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The Unsinkable, Unstoppable PCB Market
While the 146 companies on this year’s NTI-100 represent only 6% of the estimated 2,400 fabricators in the world, they produced 92% of the output. As we say, the big get bigger every year.
by DR. HAYAO NAKAHARA

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Tackling Head-in-Pillow Defects
with Vapor Phase Reflow
Reflow in an oxygen-filled environment can lead to all sorts of defects. Can the vapor phase reflow process address HiP in BGA/LGA hybrid connectors?
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by CHELSEY DRYSDALE

ON PCB CHAT (pcbchat.com)

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with GRAHAM NAISBITT

ENGINEERING SOFT SKILLS
with JOHN BURKHERT JR.

ADVANCES IN SOLDER PASTES
with JEN FIJALKOWSKI

THE FACTORY OF THE FUTURE
with DR. MATTHEW DYSON

SMART MANUFACTURING
with BRIAN MORRISON
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In the Rush to Get Big, Let’s
Not Forget the Little Guys

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

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

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

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

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

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

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

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

Take the auto industry. It is characterized by a
few big OEMs. We all know the names. Toyota. Volk-
make up about 55% of the world’s car sales.

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

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

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

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

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

Finally, we welcome our first corporate mem-
bers: EMA Design Automation, Quantic Ohmega,
Polar Instruments, ElConnect, Ventec and Ameri-
can Standard Circuits. There are many benefits to
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Calumet to Invest $6.5M in Michigan PCB Plant

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

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

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

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

PCEA Announces Dates for PCB East 2023

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

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

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

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

Ventec Increases Prepreg Capacity in Taiwan

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

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

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

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

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

“The investment in manufacturing capacity at our Taiwan facility is driven by strong growth in demand for our high-reliability solutions manufactured on state-of-the-art machinery,” said Mark Goodwin, COO, EMEA & America. “Combined with our know-how in PCB base material technologies and our strong track record in global supply chain control, the capacity increase and multiple independent pipework design further enhances our capability to switch between resin systems quickly and
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low-heat solder and metallic join-
Iowa-based startup that is creating no-heat
facility in Southern California.
Veris Manufactur-
ing placement system at its
Emerald EMS
Juki
FX-3RAXL
Sincotron Oy
to distrib-
appointed
Uncork Capital.
joined by new and existing investors includ-
ing to reports.
PCBA manufacturing tech development
Amol Kane
Project Kuiper named
Western Regional sales manager.
Pillarhouse USA appointed
Deon Nungaray
Western Regional Sales manager.
Escatec named
HL Wong
chief operating officer. He was for-
merly the general manager of
Plexus in Penang.
Pillarhouse USA appointed
Deon Nungaray
Western Regional Sales manager.
Project Kuiper named
Amol Kane
senior
Engineer.
BTU International.
Arrow Electronics named
Richard Henrick
environmental,
social and governance manag-
er. He has 35 years’ experience
in management and technical
positions in quality manage-
ment, regulatory compliance, manufactur-
ing engineering, test and evaluation, the
last 15 with Sanmina.
Aegis promoted
Paul Vassallo
to director of engineering.

CA Briefs

Ampere Proto shut down its EMS opera-
tions permanently in Quebec City because of
a lack of staff and components, accord-
ing to reports.
Arch Systems announced $15 million in
new funding led by
Two Bear Capital and
joined by new and existing investors includ-
ing seed lead investor
Uncork Capital.
Bentham appointed
Sincron Oy
to distrib-
ute XDry drying cabinets.
Cobham moved closer to UK government
approval for its takeover of
Ultra Electronics.
Delta Electronics acquired a 30-acre com-
plex in Plano, Texas, for a new smart,
green R&D and manufacturing site.
Emerald EMS installed a
Juki FX-3RAXL
placement system at its
Veris Manufacturing
facility in Southern California.
Indium is partnering with
SAFI-Tech, an
Iowa-based startup that is creating no-heat
and low-heat solder and metallic join-
ing products. The companies will evaluate
market applications for supercooled sol-
der materials and explore development of
new products.

Zollner Acquires EIT’s EMS Unit, Expands US
Presence

ZANDT, GERMANY – Zollner Elektronik has acquired Electronic Instrumentation and
Technology’s (EIT) EMS division for an undisclosed amount.
The deal includes EIT’s three EMS facilities in Salem, NH, Leesburg, VA, and
Danville, VA, and a cabling and machining operation, also in Danville. The total size
of the acquired plants encompasses more than 200,000 sq. ft.
The move was not a surprise as the two companies have partnered for years.
EIT’s UV measurement instruments, avionics, and applied technology consulta-
tion services will continue under the name of EIT2.0. Zollner will also provide EMS
services to EIT2.0.
EIT was founded by Joe May in 1977 and serves customers in the industrial,
communications, aerospace, defense, and medical markets It has ISO 9001, ISO 13485
and AS9100 certifications, and is ITAR-registered.
“We are very pleased to see our long-time business relationship with Zollner
evolve,” said Joe May, founder and chief technology officer, EIT. “Our customers will
benefit from Zollner’s strong purchasing and distribution capabilities, and Zollner
recognizes that we have very talented, skilled employees; the acquisition of our EMS
division is an ideal fit for all. I have great confidence that our employees and customers
will see this move as advantageous to everyone.”
“We are excited to have EIT as part of the Zollner Group,” said Markus Aschen-
brenner, member of the managing board, Zollner. “EIT brings experienced employees,
trained management, a positive corporate culture, and has a solid customer base. With
this move, we can serve our existing customers in an expanded US market. We also
expect to utilize Zollner’s global presence to bring great advantages for EIT.” (MB)

IPC: Rising Material and Labor Costs Still
Affecting EMS

BANNOCKBURN, IL – Nine in 10 electronics manufacturers are currently experiencing
rising material costs, while four-fifths are experiencing rising labor costs, according
to IPC survey data released in July. Eighty percent of respondents reported they have
increased pricing due to higher material and labor costs.
Data from IPC’s July report indicate forces exerting pressure on the global
economy, and, conversely, the electronics manufacturing industry, include growing
recession uncertainties, higher gasoline and food prices, geopolitical uncertainties,
and China Covid policies and lockdowns exacerbating supplychain disruptions.
“Other risks remain acute,” said Shawn DuBravac, chief economist, IPC. “Infla-
tionary pressures remain historically high in many parts of the world. While supply
chains appear to be improving, pricing pressure remains stiff. This is hurting profit-
ability for many businesses but also leading both businesses and consumers to hold
off purchases in hopes that prices will normalize. Moreover, higher prices for things
like gasoline are crowding out other purchases consumers and businesses might
make. How these forces will evolve in the coming months adds to the long list of
uncertainties around the globe that will continue to dominate the near-term outlook.”
Additional survey results indicate demand remains strong. More than half of
survey respondents indicate orders will expand in the next six months. While some
improvements to inventory are expected, ease of recruiting/finding skilled talent
are likely to remain challenging. Electronics manufacturers have expressed concern

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Note Acquires Dynamic Precision Solutions

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

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

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

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

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

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

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

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

The 6000m² (65,000 sq. ft.) expansion brings the total factory size to about 24,000m² (258,000 sq. ft.). The campus now employs about 600 workers and builds 200,000 electronics assemblies per day. Both figures are expected to climb as demand and the number of lines grow.

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

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

The Meung-sur-Loire site was built by Valeo in 1992, then acquired by Jabil in 2012. After Jabil decided to close the site, All Circuits acquired it in 2012.
Support For Flex, Rigid Flex and Embedded Component Designs Now Available.

