PCB007 PRESENTS

November 2015

the pcb magazine

an I-Connect007 publication

The Data Factor(y): The Power of Data

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This Month's Feature Articles

THE DATA FACTOR(Y): The Power of Data

This month, *The PCB Magazine* presents The Data Factor(y): The Power of Data. Feature articles explore and explain why accurate data is important, how to gather it (Internet of Things, for starters), and what exactly you can do with it once you've got it.

FEATURES

FEATURE COLUMNS

PCB007 PRESENTS

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Data, Data and More Data!

by Patty Goldman
I-CONNECT007 TECHNICAL EDITOR

It seems that whenever I'm working on a magazine topic, suddenly it's everywhere. So much so that I begin to wonder who was in on our topic discussion. It was that way with this month's theme, "The Data Factor(y): The Power of Data." Articles suddenly seemed to be appearing all over the place, especially on the topic of the Internet of Things (IoT). Yeah, they were always there; I just started noticing them.

Speaking of the IoT, I found myself wondering, "What does that really mean and how does it affect us?" I read an article at Forbes.com, "A Simple Explanation of the 'Internet of Things'" that offered a solid explanation[1], which really helped. Basically, it's all about connections connecting…electronically, of course. Personally, I haven't felt a great need to wear an armband or have my front door lock automatically (I don't even like my car's locks activating automatically) or have my washing machine start up at some odd time. I have timers on lamps, and I use a few auto sensors for other things. Isn't that enough? Apparently, not anymore!

We did a survey on our topic this month, as we do every month (sent to our subscribers). You can see some of the results in Figures 1 and 2. We also asked an open-ended question about your "largest issues" with data. Your answers seemed to revolve around the accuracy of data collected (and whether it is the right data), lack of time, collecting in real-time, and then how to organize and analyze what has been collected.

Figure 1: What data is most important to you?

		Response Percent
1	Sales/marketing data	25.00%
2	Front end/engineering data	25.00%
3	Data from manufacturing processes	40.91%
4	Inspection data	2.27%
5	Other (please specify):	6.82%

Other (please specify): (3)

Figure 2: How do you identify the data you need to manufacture your products?

		Response Percent
1	Value Stream mapping	27.27%
2	Low yield or out-of-control process(es)	27.27%
3	Advice of supervisor in area	15.91%
4	Advice of consultant or other	13.64%
5	Other (please specify):	15.91%

We also asked how you turn data into useful and right action. Most of these answers were a little vague, suggesting that many of you aren't quite sure what to do with the data you collect. And some of you mentioned, "Too much data!"

To help you with your data and IoT issues, we've got some great articles for you this month. Jason Marsh of Insulectro starts us off with the big picture, or as he calls it, the 50,000-foot view of the Internet of Things. He not only presents it in a very readable way, he succeeds in bringing IoT home and explains what it means to the PCB industry (good things!). This will get you charged up.

Next, Steve Williams gets down to brass tacks with regard to analyzing data. He explains statistical methods, and why you should use them. He gets right in the trenches with you and makes it easy to understand.

Dave Becker of All Flex gets right to the practical side of things with a discussion of wet process control in a PCB facility, including the most important parameters to be measuring and controlling.

In some areas, though, identifying which data to collect is not as obvious. If this has you a little baffled, be sure to read Dave Dibble's commentary on what and how to measure, followed by some advice on what to do with your results.

Now, because some of you have been asking for more technical articles, I am pleased to offer several in this issue. Thomas Gottwald and Christian Rößle of Schweizer Electronic AG have written about the challenges of power electronics, from substrate requirements through assembly. They also present some technologies that address these issues.

In his column, Karl Dietz revisits digital imaging—it's not just laser anymore. Then, Dirk Muller of Coherent Inc. provides a detailed overview of the various types of lasers used for making vias and how to decide which one to use.

Finally, we have what may be best described as an article of interest. Doug Bathauer of Integral Technologies talks about disruptive technologies and their effect on companies, using conductive polymers in the automotive industry as his case in point.

Once again, all three of our e-magazines have this same data focus. Do check out the others for more perspectives on this sometimes difficult-to-get-your-arms-around subject: *SMT Magazine* and *The PCB Design Magazine*.

To wrap up the year, in December we will be exploring the nitty-gritty of our industry's associations—IPC, SMTA, IEC, CPCA and a host of others. Be sure to tune back in. I hope by now you have subscribed so you can get it (and our newsletters) delivered right to your virtual door/mailbox. **PCB**

References

1. Forbes.com

Patricia Goldman is a 30+ year veteran of the PCB industry, with experience in a variety of areas, including R&D of imaging technologies, wet process engineering, and sales and marketing of PWB chemistry. She has worked actively with IPC since 1981 and served as TAEC chairman, and is also the co-author of numerous technical papers. To contact Goldman, click here.

What is the Internet of Things and Why Should it Matter to Us?

by Jason Marsh
INSULECTRO

It is often surprising how closely our science fiction novels and movies model the future. The Internet of Things (IoT) and big data may prove to be an excellent example of this phenomenon. Coined in 1999 by Kevin Ashton (the RFID standards pioneer), the IoT is one of the least descriptive monikers of all time for something very important in the history of technology.

At its core, the IoT (or IoE or IoX) is a catch-all grouping for a network of interconnected devices across multiple technologies that span everything from smartphones, to utility systems, medicine, to vehicles—all of which will collect data and communicate with the cloud and with each other to make "intelligent" decisions about their operation within the total context of the network.

Add to this an astounding proliferation of sensors measuring everything from temperature to vibrations, chemicals, and magnetic fields. Drop in some big data analytics, make the leap from traditional neural nets and genetic algorithms written in LISP or Prolog to more modern programming languages like Python or Haskell, transition to distributed parallel architecture and a bunch of Google programmers lead by Jeff Dean, Geoffrey Hinton and Raymond Kurzweil, and you begin to have something that looks very much like James Cameron's mythical "Skynet" from the 1984 movie "The Terminator."

What exactly are these devices that will be connected?

In 2015, with 13.4 billion connected devices, we are close to saturation on human computer interface devices such as tablets, mobile phones and personal computers. The connected device landscape that is being predicted to drive the IoT will see significant growth in other segments which will span everything from medical devices, such as glucose sensors and blood

Figure 1: A wireless blood glucose monitoring design that connects to the cloud. (Source: Journal of Diabetes Science and Technology)

Figure 2: Semios orchard monitoring system has sensors which measure frost, leaf-wetness, soil moisture, and pest pressure and uploads that data to the cloud.

oxygen monitors (Figure 1), to wearables (Fitbit, Apple watch), to home automation (Nest thermostats or Kwikset Kevo Bluetooth locks), to self-driving vehicles (Google car, Delphi car) and even agriculture technologies (Semios [Figure 2]).

Each of these devices will collect significant data and then upload it to the cloud in either raw or semi-processed format where analysis will be done and machines will make decisions based on the results and alert users, make automated adjustments, or communicate with other machines to react to the conditions. Understandably, much of the press surrounds consumer devices, however Sam Smith at Juniper Research indicates that, "While IoT 'smart home' based applications grab media headlines, it is the industrial and public services sector—such as retail, agriculture, smart buildings and smart grid applications—that will form the majority of the device base."

There are also varying degrees of adoption. Countries like South Korea and Denmark lead the field with the largest number of connected devices, with 37.9 and 32.7 per 100 residents, respectively. The United States by comparison is at a level of 24.9 connected devices per 100 residents. All together, it is anticipated there will be nearly 40 billion connected devices by 2020. Flavio Bonami, former Cisco Fellow and co-lead of its IOT initiative explains that "the Economic Impact of the Internet of Things is forecasted by Cisco to grow by $19 trillion between 2014 and 2020."

One key to this is the adoption of the IPv6 device addressing protocol. IPv4 (the current standard, ex: 66.147.252.109) allows for about 4.3 billion addresses. In June of this year, John Curran, CEO of the American Registry for Internet Numbers (ARIN), told attendees at a conference in Boston that the "ARIN's IPv4 Address pool has dwindled to 90,000 and [would] be exhausted within two weeks." He urged IT professionals from educational institutions to "upgrade their public facing websites to IPv6 as soon as possible." IPv6 by contrast, will facilitate unique addressing for 4.3x10^38 devices (ex: 2600:1404:17:18b::19ff).

