between local atomic structures and global electronic transport coefficients. In this work, the authors propose an electronic-transport-informatics (ETI) framework that trains on ab initio models of small systems and predicts thermopower of fabricated silicon/germanium heterostructures, matching measured data. They demonstrate application of ML approaches to extract important physics that determine electronic transport in semiconductor heterostructures, and bridge the gap between ab initio accessible models and fabricated systems. The authors anticipate ETI framework would have broad applicability to diverse materials classes. (*npj Computational Materials,* Jun. 17, 2021, www.nature.com/articles/s41524-021-00562-0))

Soldering

"Pioneering Chemistry Approach Could Lead to More Robust Soft Electronics"

Authors: Xu Han, *et al.*

Abstract: Solder joints with different microstructures are obtained by ultrasonic-assisted soldering. To analyze the effect of ultrasounds on Cu_6Sn_5 growth during the solid–liquid reaction stage, the interconnection heights of solder joints are increased from 30 to 50µm. The authors found scallop-like Cu_6Sn_5 nucleate and grow along the Cu_6Sn_5/Cu_3Sn interface under the traditional soldering process. By comparison, some Cu_6Sn_5 are formed at Cu_6Sn_5/Cu_3Sn interface and some Cu_6Sn_5 are randomly distributed in Sn when an ultrasonic-assisted soldering process is used. The reason for the formation of non-interfacial Cu_6Sn_5 has to do with the shockwaves and micro-jets produced by ultrasonic treatment, which leads to separation of some Cu_6Sn_5 from the interfacial Cu_6Sn_5 to form non-interfacial Cu_6Sn_5. The local high pressure generated by the ultrasounds promotes the heterogeneous nucleation and growth of Cu_6Sn_5. Also, some branch-like Cu_3Sn formed at the Cu_6Sn_5/Cu_3Sn interface; the interfacial Cu_3Sn in ultrasonic-assisted solder joints present a different morphology from the wave-like or planar-like Cu_3Sn in conventional soldering joints. Meanwhile, some non-interfacial Cu_3Sn are present in non-interfacial Cu_6Sn_5 due to reaction of Cu atoms in liquid Sn with non-interfacial Cu_6Sn_5 to form non-interfacial Cu_3Sn. Overall, full Cu_3Sn solder joints are obtained at ultrasonic times of 60 sec. The obtained microstructure evolutions of ultrasonic-assisted solder joints in this paper are different from those reported in previous studies. Based on these differences, the effects of ultrasounds on the formation of non-interfacial IMCs and growth of interfacial IMCs are systematically analyzed by comparing with the traditional soldering process. (*Soldering & Surface Mount Technology,* Jul. 12, 2021, www.emerald.com/insight/content/doi/10.1108/SSMT-06-2020-0026/full/html)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