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N. America Component Sales Sentiment Swings Negative

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

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

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

### STEADY STORAGE

<table>
<thead>
<tr>
<th>Trends in the US electronics equipment market (shipments only)</th>
<th>% CHANGE</th>
<th>MAR.</th>
<th>APR.</th>
<th>MAY</th>
<th>YTD%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computers and electronics products</td>
<td>-0.3</td>
<td>0.6</td>
<td>0.3</td>
<td>4.8</td>
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<tr>
<td>Computers</td>
<td>-2.9</td>
<td>1.1</td>
<td>-0.5</td>
<td>-2.7</td>
<td></td>
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<tr>
<td>Storage devices</td>
<td>-0.7</td>
<td>6.6</td>
<td>0.5</td>
<td>12.5</td>
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<tr>
<td>Other peripheral equipment</td>
<td>7.2</td>
<td>-11.6</td>
<td>-2.0</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Nondefense communications equipment</td>
<td>-3.1</td>
<td>1.5</td>
<td>0.8</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
<td>Defense communications equipment</td>
<td>-3.3</td>
<td>5.9</td>
<td>-4.2</td>
<td>9.6</td>
<td></td>
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<tr>
<td>A/V equipment</td>
<td>5.0</td>
<td>-1.9</td>
<td>-8.6</td>
<td>40.5</td>
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</tr>
<tr>
<td>Components¹</td>
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¹Revised *Preliminary *Includes semiconductors. Seasonally adjusted. Source: U.S. Department of Commerce Census Bureau, July 5, 2022

### US MANUFACTURING INDICES

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Source: Institute for Supply Management, July 1, 2022

### KEY COMPONENTS

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<td>PCBs³ (North America)</td>
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Sources: ¹IPC, ²SIA (3-month moving average growth), ³IPC, ⁴Census Bureau, ⁵Preliminary, ⁶Revised

### MARKET WATCH

**Hot Takes**

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

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

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

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

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

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

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

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

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

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

continued on pg. 55
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- **Via in Pad Expedited:** 3 Days
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- **HDI Expedited:** 5 – 12 Days

- **FLEX / RIGID-FLEX**

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- **Flex 1 – 6 Layers Expedited:** 5-15 Days
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Full Freight: PCB Buyers Should Demand a Delivered Price

Shortsighted approaches lead to overspending.

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

That’s why they should negotiate with suppliers for a “delivered” price.

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

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

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

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

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

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

■ Without a delivered price, your company takes possession of the shipment at the factory. If, as sometimes happens, several boxes of boards are lost in transit, it will not be the factory’s responsibility to replace them.

■ When product comes in and does not meet your quality standards, or it’s built wrong, you’ve already paid for freight. Sure, you can renegotiate with the manufacturer, but that is another headache that could have been avoided.

■ Two bills are to be paid: that of the manufacturer and that of the freight company; each may have different terms. The manufacturer, which ships in volume, will likely get better rates – especially with shipping rates quoted in Asia instead of the US – than you would get paying for shipping yourself.

■ The PCB manufacturer – and not you – will have to absorb fuel and holiday surcharges imposed by freight companies to have the product delivered.

■ Tariffs on PCBs manufactured in China are due at time of arrival, which you will pay. A negotiated delivered price would include tariffs (DDP). That means payment for the product, the freight, and the tariffs would be due at the later, pre-negotiated date.

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

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

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

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

The more certainty buyers can build into their supply chains, the better. Working with a good board manufacturer and practicing smart PCB purchasing will help control costs year-round and increase corporate cash flow.
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ASK ANY EMS company what its top challenges are, and labor shortages are now tied with material constraints. The labor market was already in the process of a culture change pre-Covid. More than two years of Covid’s impact on workplaces have made many in the workforce question their priorities in terms of work/life balance. It’s an applicant’s market.

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

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

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

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

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

- Are there opportunities to promote your company at job fairs, schools or workforce recruitment organizations you haven’t accessed?

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

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

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

Tuition reimbursement programs are another potential retention tool. It is a benefit that attracts employees with initiative, so it is important to consider a structure that capitalizes on that. First, there should
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RUSH JOBS CAN be a pain. They usually come in the form of a small, simple board or a seemingly minor revision to something more substantial. The common thread is somebody wants it right now. Normally, this means setting aside your current project and whipping out a quick spin. It’s a cumulative thing that stretches the longer-term projects.

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

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

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

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

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

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

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

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

**FIGURE 1.** A simple, predetermined outline is a good vehicle for design reuse.
complete the board, informing anyone who would listen.

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

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

Here comes the plot twist.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

continued on pg. 42
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A DESIGNER COMPLETED their first flex circuit design and sent it to several suppliers to quote. When the quotes came back, they noticed all of them had nonrecurring engineering/tooling costs that were higher than normally seen on a quote for a rigid PCB. Is this typical, or did something in the design cause this?

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

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

**Bare flex tooling.** Virtually every single- or double-sided and multilayer flex will require at least one die that will be used to cut the final part outline. Rigid PCBs are usually excised from the processing panel using a CNC router, so no outline die is required. Due to the very thin nature of flexible circuits, they do not route well and are prone to tears and edge stringers after a routing operation. Plus, CNC routing is much slower than punching. For this reason, either a steel rule die (for smaller volumes) or a hard tool (larger volumes, see FIGURE 1) is used to remove circuits from the panel.

The exception is rigid-flex construction. Since rigid-flex circuits have rigid areas that often don’t punch well, these circuits are typically routed. Most rigid-flex circuits have many flex layers that add thickness and improve edge quality after routing. If the rigid-flex design has very few internal layers, the fabricator may choose to either punch (another die) or laser the flex areas, then route the rigid areas.

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

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

**Component assembly.** Assembling components onto flexible circuits is not easy. Unlike rigid PCBs, flex circuits cannot run through the SMT process without tools and fixtures to support the flexible substrates.
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The author attended his first IPC meeting in 1966. At that time, the consensus was the world PCB output was $500 million. Some “knowledgeable” experts predicted PCB output would dwindle since semiconductors were rising rapidly and PCBs would not be needed. If that $500 million assessment was correct, in 55 years the PCB market grew 192 times, to $96 billion!

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

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

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

Exchange Rates

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

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

## TABLE 1. Average Exchange Rates: Local Currency/USD

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Japan yen</td>
<td>121.06</td>
<td>107.84</td>
<td>112.93</td>
<td>110.44</td>
<td>109.01</td>
<td>106.77</td>
<td>108.98</td>
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<td>Taiwan dollar (NTD)</td>
<td>31.777</td>
<td>32.25</td>
<td>30.44</td>
<td>30.16</td>
<td>30.93</td>
<td>29.47</td>
<td>27.64</td>
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<td>S. Korea won</td>
<td>1,132.33</td>
<td>1,160.80</td>
<td>1,130.59</td>
<td>1,100.8</td>
<td>1,165.7</td>
<td>1,180</td>
<td>1,136</td>
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<tr>
<td>Thailand baht</td>
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<td>35.290</td>
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<td>31.32</td>
<td>31.03</td>
<td>31.76</td>
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<td>Singapore dollar</td>
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<td>1.440</td>
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<td>1.349</td>
<td>1.364</td>
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<td>1.333</td>
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<td>Malaysia ringgit</td>
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<td>4.100</td>
<td>4.32</td>
<td>4.035</td>
<td>4.123</td>
<td>4.203</td>
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<td>Vietnam dong</td>
<td>21,920.68</td>
<td>22,763.00</td>
<td>22,721.03</td>
<td>22,001.08</td>
<td>23,202.59</td>
<td>23,201</td>
<td>22,879</td>
</tr>
<tr>
<td>Philippines peso</td>
<td>44.520</td>
<td>47.300</td>
<td>50.44</td>
<td>52.7</td>
<td>50.82</td>
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<td>49.94</td>
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<tr>
<td>Indonesia rupiah</td>
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<td>13,320.00</td>
<td>13,440.00</td>
<td>14,236.00</td>
<td>13,798.61</td>
<td>14,559.25</td>
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<tr>
<td>Canada dollar</td>
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<td>0.997</td>
<td>1.297</td>
<td>1.296</td>
<td>1.327</td>
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<td>India rupee</td>
<td>64,235</td>
<td>67,800</td>
<td>64.87</td>
<td>68.43</td>
<td>70.39</td>
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<tr>
<td>Mexico pesos</td>
<td>15.792</td>
<td>19.05</td>
<td>18.95</td>
<td>19.00</td>
<td>19.25</td>
<td>21.5</td>
<td>20.13</td>
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<tr>
<td>Russia ruble</td>
<td>61.195</td>
<td>57.4</td>
<td>58.31</td>
<td>62.78</td>
<td>64.69</td>
<td>72.412</td>
<td>73.12</td>
</tr>
<tr>
<td>Switzerland franc</td>
<td>0.962</td>
<td>0.997</td>
<td>0.98</td>
<td>1.022</td>
<td>0.994</td>
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<td>0.967</td>
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<tr>
<td>UK pound</td>
<td>0.655</td>
<td>0.74031</td>
<td>0.81</td>
<td>0.75</td>
<td>0.784</td>
<td>0.78</td>
<td>0.721</td>
</tr>
<tr>
<td>Euro</td>
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<td>0.904</td>
<td>0.886</td>
<td>0.844</td>
<td>0.894</td>
<td>0.8677</td>
<td>0.839</td>
</tr>
</tbody>
</table>