Where will this $19 trillion come from?

There are three basic categories of things that promise to undergo a significant amount of growth as a result of this IoT trend:

1) Sensors and edge devices: These devices will include sensors using Silicon ICs, MEMS technology (Figure 3), printed electronics, traditional circuit boards, and even organic biological sensors. These will include almost anything you can think of, from biometrics

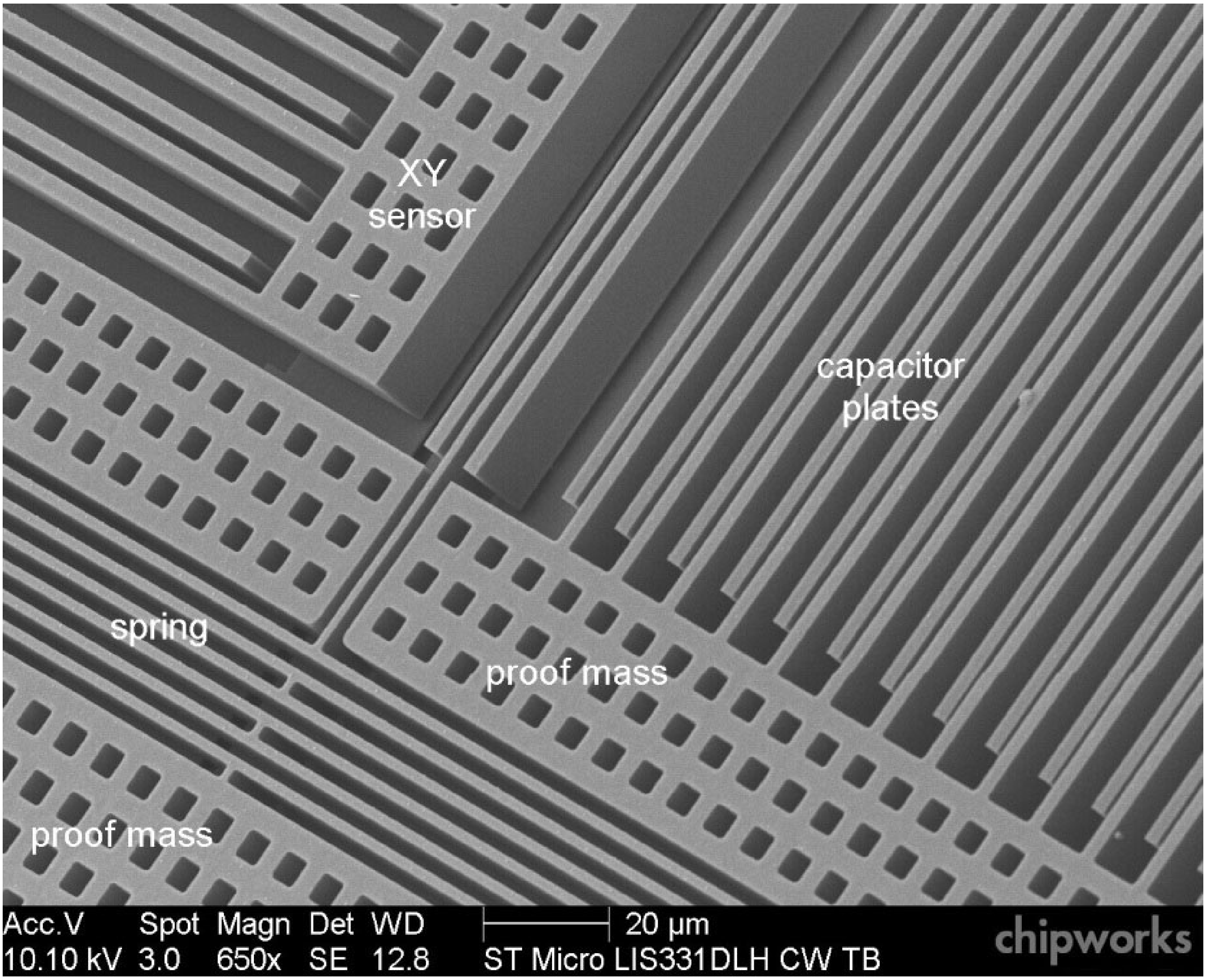

Figure 3: MEMS accelerometer inside iPhone that detects vibration and orientation and can be accessed by app programmers to measure other physical events. (Source: Chipworks)

for security and health monitoring, container tracking for shipments, weather and earthquake monitoring, and even food storage and temperature history for wine or vegetables (Figure 4).

2) Wireless communication protocols: It would be far too cumbersome to wire all these products to the grid so an avalanche of new, low power wireless protocols will be launched. Dr. Kris Pister, founder of Dust Networks explained in a presentation last year in San Diego that Linear Technology and Intel are already shipping IPv6 wireless evaluation kits under the Dust Networks and Edison brands respec-

Figure 4: Thinfilm ASA's smart label which stores temperature history of a vegetable package using printed electronics technology.

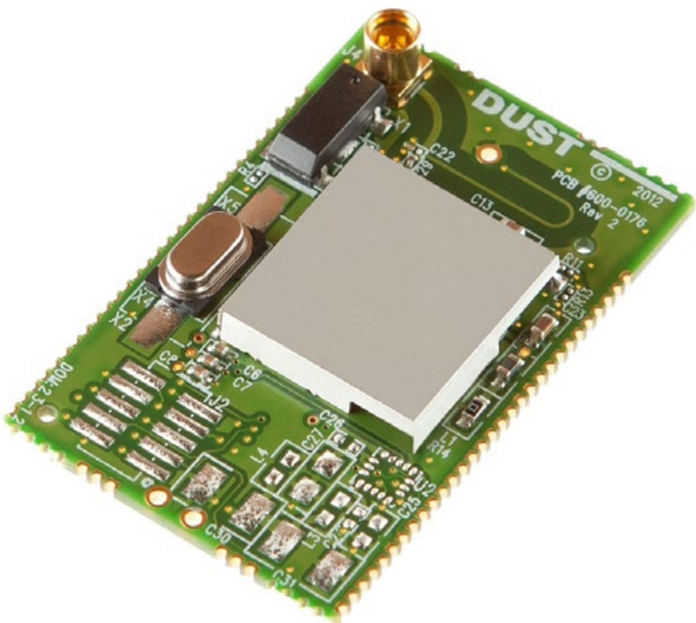

Figure 5: Dust Networks' Eterna™ 802.15.4 SoC system that communicated wirelessly and can be powered by harvested energy.

tively. Groups such as Wireless HART, IETF, ISA and WINA have been hard at work helping to drive standards and ensure interoperability of these low-power wireless sensor networks, some of which can function on minute amounts of energy harvested from their environment (Figure 5). These local networks will in turn interact with the Internet backbone through WiFi, GPRS, LTE and other existing infrastructure protocols driving buildout of base station transceivers and progress towards the adoption of higher data rate solutions like 5G which was developed under a NASA and M2Mi (Machine-to-Machine Intelligence Corp) cooperation beginning in 2008.

2) Data storage and networking infrastructure: There are two approaches which will likely prove to be not exclusionary but rather complementary. "Fog computing" in which edge devices (our phones and the LTE network are a good example of this) do a significant amount of computation on board and only send resultant data back to centralized data centers. The other side is cloud computing, whereby all the data (much of it raw and unprocessed) will travel over the Internet backbone to data centers where it will be stored and analyzed. The question as to how much of each will handle what types of data is the subject of frequent debate. The drawback to fog computing centers on accuracy, security and interoperability. In contrast, the cloud computing side will suffer from latency, expensive infrastructure and an absurd number of startups that struggle to articulate what their actual product is. Regardless of the protocols or the division between Fog and Cloud, a significant increase in back-end data storage and network speed is a foregone conclusion. As a result, IEEE has released its 802.3bj standard which provides for 100 Gb/s data rates in four parallel channels of 25 Gb/s, and has been working on the next generation of 32 Gb/s channels, to be followed by 56 Gb/s and later 112 Gb/s.