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

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

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

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

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

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

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

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

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

Computing. Fabricators of motherboards for smartphones, PCs and tablets did well because of demand for these products for work and school. As students returned to classrooms and enough PCs were made and distributed, however, motherboard demand for these products seems to be slowing.
The Printed Circuit Engineering Professional curriculum teaches a knowledge base and develops a competency for the profession of printed circuit engineering layout, based on current technology trends. It also provides ongoing reference material for continued development in the profession. The 40-hour course was developed by leading experts in printed circuit design with a combined 250 years of industry experience and covers approximately 67 major topics under the following headings: Basics of the profession, materials, manufacturing methods and processes; circuit definition and capture; board layout data and placement; circuit routing and interconnection; signal-integrity and EMI applications; flex PCBs; documentation and manufacturing preparation; and advanced electronics (energy movement in circuits, transmission lines, etc.).

Class flow: Books sent to students prior to an instructor lead review. This is followed by an optional exam with a lifetime certification that is recognized by the PCEA Trade Association.

The course references general CAD tool practices and is vendor-agnostic. Instructors include Mike Creeden, CID+, who has over 44 years of industry experience as an educator, PCB designer, applications engineer and business owner; and Tomas Chester, P.Eng., CPCD, who has designed over 100 circuit boards through all phases of the product lifecycle, and managed a variety of multifaceted, interdisciplinary projects, from simple interconnect designs to complex microprocessors.

AUTHORS

Mike Creeden  Gary Ferrari  Susy Webb  Rick Hartley  Steph Chavez

For Information or Registration: https://pcea.net/pce-edu-design-engineer-curriculum/
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## Printed Circuit Engineering Professional

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2.3 Schematic Types and Conventions – Functional, logic, flat and hierarchical
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5.3 Flexible Circuits Applications – Industry sectors and usage
5.4 Materials for Flexible Circuits – Properties and process
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5.6 FPC Stackup Constructions – Usage and process
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5.10 Stiffeners – Types and applications
5.11 Shielding Material – EMI and EMC considerations
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7.2 Critical Frequencies in Circuits on PC Boards Frequency and Rise Time (Tr)
7.3 Transmission Lines in PC Boards – Relational nature in electronics
7.4 Understanding Impedance of Transmission Lines – Modification from layout
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7.6 Controlling Impedance of Digital ICs – Controlled and set to specific values
7.7 Controlling Noise Margin – Critical lengths understanding
7.8 Crosstalk and Cross-coupling – Capacitive and inductive coupling
7.9 Controlling Timing of High-speed Lines – Timing matched, not length
Entries by Country

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

Looking at Table 2, if the revenue of the top Taiwan and Chinese fabricators is added (28,873+27,634), the sum is 66% (56,507/87,765) of the world output. This ratio is very close to the total share (64%) of the Taiwan and China fabricators on the NTI-100 list. With 100 or more new PCB projects pending over the next several years in China, many on a grand scale (if realized), China’s and Taiwan’s share of global production will exceed 70%.

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

<table>
<thead>
<tr>
<th>Rank</th>
<th>Maker Name</th>
<th>Nationality</th>
<th>Local Name</th>
<th>YoY chng</th>
<th>2020</th>
<th>2021</th>
<th>Brief Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Zhen Ding Technology</td>
<td>TW/China</td>
<td>瑯鼎科技</td>
<td>18.1%</td>
<td>4,749</td>
<td>5,609</td>
<td>60% from FPC &amp; FPCA, Into IC PKG Sub</td>
</tr>
<tr>
<td>2</td>
<td>Unimicron</td>
<td>TW/China</td>
<td>欣興電子</td>
<td>19.0%</td>
<td>3,178</td>
<td>3,783</td>
<td>IC PKG Sub: $2.08B, HDI: $945M</td>
</tr>
<tr>
<td>3</td>
<td>DSBJ China</td>
<td>東山精密</td>
<td>9.2%</td>
<td>2,932</td>
<td>3,201</td>
<td>Milflex + Multek, 80% FPC &amp; FPCA</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Nippon Mektron Japan</td>
<td>日本メクトロン</td>
<td>13.9%</td>
<td>2,585</td>
<td>2,944</td>
<td>100% FPC &amp; FPCA, No. 1 Auto PCB</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Compeq TW/China</td>
<td>華通電腦</td>
<td>4.2%</td>
<td>2,189</td>
<td>2,281</td>
<td>75% made in China, China plants expanding</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Tripod TW/China</td>
<td>健德科技</td>
<td>18.4%</td>
<td>2,010</td>
<td>2,279</td>
<td>96% made in China, China plants expanding</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>TTM Technologies US</td>
<td>TTM Technologies</td>
<td>6.8%</td>
<td>2,110</td>
<td>2,249</td>
<td>New plant under construction in Penang</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Shennan Circuits China</td>
<td>深南電路</td>
<td>20.2%</td>
<td>1,812</td>
<td>2,178</td>
<td>$1.5B investment on IC PKG substrate</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Ibiden Japan</td>
<td>イビデン</td>
<td>42.7%</td>
<td>1,524</td>
<td>2,174</td>
<td>IC PKG Sub: $1.98B</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>HannStar Board TW/China</td>
<td>靜宇博德</td>
<td>24.7%</td>
<td>1,654</td>
<td>2,062</td>
<td>Includes GBM, which contains ELNA</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>AT&amp;S Austria</td>
<td>AT&amp;S</td>
<td>33.8%</td>
<td>1,416</td>
<td>1,895</td>
<td>$2.2B IC PKG Sub in Malaysia, $500M in Austria</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Nanya PCB TW/China</td>
<td>南亞電路</td>
<td>35.6%</td>
<td>1,393</td>
<td>1,890</td>
<td>IC PKG Sub: $1.23B, 65% of total revenue</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Kingboard PCB China</td>
<td>建滔集団</td>
<td>31.4%</td>
<td>1,390</td>
<td>1,828</td>
<td>Includes E&amp;E, Techwise, Glory Faith, etc.</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>SEMCO S. Korea</td>
<td>삼성전자</td>
<td>7.6%</td>
<td>1,551</td>
<td>1,669</td>
<td>100% IC PKG Sub and expanding</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Shinko Electric Ind. Japan</td>
<td>新光電気工業</td>
<td>49.5%</td>
<td>1,040</td>
<td>1,554</td>
<td>100% IC PKG Sub and expanding</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Kinwong China</td>
<td>景旺電子</td>
<td>35.0%</td>
<td>1,101</td>
<td>1,489</td>
<td>Into high-end HDI and high-layer-count MLB</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Young Poong Group S. Korea</td>
<td>영풍그룹</td>
<td>18.7%</td>
<td>1,253</td>
<td>1,487</td>
<td>YPE, Interflex &amp; Korea Circuit ($840M FPC)</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Meiko Japan</td>
<td>メイコー</td>
<td>26.8%</td>
<td>1,092</td>
<td>1,388</td>
<td>$672M automotive; into IC PKG Sub in Japan</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>LG Innoltek S. Korea</td>
<td>LG이노텍</td>
<td>26.2%</td>
<td>1,095</td>
<td>1,382</td>
<td>100% IC PKG Sub</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>WUS Group (TW+CN) TW/China</td>
<td>楠梓電子(滬士電子)</td>
<td>1.1%</td>
<td>1,337</td>
<td>1,352</td>
<td>Taiwan Wus plus China Wus</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Kinsus TW/China</td>
<td>景碩科技</td>
<td>31.6%</td>
<td>980</td>
<td>1,291</td>
<td>90% IC PKG Sub, new plant in Taiwan</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Flexium Technology TW/China</td>
<td>台群科技</td>
<td>19.0%</td>
<td>1,082</td>
<td>1,287</td>
<td>100% FPC &amp; FPCA, 63% made in China</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Simmtech S. Korea</td>
<td>심텍</td>
<td>11.8%</td>
<td>1,057</td>
<td>1,200</td>
<td>New IC PKG Sub plant in Penang</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Victory Giant China</td>
<td>勝宏科技</td>
<td>32.7%</td>
<td>875</td>
<td>1,161</td>
<td>Rapid growth in HDI, IC PKG Sub to Nantong</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>AKM Meadville China</td>
<td>安捷利美維</td>
<td>32.7%</td>
<td>846</td>
<td>1,123</td>
<td>AKM &amp; AKM Meadville combined</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Taiwan Techvest (TPT) TW/China</td>
<td>志超科技</td>
<td>20.4%</td>
<td>827</td>
<td>995</td>
<td>PC motherboards</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Gold Circuit (GCE) TW/China</td>
<td>金像電子</td>
<td>13.8%</td>
<td>846</td>
<td>956</td>
<td>High-layer-count MLB</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Suntak China</td>
<td>崇達科技</td>
<td>37.3%</td>
<td>682</td>
<td>937</td>
<td>Into IC PKG Substrate</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>BH Flex S. Korea</td>
<td>ベーハイフレックス</td>
<td>43.8%</td>
<td>635</td>
<td>913</td>
<td>100% FPC &amp; FPCA, plants in Vietnam</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Daeduck Electronics S. Korea</td>
<td>대덕전자</td>
<td>8.1%</td>
<td>815</td>
<td>881</td>
<td>65% IC PKG Sub, more toward PKG Sub</td>
<td></td>
</tr>
</tbody>
</table>