How much data are we talking about?

As of 2015, Cisco believes that only about 1% of physical things or systems are connected to the Internet. To get an idea of how much data we are talking about at the 2020 milestone, we will use the example of self-driving cars. The reason many self-driving cars are built using SUVs or station wagons is to hold a significant amount of computing capacity to process all the data which the network of GPS, Lidar, cameras and radar sensors inputs. The Continental self-driving car prototype operates a 24-computer linux cluster in the trunk to process this data. IWPC (the wireless industry consortium) calculates that communication needs for these vehicles currently exceeds the data capacity of 10 MB/s Ethernet. This means a typical drive from San Francisco to Los Angeles, which is 420 miles, would create (conservatively) about 45 GB of stored data. Consider an estimated 1.2 billion cars on the road globally and 84 million new cars which were sold in 2014 and then each of those driving an average of about 19,000 miles per year, the amount of generated data is simply astronomical.

How will all the data be handled?

There is no doubt that these speeds are challenging nearly every aspect of traditional PCB construction and materials. A significant

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amount of borrowing of technology and test methods from the RF and analog world is making its way into the digital design realm. Semico Research hosted an exchange on Oct 13 between the silicon and the bare-board industries, discussing how technologists can get to data speeds of 56 GB/s per channel with a 112 GB/s strategy expected to follow. Signal integrity experts such as Lee Ritchey of Speeding Edge, Scott McMorrow of Samtech, and Heidi Barnes of Keysight focused on the physics challenges of pushing copper and PCB production technologies to these speeds. Michael Gay of Isola explained the manufacturing methods of base materials and how Isola will provide next generation materials to meet these design needs.

The collaboration with the silicon designers helps everyone understand what is important to each group in order to realize these speeds in the entire chip-to-chip signal chain (chip-package-interposer-linecard-connector-backplane-return). In some cases, chip designers have the silicon space on the ASIC to build pre-compensation or eye-opener circuits in the die. However, for most applications, these speeds will mean increasingly tight signal integrity budgets on the circuit boards. This means that low loss and skew mitigation materials are very important. The next generation of designs will likely require highly specialized materials, and very well-controlled PCB manufacturing processes. This effort will necessitate collaboration, communication and cooperation between fabricators, designers, materials manufacturers and OEMs on an unprecedented scale.

What does all this have to do with my bottom line?

The IoT roadmap, if realized, means a significant amount of growth in all segments of the North American PCB market.

First, there will be a significant development in ASICs, FBGAs and other silicon products that will require burn-in boards and automated test equipment boards (Figure 6). Companies like Gorilla Circuits, TTM, Sanmina and Multitest will be see good opportunities in this business supporting companies like Qualcomm, Xylinx and Altera, as well as numerous Semiconductor OSATs (outsourced semiconductor and test) who will be building ASICS and packaging for a new generation of IoT oriented fabless semiconductor players.

Second, there will be the edge devices in both the PCB and printed electronics space. This will mean a significant number of prototypes of new technology systems for shops like Flex Interconnect, Lenthor Engineering and Protech. These will include prototypes for the household name mobile phone and tablet makers as well as a litany of new companies, some of them well-funded startups, making novel sensor packages in spaces like medical, wearables and home automation. The Flexible

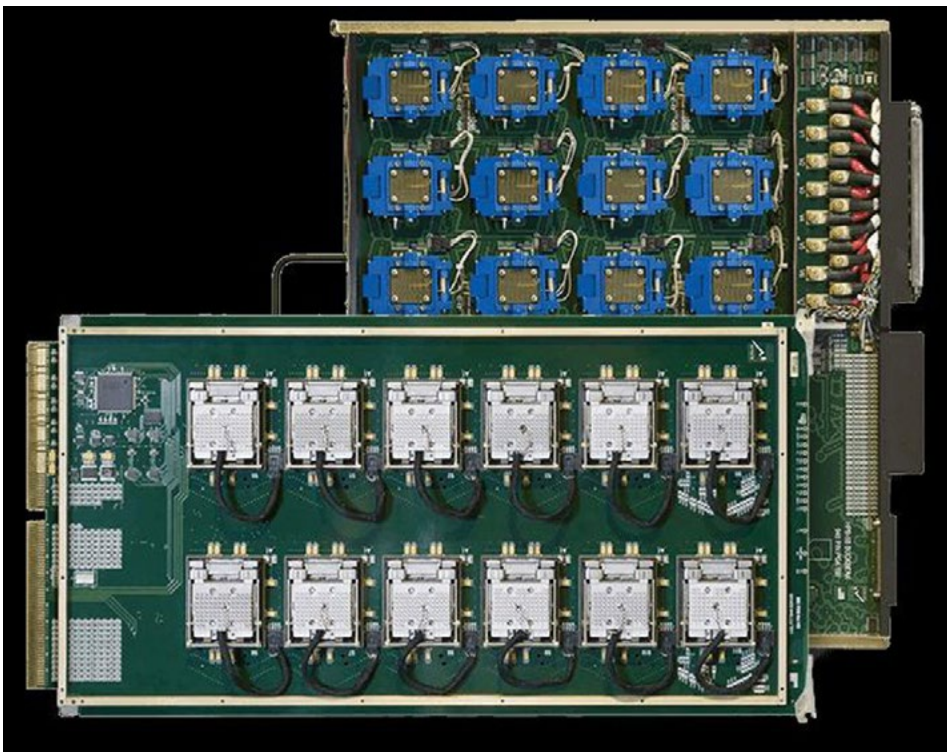


Figure 6: A burn-in board for ASICs. (Source: Micro Control Company)

Hybrid Electronics Manufacturing Innovation Institute in San Jose California, a project for IPC's Government Relations Committee, was announced in September and will receive $75 million in funding from the U.S. DoD and will be overseen by the Flex Tech Alliance, as a consortium of 96 companies, 11 laboratories and non-profits, 42 universities, and 14 state and regional organizations. The FHEMII will develop next generation materials and manufacturing methods for flexible electronics.

Innovation in novel materials such as graphene and PEDOT will create new devices that are not possible today. Materials science heavyweights such as DuPont are already working on materials to make next generation high-speed flexible circuits, high-temperature circuits' materials and even copper-based inks to print antennas for these next generation designs (Figure 7).

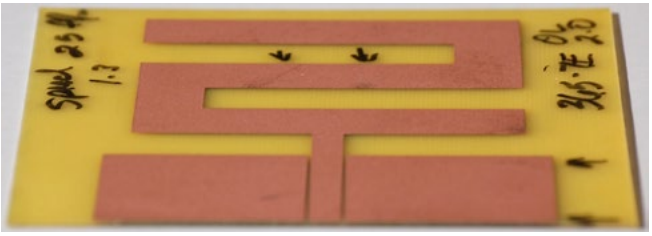
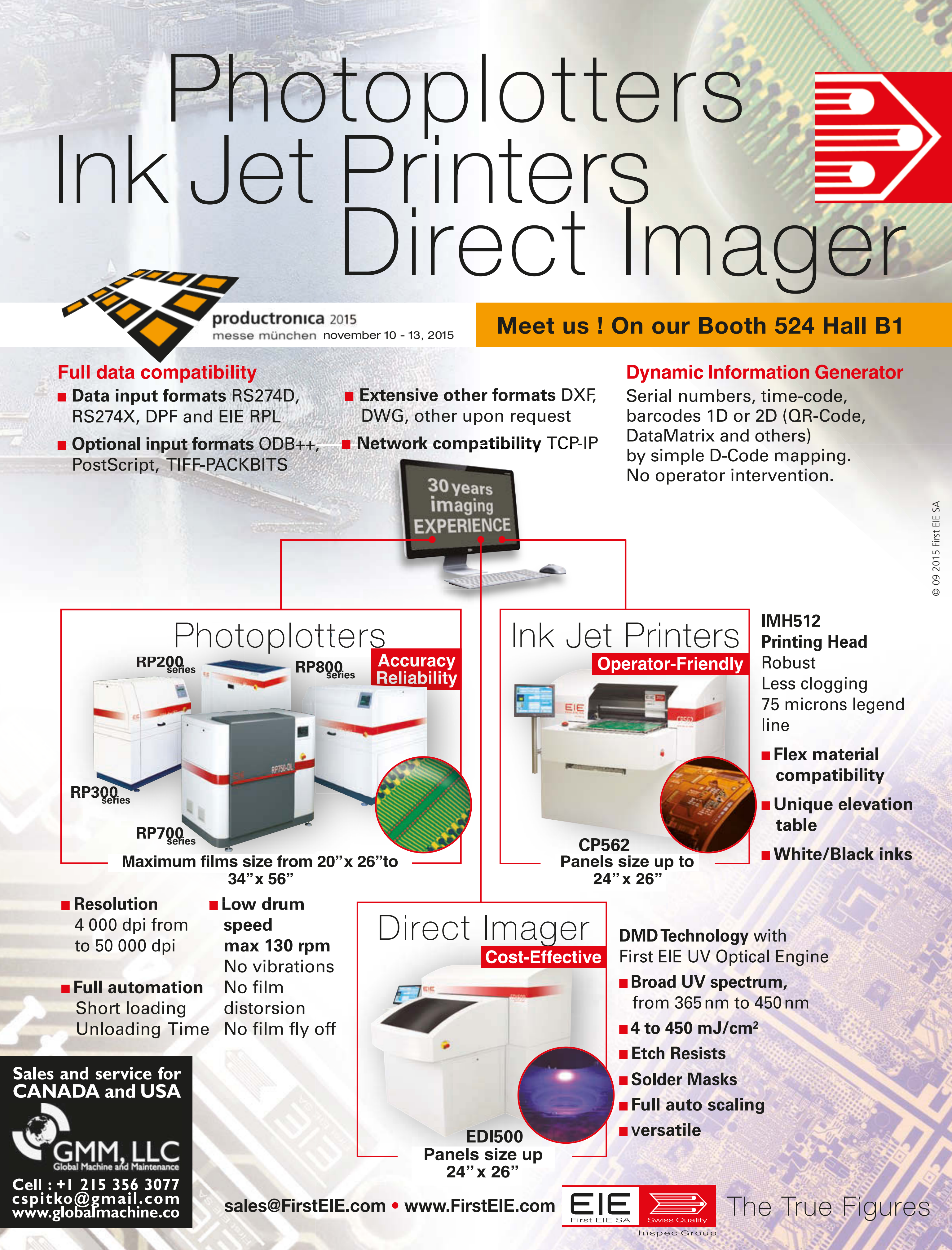


Figure 7: RF antennae printed with DuPont's copper ink.

Then there is the Internet backbone that will drive a significant share of the investment. OEMs like Cisco, Juniper, Alcatel-Lucent, Ciena, Brocade and HP will pave the way for more telecom infrastructure with ultra-high-speed backplane and daughter card systems. Cisco maintains a team of industry experts to test and characterize materials and manufacturing methods to achieve these next generation speeds. Team members like Scott Hinaga work diligently to devise new test methods and construction strategies to characterize materials that will allow copper circuits to push the physics envelope and maintain digital reliability up to 56 Gb/s per channel.

The fabricators who will see growth in this segment will include companies like TTM, Sanmina, WUS, Gold Circuits, ISU Petasys and Amphenol. Those who will truly stand out, will

Figure 8: Open Compute server in a Facebook data center.



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WHAT IS THE INTERNET OF THINGS AND WHY SHOULD IT MATTER TO US?

Figure 9: Excerpt from Google vs. Skynet cartoon.

be innovators like Amphenol Printed Circuits, led by Pam Simonds and Christine Harrington, who are collaborating with materials suppliers to design next generation systems and patented technology for high-speed data rates, as well as taking a disruptive look at traditional industries like commercial aviation where they share a passionate vision around the possibility to improve safety through the adoption of high-reliability PCBs.

Projects like Open Compute provide an open source platform for "vanity-free" servers (Figure 8) that will be embraced by companies like Facebook and Microsoft who see their software and not their hardware as the competitive advantage.

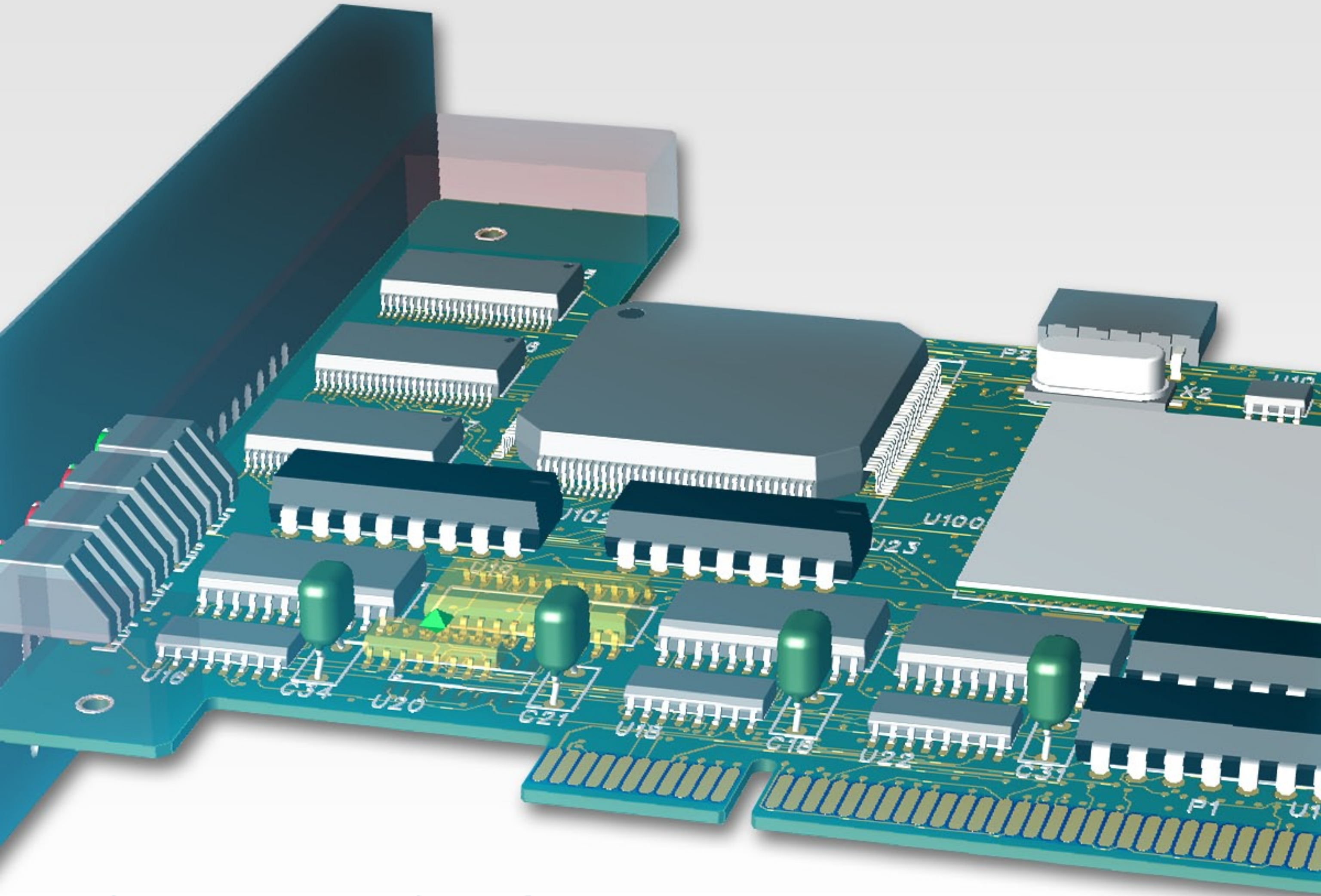
All of these segments will come together to create the unique vision of the IoT. The aggregate data that is collected through the IoT will allow analytics, correlations and understanding of things that today stand in the unexplainable column.

Knowing all this, should I be worried about Skynet and the end of the human race?