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

**Top 30 Total** | 20.4% | 46,056 | 55,438
## TABLE 3. PCB Fabricators in 2021 with Revenue $100M (Continued)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Maker Name</th>
<th>Nationality</th>
<th>Local Name</th>
<th>YoY chng</th>
<th>2020</th>
<th>2021</th>
<th>Brief Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Nitto Denko</td>
<td>Japan</td>
<td>日東電工</td>
<td>71.0%</td>
<td>514</td>
<td>879</td>
<td>$100% FPC and expanding</td>
</tr>
<tr>
<td>32</td>
<td>Fujikura</td>
<td>Japan</td>
<td>フジクラ</td>
<td>-21.0%</td>
<td>1,051</td>
<td>828</td>
<td>100% FPC almost all in Thailand &amp; Vietnam</td>
</tr>
<tr>
<td>33</td>
<td>Shenzhen Fast Print</td>
<td>China</td>
<td>深圳興森快捷電路</td>
<td>24.9%</td>
<td>630</td>
<td>787</td>
<td>IC PKG Sub is increasing with new investment</td>
</tr>
<tr>
<td>34</td>
<td>CMK</td>
<td>Japan</td>
<td>日本シーイムケー</td>
<td>16.5%</td>
<td>641</td>
<td>747</td>
<td>80% automotive PCB</td>
</tr>
<tr>
<td>35</td>
<td>ASK PCB</td>
<td>China</td>
<td>奥士康</td>
<td>52.4%</td>
<td>455</td>
<td>693</td>
<td>New plant is contributing</td>
</tr>
<tr>
<td>36</td>
<td>Kyocera</td>
<td>Japan</td>
<td>京セラ</td>
<td>38.0%</td>
<td>500</td>
<td>690</td>
<td>$2.6B IC PKG Sub including ceramic Sub</td>
</tr>
<tr>
<td>37</td>
<td>Chin Poon</td>
<td>TW/China</td>
<td>敬鵬工業</td>
<td>19.0%</td>
<td>554</td>
<td>659</td>
<td>Automotive increasing</td>
</tr>
<tr>
<td>38</td>
<td>Mutara Manufacturing</td>
<td>Japan</td>
<td>村田製作所</td>
<td>16.4%</td>
<td>550</td>
<td>640</td>
<td>80% automotive PCB</td>
</tr>
<tr>
<td>39</td>
<td>Olympic</td>
<td>China</td>
<td>世運電路</td>
<td>48.2%</td>
<td>396</td>
<td>587</td>
<td>Automotive increasing</td>
</tr>
<tr>
<td>40</td>
<td>Shengyi Electronics</td>
<td>China</td>
<td>生益電子</td>
<td>-0.4%</td>
<td>576</td>
<td>570</td>
<td>Huawei orders nose-dived</td>
</tr>
<tr>
<td>41</td>
<td>Dynamic Electronics</td>
<td>TW/China</td>
<td>定穂電子</td>
<td>24.9%</td>
<td>456</td>
<td>570</td>
<td>Having more than 50% from automotive PCB</td>
</tr>
<tr>
<td>42</td>
<td>Sumitomo Elect Ind.</td>
<td>Japan</td>
<td>住友電気工業</td>
<td>0.4%</td>
<td>562</td>
<td>564</td>
<td>Dormant</td>
</tr>
<tr>
<td>43</td>
<td>Wuzhu</td>
<td>China</td>
<td>五株科技</td>
<td>20.3%</td>
<td>456</td>
<td>560</td>
<td>HC &amp; FPC</td>
</tr>
<tr>
<td>44</td>
<td>Bomin Electronics</td>
<td>China</td>
<td>博敏電子</td>
<td>26.4%</td>
<td>435</td>
<td>550</td>
<td>Plant only in Thailand, increasing with new plant</td>
</tr>
<tr>
<td>45</td>
<td>APEX International</td>
<td>TW/China</td>
<td>泰鼎電路</td>
<td>25.1%</td>
<td>428</td>
<td>535</td>
<td>100% FPC and FPCA</td>
</tr>
<tr>
<td>46</td>
<td>Career Technology</td>
<td>TW/China</td>
<td>嘉聯電子</td>
<td>-8.5%</td>
<td>580</td>
<td>531</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>47</td>
<td>Sun &amp; Lynn</td>
<td>China</td>
<td>深南電路</td>
<td>37.8%</td>
<td>369</td>
<td>508</td>
<td>ESI Flex</td>
</tr>
<tr>
<td>48</td>
<td>Founder PCB</td>
<td>China</td>
<td>方正印刷工業</td>
<td>-0.3%</td>
<td>502</td>
<td>501</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>49</td>
<td>Hongxin Electronics</td>
<td>China</td>
<td>弘信電子</td>
<td>21.1%</td>
<td>412</td>
<td>499</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>50</td>
<td>Unitech</td>
<td>TW/China</td>
<td>樣華電子</td>
<td>-6.2%</td>
<td>521</td>
<td>488</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>51</td>
<td>KCE</td>
<td>Thailand</td>
<td>KCE Electronics</td>
<td>31.0%</td>
<td>370</td>
<td>483</td>
<td>70%+ is from automotive, new plant</td>
</tr>
<tr>
<td>52</td>
<td>Gul Technology</td>
<td>Singapore</td>
<td>Gul Technology</td>
<td>21.6%</td>
<td>393</td>
<td>478</td>
<td>Automotive increasing</td>
</tr>
<tr>
<td>53</td>
<td>China Eagle (CEE)</td>
<td>China</td>
<td>中京電子</td>
<td>25.9%</td>
<td>366</td>
<td>460</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>54</td>
<td>Ellington</td>
<td>China</td>
<td>依頓電子</td>
<td>12.5%</td>
<td>404</td>
<td>454</td>
<td>Conservative. Automotive PCB &amp; FPC</td>
</tr>
<tr>
<td>55</td>
<td>CCTC</td>
<td>China</td>
<td>汐頭超聲印製板</td>
<td>16.3%</td>
<td>387</td>
<td>450</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>56</td>
<td>Guangdong Junya</td>
<td>China</td>
<td>広東鯨龍電子</td>
<td>15.8%</td>
<td>368</td>
<td>426</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>57</td>
<td>SI Flex</td>
<td>S. Korea</td>
<td>에스아이필름스</td>
<td>4.7%</td>
<td>406</td>
<td>425</td>
<td>100% FPC &amp; FPCA, plants only in Vietnam</td>
</tr>
<tr>
<td>58</td>
<td>Kyoden</td>
<td>Japan</td>
<td>キョウデン</td>
<td>25.8%</td>
<td>333</td>
<td>419</td>
<td>Automotive increasing</td>
</tr>
<tr>
<td>59</td>
<td>Isu-Petasys</td>
<td>S. Korea</td>
<td>이수베타시스템</td>
<td>-8.8%</td>
<td>453</td>
<td>413</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>60</td>
<td>Lincstech</td>
<td>Japan</td>
<td>リンクステック</td>
<td>23.8%</td>
<td>323</td>
<td>400</td>
<td>Former PCB Div of Showa Denko</td>
</tr>
<tr>
<td>61</td>
<td>ASE</td>
<td>TW/China</td>
<td>日月光</td>
<td>34.7%</td>
<td>282</td>
<td>380</td>
<td>100% IC PKG Sub, Kaoshiung &amp; Shanghai</td>
</tr>
<tr>
<td>62</td>
<td>Red Board</td>
<td>China</td>
<td>紅板</td>
<td>17.0%</td>
<td>319</td>
<td>373</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>63</td>
<td>GD Keixiang Kingshine</td>
<td>China</td>
<td>広東科翔電子</td>
<td>40.6%</td>
<td>250</td>
<td>352</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>64</td>
<td>Guangdong XD Group</td>
<td>China</td>
<td>広東興達鴻業電子</td>
<td>3.8%</td>
<td>318</td>
<td>330</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>65</td>
<td>STEMCO</td>
<td>S. Korea</td>
<td>스템코</td>
<td>10.0%</td>
<td>300</td>
<td>330</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>66</td>
<td>Sannina</td>
<td>US</td>
<td>Sannina</td>
<td>10.0%</td>
<td>300</td>
<td>330</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>67</td>
<td>APCB</td>
<td>TW/China</td>
<td>競業集成業務</td>
<td>9.3%</td>
<td>301</td>
<td>329</td>
<td>Taiwan, China &amp; Thailand</td>
</tr>
<tr>
<td>68</td>
<td>Delton Technology</td>
<td>China</td>
<td>広州恵通電子</td>
<td>28.2%</td>
<td>258</td>
<td>324</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>69</td>
<td>FICT</td>
<td>Japan</td>
<td>エフアイシーティー</td>
<td>25.8%</td>
<td>244</td>
<td>307</td>
<td>Purchased by a Japanese fund; expanding</td>
</tr>
<tr>
<td>70</td>
<td>Transtech</td>
<td>China</td>
<td>江蘇德芯</td>
<td>8.5%</td>
<td>276</td>
<td>300</td>
<td>High-layer-count MLB</td>
</tr>
<tr>
<td>71</td>
<td>Shenzhen Sunshine</td>
<td>China</td>
<td>深圳明陽电子</td>
<td>48.6%</td>
<td>202</td>
<td>290</td>
<td>Two plants in China &amp; subsidiary in Germany</td>
</tr>
<tr>
<td>72</td>
<td>MFS</td>
<td>Singapore</td>
<td>MFS Singapore</td>
<td>16.6%</td>
<td>241</td>
<td>281</td>
<td>Two plants in China and one in Malaysia</td>
</tr>
<tr>
<td>73</td>
<td>Shirai Denshi</td>
<td>Japan</td>
<td>シライ電子</td>
<td>31.7%</td>
<td>205</td>
<td>270</td>
<td>Three plants in Japan and one in Zhuhai</td>
</tr>
</tbody>
</table>

**Top 31-73 Total**: 17.4% 17,887 20,990

In $US million. Source: N.T. Information Ltd., July 4, 2022
CONFERENCE: May 9 - 11
EXHIBITION: Wednesday, May 10
Boxboro Regency Hotel & Conference Center
Boxborough, MA

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HEADLINING ON THE MAIN STAGE:
RICK HARTLEY ★ SUSY WEBB ★ LEE RITCHEY

GUEST PERFORMANCES BY: Gary Ferrari ★ Vern Solberg ★ Mike Creeden
### TABLE 3. PCB Fabricators in 2021 with Revenue $\geq$100M (Continued)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Maker Name</th>
<th>Nationality</th>
<th>Local Name</th>
<th>YoY chng</th>
<th>2020</th>
<th>2021</th>
<th>Brief Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
<td>DAP</td>
<td>S. Korea</td>
<td>디에이피</td>
<td>0.8%</td>
<td>265</td>
<td>267</td>
<td>HDI specialist</td>
</tr>
<tr>
<td>75</td>
<td>Leader-Tech</td>
<td>China</td>
<td>深圳上達電子</td>
<td>41.7%</td>
<td>187</td>
<td>266</td>
<td>FPC &amp; FPCA, chip-on-flex</td>
</tr>
<tr>
<td>76</td>
<td>Palwonn</td>
<td>TW/China</td>
<td>華聲電子</td>
<td>17.9%</td>
<td>223</td>
<td>263</td>
<td>Plant in Shenzhen &amp; Suzhou, no plant in TW</td>
</tr>
<tr>
<td>77</td>
<td>Onpress</td>
<td>China</td>
<td>安柏電路</td>
<td>33.9%</td>
<td>192</td>
<td>257</td>
<td>Heavily into automotive PCB</td>
</tr>
<tr>
<td>78</td>
<td>Daisho Dennshi</td>
<td>Japan</td>
<td>大昌電子</td>
<td>11.7%</td>
<td>230</td>
<td>257</td>
<td>IC PKG Sub &amp; high-density PCB</td>
</tr>
<tr>
<td>79</td>
<td>Kunshan Huanxing Grp</td>
<td>China</td>
<td>昆山華新電子集團</td>
<td>11.0%</td>
<td>229</td>
<td>254</td>
<td>kshuanxin.com.cn</td>
</tr>
<tr>
<td>80</td>
<td>ACCESS</td>
<td>China</td>
<td>珠海越華半導體</td>
<td>73.5%</td>
<td>143</td>
<td>249</td>
<td>100% IC PKG Sub, new plant in Zhuhai</td>
</tr>
<tr>
<td>81</td>
<td>Taihong Circuit Industry</td>
<td>TW/China</td>
<td>台鴻印刷電路工業</td>
<td>17.1%</td>
<td>205</td>
<td>240</td>
<td>China plant was sold</td>
</tr>
<tr>
<td>82</td>
<td>Ichia Technology</td>
<td>TW/China</td>
<td>業嘉科技</td>
<td>17.7%</td>
<td>199</td>
<td>234</td>
<td>100% FPC &amp; FPCA</td>
</tr>
<tr>
<td>83</td>
<td>SZ Jove Enterprize</td>
<td>China</td>
<td>深圳中富電路</td>
<td>33.1%</td>
<td>169</td>
<td>225</td>
<td>jovepcb.com</td>
</tr>
<tr>
<td>84</td>
<td>Würth Elektronik</td>
<td>Germany</td>
<td>Würth Elektronik</td>
<td>21.0%</td>
<td>178</td>
<td>215</td>
<td>Three plants in Germany and Chinese partners</td>
</tr>
<tr>
<td>85</td>
<td>Camelot PCB</td>
<td>China</td>
<td>金燕電子科技</td>
<td>67.6%</td>
<td>124</td>
<td>207</td>
<td>cameлотpcb.com</td>
</tr>
<tr>
<td>86</td>
<td>Forewin FPC</td>
<td>China</td>
<td>福葉電子</td>
<td>42.7%</td>
<td>143</td>
<td>204</td>
<td>forewin-flex.com</td>
</tr>
<tr>
<td>87</td>
<td>Shenzen Minzhenhong</td>
<td>China</td>
<td>深圳明正宏電子</td>
<td>33.3%</td>
<td>150</td>
<td>200</td>
<td>mzhppcb.cn</td>
</tr>
<tr>
<td>88</td>
<td>Somacis</td>
<td>Italy</td>
<td>Somacis</td>
<td>11.1%</td>
<td>180</td>
<td>200</td>
<td>Italy, China, San Diego and U.K.(?)</td>
</tr>
<tr>
<td>89</td>
<td>Guangzhou GCI</td>
<td>China</td>
<td>広州杰賽科技</td>
<td>20.4%</td>
<td>164</td>
<td>197</td>
<td>chinagcci.com</td>
</tr>
<tr>
<td>90</td>
<td>Kyosha</td>
<td>Japan</td>
<td>京写</td>
<td>23.3%</td>
<td>159</td>
<td>196</td>
<td>Japan, China, Indonesia and now in Vietnam</td>
</tr>
<tr>
<td>91</td>
<td>J’An Munkan Technology</td>
<td>China</td>
<td>吉安滿坤科技</td>
<td>-0.3%</td>
<td>192</td>
<td>186</td>
<td>mankun.com</td>
</tr>
<tr>
<td>92</td>
<td>Jiangxi ZLE</td>
<td>China</td>
<td>江西中絡電子</td>
<td>7.5%</td>
<td>169</td>
<td>182</td>
<td>zealpcb.com</td>
</tr>
<tr>
<td>93</td>
<td>Toppan Printing</td>
<td>Japan</td>
<td>凸版印刷</td>
<td>28.6%</td>
<td>140</td>
<td>180</td>
<td>100% IC packaging substrate</td>
</tr>
<tr>
<td>94</td>
<td>Summit Interconnect</td>
<td>US</td>
<td>Summit Interconnect</td>