The answer to that question is, a little. Noted futurist Raymond Kurzweil, who is now funded by Google to implement his vision, describes his law of accelerating returns, which predicts an exponential increase in technologies like computers, genetics, nanotechnology, robotics and artificial intelligence. Kurzweil believes this will lead to a technological singularity in the year 2045, a point where progress is so rapid it outstrips humans' ability to comprehend it. Once the Singularity has been reached, Kurzweil says that machine intelligence will be infinitely more powerful than all human intelligence combined.

So, has Google become Skynet (Figure 9)? At least in the near term, we can seek comfort in the fact that Google has an unofficial motto of "Don't be evil" in everything they do. This should guide them not to become Skynet. That, of course, presupposes that humans are still in charge in the data centers. In the meantime, we will have a lot of circuit boards to build and technology challenges to overcome in order to get there. **PCB**

Jason Marsh is vice president of product management at Insulectro.



FEATURE

Data Analytics through Statistical Techniques

by **Steve Williams**
THE RIGHT APPROACH CONSULTING

Introduction

Many companies get caught in data traps. They focus so heavily on cost and survival that they end up using data as merely a marketing and sales tool. In doing so, they fail to realize the true power of data: It can transform every aspect of a business.

Survey Says...

A recent survey by I-Connect007 revealed just how important data is to our industry, and also just how difficult it is to get accurate, actionable data to drive our businesses. The key takeaway from printed circuit executives was that their greatest need is accurate, real-time process data. When you apply process metrics and dashboards to your data tools, data not only drives improvement, it can drive innovation. Companies struggle with data: how to get it, is it the right data, is it accurate, and is it an automated or manual process? This is where using statistical analytics can help any company to improve their business, and not just in manufacturing but also in areas like your customer and employee hiring processes.

Data should never be pigeonholed or feared. Instead, it should be used to better understand your company. By breaking down the silos that exist within your organization you will generate new perspectives, ideas and performance levels as departments begin to measure their performance against the new metrics. Did you just realize that your company has fallen into a data trap? Luckily, it's easy to break free from its chains, and using statistical data will reveal just how efficient and innovative your business can be.

Why Statistics?

A customer has an expectation of consistency in product quality, delivered on time, and at a fair and competitive price. A business owner has an expectation of making a profit through satisfied customers. A properly implemented SPC program can dramatically increase the degree of success in meeting these synergistic expectations.

Companies tend to be extremely protective when it comes to sharing their dirty laundry with customers, with the "unenlightened" being the most resistant. Statistically-challenged companies have argued everything from a flat-out "We don't believe in SPC," to "Our customer return rate is very low, so why do we need SPC?" The answer is really quite simple: In addition to the performance-related issues that reach a customer, like late delivery and defective product, the cost of inefficiencies in any process are directly passed along to the customer in some form. Scrap (or overrun to cover anticipated scrap), rework and inefficient processing are factored into the pricing model, so the lower the efficiency, the higher the total cost to the customer. And as we all know, "It's always about the dollars."

"The answer is really quite simple: In addition to the performance-related issues that reach a customer, like late delivery and defective product, the cost of inefficiencies in any process are directly passed along to the customer in some form."

Early in my career, a wise old mentor told me, "Steve, never argue about what can be measured." Being an engineer by trade and German by lineage, he knew a little about precision craftsmanship. This advice has stuck with me, and in the quest for continuous improvement has translated into "How can we get better if we don't know where we are now?" followed by "How can we know where we are now without metrics?" An effective SPC program should be a key metric of continuous improvement and a valuable management information system.

No Fear

The great statistical myth is that SPC is another big scary concept that can only be successful in companies that have dedicated quality engineers devoted to this complicated discipline. The biggest reason for the perpetuation of this myth is a lack of understanding of basic statistical principles, which results in the tendency to focus on the math and not the benefits. I will break down the basic principles into simple, everyday concepts that will allow you to see the SPC "big picture" and focus on the continuous process improvement aspect. The math is the easy part of SPC due to the abundance of inexpensive statistical software available to do the number-crunching heavy lifting. Instead, I would challenge you to concentrate on the theory, benefits and practical application of statistical tools as a path to SPC without tears.

From a fundamental standpoint, SPC is simply "making sense of experience," and the skillset needed is one that has already been honed over the course of your normal day-to-day activities. For example, this summer my wife and I were driving past a corn field when she observed, "There must have been a lot of rain here this summer because the corn is higher than normal for this time of year." What my wife had just done was make a subconscious statistical comparison of a current data set (this summer's corn crop) to a historical data set (past summer's corn crops), and formed an educated guess as to the cause for the difference (excessive rain). From a conceptual viewpoint, statistics are no more difficult than this.

Identify Critical Processes to Avoid Useless Data

A common mistake many companies make is to try to statistically monitor and control every single variable in every one of their processes. Show me a company that proudly boasts that they have 127 control charts in their SPC program and I will show you a company that just doesn't get it. Customers do not want to see wallpaper; that many processes cannot possibly be controlled and managed properly, nor should they need to be. Use the technical resources at your suppliers to help determine the specific critical aspects of the process that should be controlled. They can also be instrumental in determining the appropriate process specification limits; for example, a chemical supplier should know the optimum operating parameters for the product they are supplying. Again, and I can't say this enough, customers want to see the processes controlled that you have deemed critical to your business; no one else can made that determination for you.

Variation

The one constant about any process is that there is inherent variation within it; in other words, variation is a given. No two things are exactly alike, and our personal experience proves this out on a daily basis. We often use the expression "Like two peas in a pod" to describe two things that, on the surface, appear to be the same. But if we took this literally and opened the pod, close examination would find differences in the size, shape, color, texture and blemishes of the two peas. Now the critical aspect of this is "Does this variation really matter?" If the only requirement is tasty peas, than this variation absolutely does not matter.

Although no two things are exactly alike, when talking about a process the goal should be to reduce the amount of variation between parts as much as possible. To do this, it is important to understand the difference between the two causes of variation; common and special.

Common Cause: Also called random or normal, this variation is inherent in the process, affects every part, is repeatable, and most importantly, is predictable. Common cause variation is created by many factors that are part of the process and are acting totally at random and independent of each other. Their origin can usually be traced to the key elements of the system within which the process operates (materials, equipment, people, environment, methods). If only common causes of variations are present, the output of the process forms a distribution that is stable over time. An example of common cause variation would be the amount of time it takes you to drive to work. Taking the same route every day, there would be variations in time that are due to which stop lights you make or miss, minor traffic fluctuations, and how closely you follow the speed limit.

Special Cause: Also called assignable, these causes of variation are not a normal part of the process, does not affect every part, and can be identified to a specific, special cause. It means that something about the process has changed and has been created by a non-random event leading to an unexpected change in the process output. The effects are intermittent and unpredictable, and thus dangerous. If special causes of variation are present, the process output is not stable over time and is not predictable. Using the above example, a special cause would be a weather-related delay on the drive to work.

Control vs. Capability

The word "control" often has a negative connotation surrounding it, which in some usages is well deserved. However, from a statistical standpoint, control refers to the consistency of a process; the ability to produce repeatable product within certain predetermined limits. As we learned above, all processes have variability, and a process is deemed to be "in statistical control" when it is affected only by common cause variation. In contrast, capability refers to the ability of a process to produce output that meets specifications, in other words, shippable parts. There are various levels of capability which we will discuss a bit later, but in general a process is said to be capable if nearly 100% of the output from the process is within the specifications. The goal of statistical process control is to develop a process that is both in control and capable.

> **The word "control" often has a negative connotation surrounding it, which in some usages is well deserved.**

A key point that may often be hard to understand is that a process can be statistically in control but not capable. This means that the normal variation in the process will not allow the process to repeatedly and reliably meet the product specifications (Figure 1). In this situation, you would need to take steps to improve or redesign the process. If this cannot be done, the only remaining solution would be to present your capability study (more on capability studies later) to the customer, quantitatively demonstrating that their specifications are outside of the current process capabilities and request a specification adjustment based on your study.

It is important to note here that creatively expanding the specification limits to artificially improve the capability numbers will not only fool no one, but will also not provide any true capability improvement.