<td>24.1%</td>
<td>145</td>
<td>180</td>
<td>Bought Royal Circuit in 2022</td>
</tr>
<tr>
<td>95</td>
<td>Oki Printed Circuit</td>
<td>Japan</td>
<td>沖PCB</td>
<td>8.5%</td>
<td>165</td>
<td>179</td>
<td>OKI Printed Circuit &amp; Circuit Tech merged</td>
</tr>
<tr>
<td>96</td>
<td>Dongguang Hongyuen</td>
<td>China</td>
<td>東莞華源電子</td>
<td>33.7%</td>
<td>133</td>
<td>178</td>
<td>hongyuen.com, expanding</td>
</tr>
<tr>
<td>97</td>
<td>Liang Dar</td>
<td>TW/China</td>
<td>良達科技</td>
<td>6.1%</td>
<td>165</td>
<td>175</td>
<td>Two plants in Taiwan and one in China</td>
</tr>
<tr>
<td>98</td>
<td>Haesung DS</td>
<td>S. Korea</td>
<td>해성디에스</td>
<td>35.2%</td>
<td>125</td>
<td>169</td>
<td>haesungds.co.kr, Leadframe &amp; PKG Sub</td>
</tr>
<tr>
<td>99</td>
<td>Brain Power</td>
<td>TW/China</td>
<td>欣強科技</td>
<td>7.7%</td>
<td>156</td>
<td>168</td>
<td>Plant only in China</td>
</tr>
<tr>
<td>100</td>
<td>Changzhou Auhong</td>
<td>China</td>
<td>常州澳弘電子</td>
<td>21.4%</td>
<td>138</td>
<td>167</td>
<td>czauhong.com</td>
</tr>
<tr>
<td>101</td>
<td>Jiangsu Suhhang</td>
<td>China</td>
<td>江蘇蘇杭電子集團</td>
<td>18.4%</td>
<td>140</td>
<td>166</td>
<td>suhang.com.cn</td>
</tr>
<tr>
<td>102</td>
<td>Glorysky</td>
<td>China</td>
<td>惠州市特創電子</td>
<td>40.9%</td>
<td>118</td>
<td>166</td>
<td>glorysky.de</td>
</tr>
<tr>
<td>103</td>
<td>Shihui Fushi</td>
<td>China</td>
<td>四合富仕電子科技</td>
<td>61.4%</td>
<td>102</td>
<td>164</td>
<td>fujiprint.com; collaboration with CMK</td>
</tr>
<tr>
<td>104</td>
<td>Xusheng Electronics</td>
<td>China</td>
<td>江西旭昇電子</td>
<td>13.1%</td>
<td>145</td>
<td>163</td>
<td>xushengpcb.com</td>
</tr>
<tr>
<td>105</td>
<td>Hyunwoo</td>
<td>S. Korea</td>
<td>현우</td>
<td>29.0%</td>
<td>135</td>
<td>162</td>
<td>?</td>
</tr>
<tr>
<td>106</td>
<td>Jiangsu Difeida</td>
<td>China</td>
<td>江蘇迪飛達電子</td>
<td>27.5%</td>
<td>124</td>
<td>159</td>
<td>dfd338.com/cn</td>
</tr>
<tr>
<td>107</td>
<td>Sichuan Intrinsics</td>
<td>China</td>
<td>四川英創電子</td>
<td>11.0%</td>
<td>111</td>
<td>157</td>
<td>iqpcb.com</td>
</tr>
<tr>
<td>108</td>
<td>TLB</td>
<td>S. Korea</td>
<td>티엘비리</td>
<td>-3.1%</td>
<td>162</td>
<td>157</td>
<td>New plant in Vietnam</td>
</tr>
<tr>
<td>109</td>
<td>Amphenol PCB</td>
<td>US</td>
<td>Amphenol PCB</td>
<td>6.9%</td>
<td>145</td>
<td>155</td>
<td>Plants in the US, UK and China</td>
</tr>
<tr>
<td>110</td>
<td>KSG</td>
<td>Germany</td>
<td>KSG</td>
<td>27.0%</td>
<td>122</td>
<td>155</td>
<td>Plants in Germany and Austria</td>
</tr>
<tr>
<td>111</td>
<td>Longyu PCB</td>
<td>China</td>
<td>龍宇電子</td>
<td>51.3%</td>
<td>102</td>
<td>154</td>
<td>longyupcb.com</td>
</tr>
<tr>
<td>112</td>
<td>Jiangxi Union Gain</td>
<td>China</td>
<td>江西聯益電子科技</td>
<td>23.2%</td>
<td>124</td>
<td>154</td>
<td>uniongaincn.com</td>
</tr>
<tr>
<td>113</td>
<td>CHPT</td>
<td>TW/China</td>
<td>中華精測科技</td>
<td>0.8%</td>
<td>152</td>
<td>153</td>
<td>Maker of probe cards &amp; burn-in boards</td>
</tr>
<tr>
<td>114</td>
<td>Kunshan Wanzhen</td>
<td>China</td>
<td>昆山万正電路板</td>
<td>-4.5%</td>
<td>155</td>
<td>148</td>
<td>wxpcb.com</td>
</tr>
<tr>
<td>115</td>
<td>Schweizer Electronics</td>
<td>Germany</td>
<td>Schweizer Electronics</td>
<td>25.0%</td>
<td>117</td>
<td>146</td>
<td>80% automotive, plants in Germany &amp; China</td>
</tr>
<tr>
<td>116</td>
<td>S2 Xinyu Tengye</td>
<td>China</td>
<td>深圳新宇騰飛電子</td>
<td>-0.5%</td>
<td>145</td>
<td>144</td>
<td>zefpc.com</td>
</tr>
</tbody>
</table>

Top 74-116 Total  

|       |       |       |       | 21.2% | 6,767 | 8,198 |

In $US million. Source: N.T. Information Ltd., July 4, 2022
no company exceeded $1 billion. The top fabricator that year was Ibiden, with $932 million in revenue. A decade ago, in 2012, 13 fabricators had revenue exceeding $1 billion, of which four topped $2 billion.