For a process to be both in control and capable, the process must meet the following criteria:

- Must remain stable over time
- Must operate in a stable and consistent manner (in control)
- Must be set at the proper level (centered)
- The natural process variation must not exceed the product's specified tolerance (capable)

Data Collection, Sample Size & Pre-Control

Once the processes, and aspects for each that need to be controlled, have been established, the next step is to begin your data collection phase. One very successful data collection strategy is to take five measurements per day, which will be then be averaged. A standard SPC control chart can be modified to use during the data collection phase, as long as it is clearly labeled as "Data Collection" and not "SPC."

A better choice may be to use a tool that is called a pre-control chart. A pre-control chart is a "visual process stoplight" and an excellent precursor to a full-blown SPC control chart. Pre-control is effective because it uses (stoplight) color-coded zones (green, yellow, and red) to make control chart interpretation very easy for operators. Pre-control limits are established based on the following and again, by collaborating with your key suppliers:

1. The middle 50% of the chart is the green zone, which makes up 50% of the specification tolerance for the feature being measured.

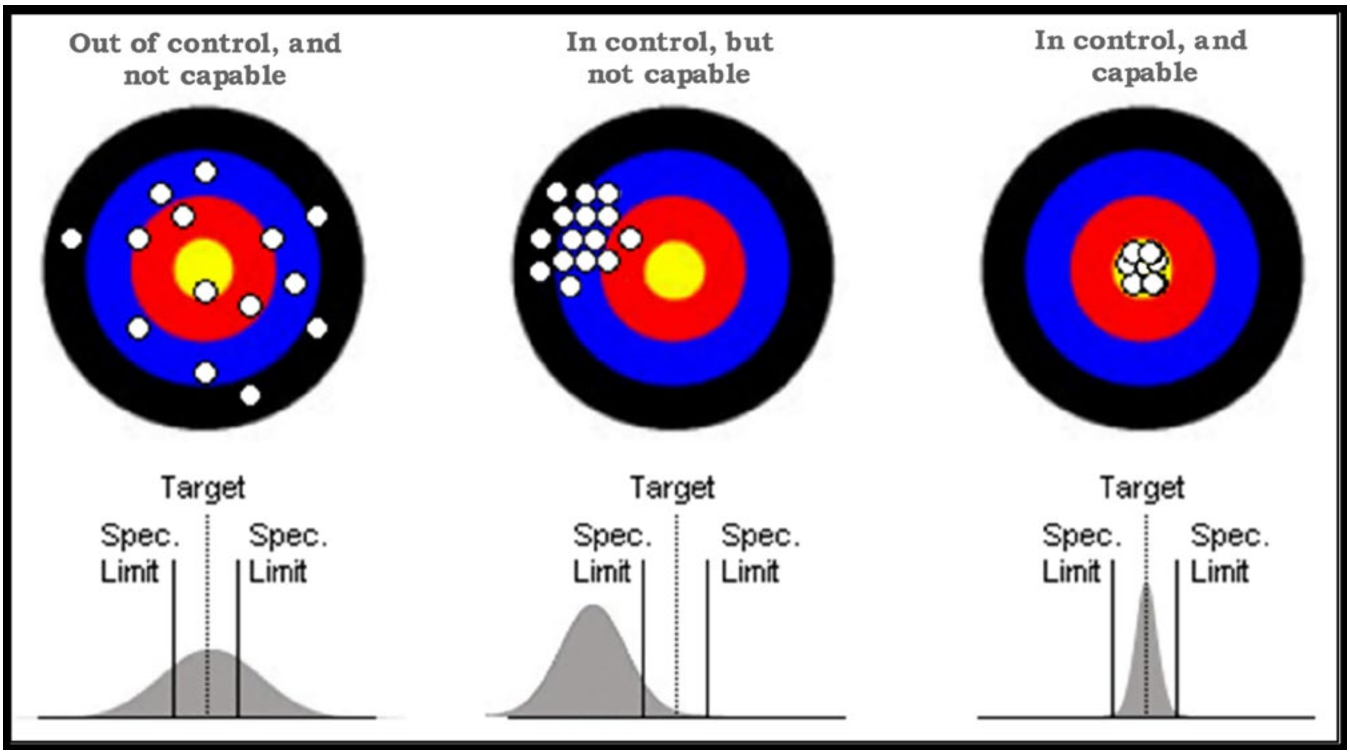


Figure 1: Control versus capability.

2. The yellow zone on either side of the green zone makes up the remaining 50% of the specification tolerance (25% for each yellow zone)
3. The red zone is everything outside of the specification limits; in other words, the zone where you are making bad parts.

Control Charts

The minimum number of samples needed to be able to perform any meaningful statistical analysis is 30, which per the above sample size methodology would be 30 days of data collection and pre-control. That being said, it is important to note that the more data available to analyze, the more accurate a picture of the process you will get. However, this needs to be balanced with real world expectations to avoid Paralysis by Analysis. The length of data collection will depend on the specific process and out of the box stability, but a 30-90-day duration is reasonable.

"The length of data collection will depend on the specific process and out of the box stability, but a 30-90-day duration is reasonable."

After the data collection period, if the pre-control results appear to be able to stay within the green and yellow zones, the next step is to move the process into the control chart phase. Control charts are a graphical representation of the current state of a process, and should be implemented at the operator level to maximize effectiveness. A control chart's true function is to provide real-time feedback to control and improve a process, which means that the data displayed on the charts must help front-line operators make better process decisions.

All control charts have three basic components: 1) a process center, or mean; 2) an upper and lower control limit; and 3) an upper and lower specification limit. Data between the control limits and the specification limits signal that a process adjustment is needed. Data exceeding the specification limits would be considered out of acceptable limits and defective. The most common form of control charts is the X-Bar and R chart. X-Bar refers to the average of the data in each sample and plotted in the top half of the chart. "R" stands for the range of the data in each sample and is plotted in the bottom half of the chart. The range of the data sample is simply the difference between the highest and lowest value in the sample of five.