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

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

---

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

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

In $US million. Source: N.T. Information Ltd., July 4, 2022
production will exceed $10 billion annually. The rate of growth in China will be larger, however.

**TABLE 4** summarizes the top 25 fabricators by country.

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

DR. HAYAO NAKAHARA is president of N.T. Information; nakanti@yahoo.com.

**TABLE 4.** Top 25 Fabricators in 2021 by Country

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>No. of Makers</th>
<th>Share</th>
<th>Total Revenue</th>
<th>Rev Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taiwan</td>
<td>9</td>
<td>36%</td>
<td>21,819</td>
<td>43.0%</td>
</tr>
<tr>
<td>2</td>
<td>China</td>
<td>6</td>
<td>24%</td>
<td>10,989</td>
<td>21.6%</td>
</tr>
<tr>
<td>3</td>
<td>Japan</td>
<td>4</td>
<td>16%</td>
<td>8,060</td>
<td>15.9%</td>
</tr>
<tr>
<td>4</td>
<td>S. Korea</td>
<td>4</td>
<td>16%</td>
<td>5,744</td>
<td>11.3%</td>
</tr>
<tr>
<td>5</td>
<td>US</td>
<td>1</td>
<td>4%</td>
<td>2,249</td>
<td>4.4%</td>
</tr>
<tr>
<td>6</td>
<td>Austria</td>
<td>1</td>
<td>4%</td>
<td>1,895</td>
<td>3.7%</td>
</tr>
</tbody>
</table>

Total 25 100% 50,756 100.0%

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

**TABLE 5.** World PCB Production* by Region

<table>
<thead>
<tr>
<th>Region</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Americas</td>
<td>3,160</td>
<td>3,220</td>
<td>3,200</td>
<td>3,400</td>
</tr>
<tr>
<td>Germany</td>
<td>940</td>
<td>841</td>
<td>743</td>
<td>845</td>
</tr>
<tr>
<td>Other Europe+Russia</td>
<td>1,330</td>
<td>1,250</td>
<td>1,210</td>
<td>1,370</td>
</tr>
<tr>
<td>Africa &amp; Middle East</td>
<td>142</td>
<td>143</td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td>West Total</td>
<td>5,572</td>
<td>5,654</td>
<td>5,273</td>
<td>5,745</td>
</tr>
<tr>
<td>China</td>
<td>42,430</td>
<td>45,420</td>
<td>49,280</td>
<td>57,100</td>
</tr>
<tr>
<td>Taiwan</td>
<td>8,140</td>
<td>7,850</td>
<td>7,570</td>
<td>11,630</td>
</tr>
<tr>
<td>S. Korea</td>
<td>7,415</td>
<td>7,220</td>
<td>6,000</td>
<td>7,200</td>
</tr>
<tr>
<td>Japan</td>
<td>5,940</td>
<td>5,830</td>
<td>5,750</td>
<td>6,900</td>
</tr>
<tr>
<td>Thailand</td>
<td>3,130</td>
<td>2,810</td>
<td>2,650</td>
<td>3,175</td>
</tr>
<tr>
<td>Vietnam</td>
<td>2,700</td>
<td>2,890</td>
<td>2,900</td>
<td>3,010</td>
</tr>
<tr>
<td>Other Asia</td>
<td>1,670</td>
<td>1,590</td>
<td>1,450</td>
<td>1,280</td>
</tr>
<tr>
<td>Asia Total</td>
<td>71,425</td>
<td>73,610</td>
<td>76,400</td>
<td>90,295</td>
</tr>
<tr>
<td>World Total</td>
<td>76,997</td>
<td>79,064</td>
<td>81,673</td>
<td>96,040</td>
</tr>
</tbody>
</table>

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

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

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

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

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JTAG/Boundary Scan
CT Scanning
AXI

2D and 3D Xray
Analytical Laboratory Services
Reverse Engineering Services
Nondestructive Failure Analysis
In-Circuit Test
Test Program and Fixture Development

Quick Deployment. Quick Action.
Tackling **HEAD-IN-PILLOW DEFECTS** with Vapor Phase Reflow

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

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

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

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

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

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

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

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

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

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

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

As PCBs and components are soldered, they undergo a heating cycle that uses different temperature zones to gradually heat the PCBA. This can lead to uneven thermal distribution, as one end of the PCBA is heated before the other, subsequently leading to PCB warpage. The different temperature zones require a higher peak temperature, as the PCB must be held above the solder paste’s melting point for up to 30 seconds. This is often achieved by increasing the maximum applied temperature up to 35°C, per the solder paste manufacturer’s specifications. The use of this overhead is to ensure thicker PCBs and high-mass components reach and exceed the solder paste’s melting point.\(^2\)

Applying peak temperatures of this magnitude disrupts the functionality of BGA/LGA-style packages due to the component’s internal material composition. These higher temperatures often exceed the limitations of the component, which cause it to unevenly expand and subsequently warp. As the PCB and/or component warp, the solder balls disengage from the pads. This leads to defective solder joints, as either oxides form in between the pad and ball, or the pad and ball cool at different rates and fail to form a proper solder joint (Figure 2). Both these effects lead to the creation of HiP defects.

What is Vapor Phase?

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

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

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

Experimental Methodology

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

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

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

Data Analysis

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

<table>
<thead>
<tr>
<th>TABLE 1. Coplanarity Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convection (µm)</td>
</tr>
<tr>
<td>Side A</td>
</tr>
<tr>
<td>Side B</td>
</tr>
<tr>
<td>Side C</td>
</tr>
<tr>
<td>Side D</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

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

FIGURE 5. Two images of solder joints of a BGA/LGA hybrid connector. The left image is after the convection oven reflow with HiP defects. The right image is after the vapor phase rework. Inspection of the solder balls revealed elongated solder joints and HiP defects. After the rework, the solder joint formed an exceptional solder ball.
through the vapor phase process it was 1µm, a 112µm decrease in the delta height measurement.

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

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

Conclusion

Using data collected during the rework of a defective BGA/LGA hybrid connector, we analyzed attributes of vapor phase soldering that benefit the manufacturing of PCBAs. The oxygen-free environment, low temperature process, and even heat distribution emulate an optimal reflow environment. This environment is extremely useful in tackling head-in-pillow defects both during the manufacturing and rework of PCBAs. The abil-

![FIGURE 6. 3-D AOI rendered image of side A before rework. Calculations made by pins seen in image.](image6)

![FIGURE 7. 3-D AOI rendered image of side A after rework. Calculations made by pins seen in image.](image7)

![FIGURE 8. 3-D AOI rendered image of side B before rework. Calculations made by pins seen in image.](image8)

![FIGURE 9. 3-D AOI rendered image of side B after rework. Calculations made by pins seen in image.](image9)

![FIGURE 10. 3-D AOI rendered image of side C before rework. Calculations made by pins seen in image.](image10)

![FIGURE 11. 3-D AOI rendered image of side C after rework. Calculations made by pins seen in image.](image11)

![FIGURE 12. 3-D AOI rendered image of side D before rework. Calculations made by pins seen in image.](image12)

![FIGURE 13. 3-D AOI rendered image of side D after rework. Calculations made by pins seen in image.](image13)
ity to rework and prevent these defects ensures the longevity of electrical devices and lessens constraints placed on PCB designers. Vapor phase reflow is a promising solution to the dreaded HiP defect.

REFERENCES

HUNTER PULLISHY is a computer engineering student at the University of Alberta currently completing his co-op internship as a junior research and development specialist at Trilogy-Net (trilogy-net.com). He has worked on multiple projects relating to innovative processes and technologies including vapor phase, EMI/EMC/RF, and optical inspection systems.