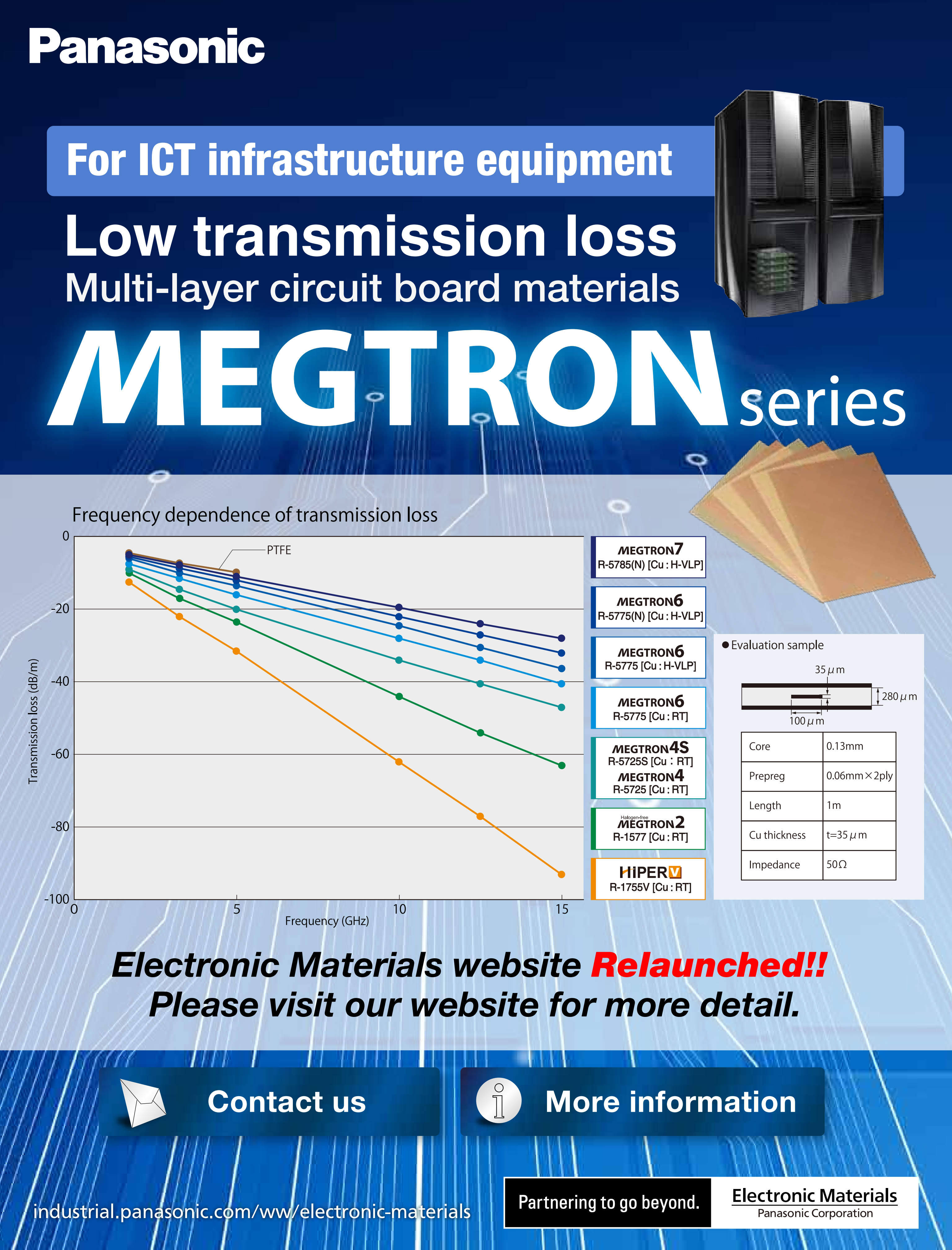
Normal Distribution

In a stable process, data will be randomly centered on the process mean and contained within the control limits. This is called a normal distribution, or bell-shaped curve, and is probably the most recognized and most widely-used statistical distribution. The reason for this is that many physical, biological, and social parameters obey the normal distribution, and thus are said to behave normally. When data takes on a normal distribution, it simply means that most of the data will fall around the center, or mean, and that the remaining data will fall progressively farther from the mean with decreasing frequency.

Cpk Analysis

Every product has an optimum value, and because every process has variation, it also has a tolerance. This is defined as specification limits, with both an upper and lower spec limit (USL, LSL) surrounding the optimum value. To review, when a product or process is outside of either of these spec limits, bad product is being produced. How well the process variation is centered on the mean and contained within these spec limits is called process capability. The relationship of this variation to the mean and spec limits is the process capability, or Cpk. The less variation in a process, and the closer the variation is to the mean, the higher the Cpk number.

Again, with all the statistical tools available, the formula is not important for this purpose, but what is important is recognizing what this


Panasonic
For ICT infrastructure equipment
Low transmission loss
Multi-layer circuit board materials
MEGTRON series
Frequency dependence of transmission loss
PTFE
Transmission loss (dB/m)
0
-20
-40
-60
-80
-100
0
5
10
15
Frequency (GHz)
MEGTRON7 R-5785(N) [Cu : H-VLP]
MEGTRON6 R-5775(N) [Cu : H-VLP]
MEGTRON6 R-5775 [Cu : H-VLP]
MEGTRON6 R-5775 [Cu : RT]
MEGTRON4S R-5725S [Cu : RT]
MEGTRON4 R-5725 [Cu : RT]
Halogen-free MEGTRON2 R-1577 [Cu : RT]
HIPER V R-1755V [Cu : RT]
● Evaluation sample
35 μm
280 μm
100 μm
Core 0.13mm
Prepreg 0.06mm×2ply
Length 1m
Cu thickness t=35 μm
Impedance 50Ω
Electronic Materials website Relaunched!!
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Partnering to go beyond.
Electronic Materials
Panasonic Corporation

number means. It is generally accepted that a Cpk of less than 1.33 would indicate a process that is not capable of consistently meeting customer requirements, and a Cpk of 2.0 would represent a six sigma level. Calculating process Cpk levels is not a one-time occurrence, it must be performed on a regular basis (quarterly is usually sufficient).

Capability Studies

The capability of the process needs to be established to use as a baseline for future improvement comparison, and is accomplished through Cpk analysis. As discussed earlier, a Cpk value is an index representing the ability, or capability, of the process to meet customer requirements. To determine process capability, collect process data as you would if you were setting up a control chart, calculate the process mean and variation, and then compare the relationship between these values and the specification limits. Any SPC software, or even Excel, can calculate the Cpk of a process data set. Figure 2 shows the various levels of process capability.

Once the baseline capability study has been completed, a final study should be performed again to verify the effectiveness of the process improvements that may have been implemented to improve the process capability. As mentioned earlier, using a minimum Cpk of 1.33 is

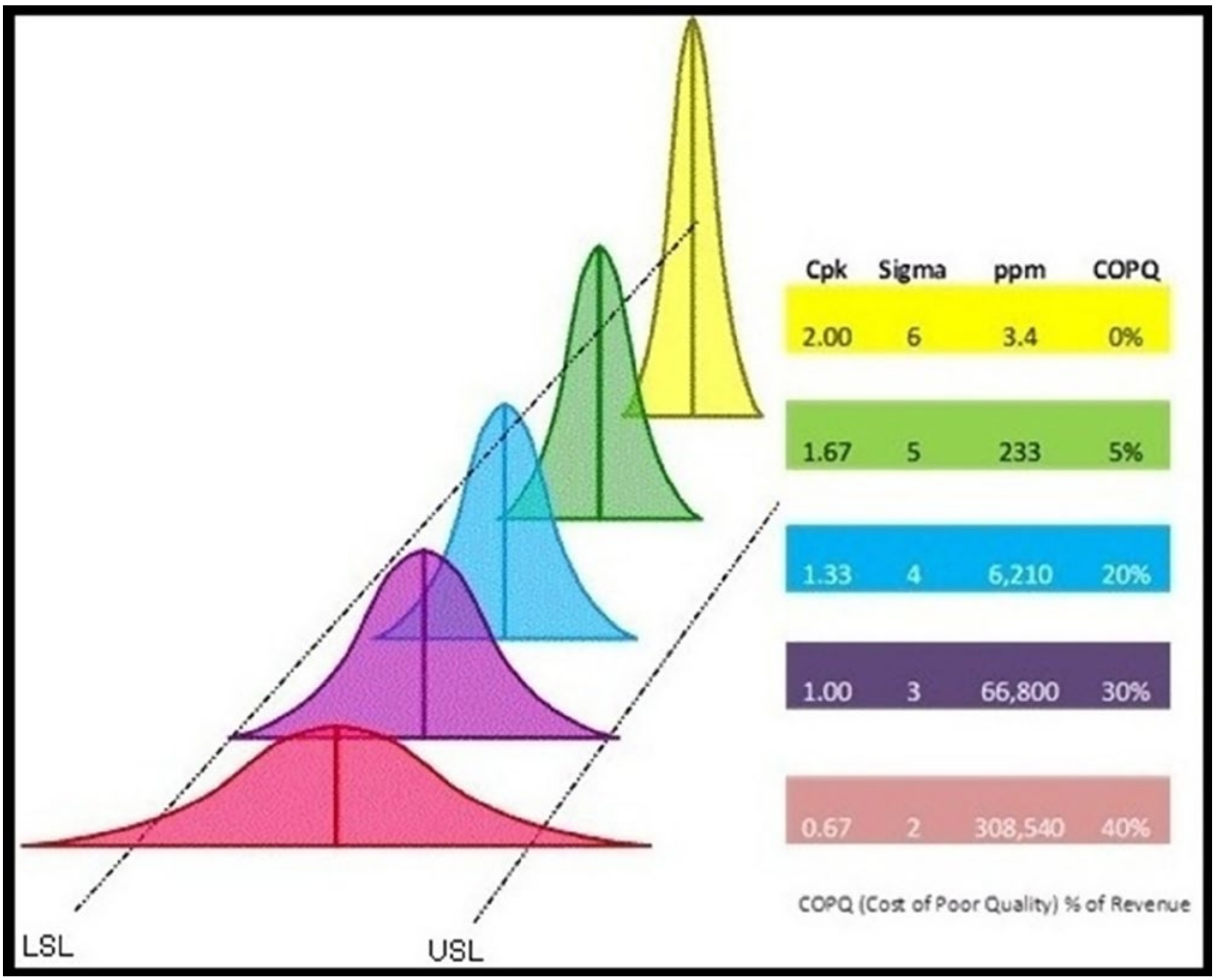

Figure 2: Cpk levels.

a good start, as this indicates a process that is capable of consistently meeting customer requirements. As with most things, process capability is a continuous improvement journey and future goals should be to move up to the next Cpk milestones of 1.66, 2.0 and beyond. The ongoing quest for improvement is a perfect opportunity for collaboration between your in-house subject matter experts (SMEs) and those of your key suppliers.