SANDY YIMBO is a research and development specialist at Trilogy-Net. She has a bachelor’s in astrophysics and is currently pursuing a master’s in geomatics engineering at the University of Calgary. She has spearheaded the research of cutting-edge technologies to revolutionize the electronics manufacturing industry. Her knowledge of detailed physical phenomena pertaining to electronics provides a solid foundation to research and develop innovative manufacturing processes; sandy.yimbo@trilogy-net.com.

JOSE PINEDA is production manager at Trilogy-Net Inc. and has over 26 years of experience in electronics manufacturing. His expertise lies in creating adaptable manufacturing process controls, quality control, warehouse processes, operations planning, production execution, and staff development.
We hear a lot these days about smart manufacturing, but is there a broad consensus on what it means, and more specifically, its application in electronics assembly?

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

Chelsey Drysdale: Let’s get this out of the way first: How do you define “smart manufacturing?”

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

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

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

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

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

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

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

BM: I’ve never seen where an equipment manufacturer reached out to another one. Although it is rare, some manufacturers
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are moving toward adopting a standardized format to facilitate communication, but typically [these requests] come from the manufacturer: “I have a need. I need equipment A to talk to equipment B. They don’t have an interface available. This one has output D that doesn’t work with C. How do we make those things work?” I think a lot of it is collaboration, from the assembler bringing the parties together, coming to a mutual agreement, and a common place. What will happen is with the IP we generate, the manufacturer and software vendor will see the value in it because other assemblers had asked the same thing, and we’ll work together to provide that level of smart integration, and they’ll actually sell it to the next customer, and it just becomes a great working relationship.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1. **Machine calibration.** Check the date of the last machine calibration. In my experience, probably eight of 10 machines require calibration after they are released onto production floors. If the calibration is out of date, do it! And, if it has been calibrated, but you are seeing issues, check the onboard systems to ensure nothing has gone awry with the machine.

2. **Product program.** It’s not that uncommon to see the wrong program loaded for a specific product, especially if the fiducials and board size are the same (and that’s not the printer’s fault, really), though other requirements may be different. To ensure you have the proper recipe, check that the parameters match the instructions, such as those for speed and pressure.

3. **Squeegees.** The proper squeegee length and angle are critical. Unless you are a printing specialist, the angles can look very similar when loaded on the machine. If the program calls for a 60°, 200mm-long blade, make sure you’re not running a 45°, 300mm-long squeegee. This will result in a completely different process. In addition, check the condition of the squeegee to verify flatness and sharpness. The squeegee is doing all the work, so respect the squeegee.

4. **Solder paste material.** In the rare case a manufacturer uses only one solder paste vendor and one paste type/recipe variant, then half the battle is over because the correct material will always be on hand. This isn’t likely, however, especially in an EMS environment. Check the barcodes, confirm metal loading of the material, expiry date and that the paste...
Focus on Business, continued from pg. 18

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

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

Finally, work arrangements are another good retention tool. Three-day, 12-hour shifts are gaining in popularity with employees who like four days off. Four 10-hour days are another option for a compressed workweek. Hybrid remote and in-office administrative jobs are attractive, as are entirely remote jobs. There are challenges managing each of these options, but Covid has increased employee desire for more free time. Eliminating the commute or compressing the workweek achieves that goal. Eliminating the commute is also a form of pay raise with current gas prices. Employees with longer commutes have seen the cost of that commute nearly double over the last year. None of these suggestions is a magic pill to solve labor challenges. Nevertheless, companies that create a well-rounded promotional strategy, combined with benefits appealing to their target workforce, do better than companies that don’t. This is a cyclical problem that will eventually resolve, but until it does, companies need to take a multipronged approach to attracting and retaining good talent.
AVISHTECH GAUSS STACK PRO SOFTWARE

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

Avishtech
avishtech.com

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

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

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

Keysight Technologies
keysight.com

KiCad 6.0.6 PCB CAD

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

KiCad
kicad.org

MOLEX QUAD-ROW BOARD-TO-BOARD CONNECTORS

Quad-Row board-to-board connectors feature staggered-circuit layout. Support compact form factors, including smartphones, smartwatches, wearables, game consoles and AR/VR devices. Pins are positioned across four rows at signal contact pitch of 0.175mm. Adhere to 3.0A current rating. Align with standard soldering pitch of 0.35mm to expedite volume manufacturing using typical SMT processes. Interior armor and insert-molded power nail safeguard pins from damage during volume manufacturing and assembly. Suited for applications requiring small PCBs and flex assemblies. Come in 32- and 64-pin configurations coming soon. Plans are underway to support up to 100-pin counts.

Molex
molex.com

ROHM BD9XXN1 SERIES AUTOMOTIVE LDO REGULATOR ICs

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

Rohm Semiconductor
rohm.com

SATURN PCB DESIGN TOOLKIT V. 8.20

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

**Saturn PCB Design**

saturnpcb.com

**STACKPOLE HCSM2818 RESISTORS**

HCSM2818 resistors are rated at 5W and now provide a 2mΩ resistance value with TCR of 100ppm. Are stable at wide range of temperatures and power loads. Applications include power modules and inverters, lithium ion battery management, portable power management for electric and hybrid motor control, and defense electronics.

**Stackpole Electronics**

seielect.com

**STACKPOLE CSNL2512-3W RESISTOR**

CSNL2512-3W current sensing resistor now includes 0.2mΩ resistance value. Handles 3W of power, while providing TCR from ±50ppm for 1 and 2mΩ to ±175ppm for 0.2mΩ. AEC-compliant CSNL offers stable performance with expected change in resistance of less than 1% for most industry standard performance tests, including load life, short-time overload and biased humidity. Ideal for electric vehicles, power tools, HVAC controls, instrumentation, programmable power supplies, networking and infrastructure equipment, and communications equipment.

**Stackpole Electronics**

seielect.com

**UCAMCO REFERENCE GERBER VIEWER**


**Ucamco**

gerber-viewer.ucamco.com

**ZUKEN ECADSTAR 2022 ECAD**

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

**Zuken**

zuken.com

**INSITUWARE SM-100 SMART MIXER**

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

**Insituware**

insituware.com

**INSITUWARE CC-100 THICKNESS TESTER**

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

**Insituware**

insituware.com
INSPEKTO S70 AUTONOMOUS MACHINE VISION SYSTEM SOFTWARE

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

MACHINES            MATERIALS           TOOLS            SYSTEMS               SOFTWARE

MASTER BOND EP17TF EPOXY

EP17TF one-part epoxy has paste consistency and can be dispensed evenly and uniformly. Has glass transition temp. of 150°-155°C and service temp. range from -150° to +550°F. Is designed to compensate for thermal mismatches. Resists impact, vibration, shock and rigorous thermal cycling. Is reliable electrical insulator, possessing volume resistivity greater than 10¹⁵ ohm-cm and dielectric constant of 4.5 at 60Hz at room temp. Maintains electrical insulation properties. Has good toughness with elongation of 5-10%. Exhibits superior strength prop-
erties, bonding well to similar and dissimilar substrates such as metal, ceramics, plastics and composites. Offers lap shear strength of 3,200-3,400psi, tensile strength of 8,000-9,000psi and tensile modulus of 350,000-400,000psi at 75°F. Requires elevated temp. cure of 300°F for 5-6 hr., followed by post-cure at 350°F for 4-5 hr. Additional post cure is recommended. Withstands acids, bases, fuels, oils and many solvents. Is available in standard packaging from ½ pint containers up to 5-gal. pails.

Master Bond
masterbond.com

KYOCERA AVX INTERACTIVE COMPONENT SEARCH TOOL

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

Kyocera AVX
kyocera-avx.com

PROMATION PANDA 500 CE ROBOTIC SOLDERING SYSTEM

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

Promation USA
promotionusa.com

SHENMAO SMEF-Z52 FLUX

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

Shenmao
shenmao.com
In Case You Missed It

Components

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

Authors: Nathaniel Bleier, et al.

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

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

Materials

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

Authors: Julie I. Frish, et al.

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

SPC

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

Authors: Sajjad Bahrebar and Rajan Ambat

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

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