A Note on Operator-Level Involvement

There is a tendency for companies to relegate the SPC program to a process-engineer or other staff function, which may not always be real-time. While this can be moderately effective, the greatest benefit would be achieved through active participation of the personnel actually running the process and producing product. A control chart's true function is to provide real-time feedback to control and improve processes. The program will fail if the data displayed on the charts do not help front-line operators make better process decisions to actually monitor, adjust and control their processes.

Whatever the level of participation, SPC requires specialized formal training over-and-above the standard job function and operational training all employees receive. Statistical theory and methods, process capability, and control chart maintenance, interpretation, and reaction are key topics to be covered in depth.

Let Data Drive Your Decisions

With the abundance of data available to business managers, it is important to filter out the data that does not have a major impact on the business and focus on what does. Statistical techniques are an excellent tool to identify how your processes are really operating, and can be implemented to provide real-time feedback to base your day-to-day decisions on. **PCB**

Steve Williams is the president of The Right Approach Consulting LLC and the former strategic sourcing manager for Plexus Corp. He is the author of four books, including *Quality 101 Handbook* and *Survival Is Not Mandatory: 10 Things Every CEO Should Know about Lean.* To read past columns, or to contact Williams, click here.

Interim CEO Jeff McCreary on Changes at Isola

In a recent interview with I-Connect007, Isola's interim President and CEO Jeff McCreary discussed the impetus for the recent personnel reduction and plant closing that took place, mainly in the U.S. With a realignment towards the Asian market and improved plant utilization in the U.S., Isola expects to become more internationally competitive and improve revenue.

McCreary explained that, with long-time president Ray Sharpe stepping down followed by the reductions, many are probably wondering about the company's stability. He stated that the company has remained profitable but has suffered revenue-wise in the past few years, due in part to a general market slump in Asia. By improving on their manufacturing utilization rate in the U.S. (savings in the millions) along with more focus on the Asian market, McCreary sees the company as highly competitive going forward.

McCreary also shared his bullish view on the electronics industry in general and on what the industry may expect from Isola going forward. In addition, he explained what the company is looking for in a new CEO, which should be announced in the next few months.

To read the entire interview click here.

Process Controls for Flexible Circuit Fabrication

by Dave Becker
ALL FLEX FLEXIBLE CIRCUITS LLC

Manufacturers of flexible circuits use several chemical processes for fabrication. These processes are generally located in a common area of the plant because of facility requirements and environmental considerations. These chemical operations are referred to as wet processes.

Some of the specific processes that would be characterized as wet process in circuit fabrication:

- **Develop-etch-strip:** Photosensitive resist is developed so the unneeded resist is washed away, leaving a pattern of resist that defines the circuitry. The subsequent etching operation removes the base metal (normally copper) that has been exposed by the patterned resist. The last step is to remove (strip away) the resist that defined the circuitry.
- **Copper plating:** This is typically an electro-chemical operation. Metal is electrodeposited onto the base metal surface thereby creating a thin, robust coating. Electroplating of copper is the most common example and is used to create electrical connection between traces on the top and bottom of the insulating dielectric film.
- **Shadow plating:** A laminate of metal-dielectric-metal is initially drilled, punched, or laser ablated to form the vias. In order to initially create an electrical connection between the layers of metal, the dielectric must be coated with a conductive material. Shadow plating coats graphite inside a via and is a chemical process commonly used by flexible circuit manufacturers.

Figure 1: Digital nomenclature printer.

Each of these operations relies on chemical reactions, which may be supplemented with mechanical agitation, temperature and voltage/current. In most cases the chemical makeup is the most critical element that affects the output.

It is vital that critical process parameters are tightly controlled to assure desired results. The following are the basic outputs that are monitored and compared to a process or customer specification:

- Trace width and spacing
- Metal thickness
- Via integrity
- Metal composition

Process control in a high product-mix wet process area presents a number of unique chal-


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P: 800-536-1959 • F: 908-222-3344

lenges. The following techniques should be used for controlling the wet process operations:

- Statistical process control on chemistry
- Control of process parameters
- Preventative maintenance
- Monitoring of process outputs

Chemistry: Statistical process control techniques are frequently used for controlling critical chemistry parameters. Consistent output is maintained by tightly controlling chemical bath compositions. In a high product-mix environment, copper thicknesses with varying treatment types can change several times during a shift. This will necessitate adjustments in parameters such as conveyor speed, but chemistry and chemical properties are monitored to stay constant within a controlled range, allowing for a more statistically valid control system.

Process parameters: Process parameters may include dwell time, conveyor speed, bath temperature, spray pressure, voltage and current. Each of these parameters is controlled within a set range, and the exact parameter settings are based on a recipe card for each product family. Parameter settings for recipes are best when statistically determined by designed experiments; recommendations from material suppliers are a good starting point and should be combined with data gathered during process development.

Preventative maintenance: A total preventative maintenance program (TPM) should be developed based on analysis of equipment performance and designed to keep machines

Figure 2: Flying probe electrical tester.

running within ideal process parameters, as opposed to a program that is merely designed to keep a machine from breaking down.

Output monitoring: Critical outputs are monitored and recorded at the source. Measurements include plating thickness, etch ratio, trace width, metal composition, via wall integrity, and other numerical measurements. Discrepancies found should generate a "non-conforming material report." Non-conforming material reports should be regularly reviewed, corrective actions identified, and results tracked. This ongoing corrective action system becomes a closed loop system of "plan-do-check-act" as part of an effective continuous improvement program. Similar systems for process control have proven effective in achieving desired quality levels at acceptable yields across a wide range of industries.

Effective process controls are a critical, but incomplete, method for insuring proper customer product quality. The addition of strategic inspection and monitoring operations also play a role. Within the world of printed circuit boards, several containment methods are common:

- Bare board automated optical inspection (AOI): Any discrepancy in conductor width and spacing is flagged by this test. All layers should undergo this 100% inspection.

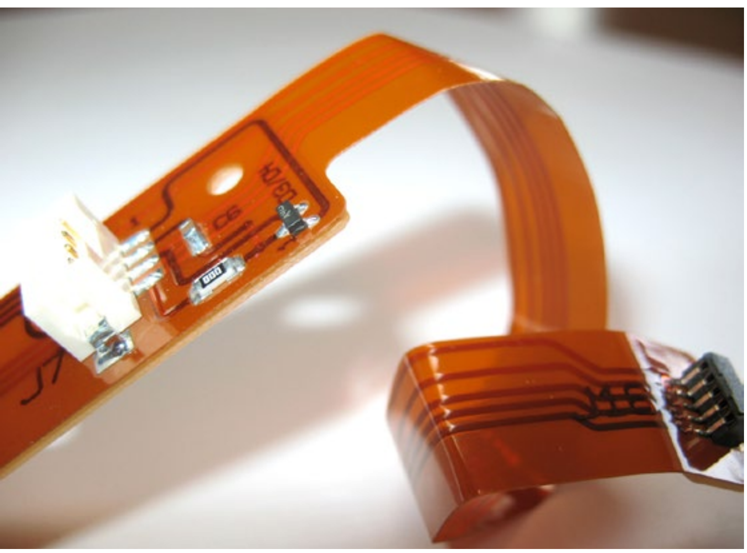


Figure 3: Flex circuit with component assembly.

- Bare board electrical testing: These circuits without components often undergo an electrical test designed to catch all opens and shorts. This can be done with a bed-of-nails test fixture or with a point-to-point flying probe tester.
- Populated board electrical testing: Circuits with connectors, passive components and/or active components may also undergo a functional electrical test.
- Populated board AOI: Optical inspection machines also are used to examine populated circuits to ensure all components are present, orientation is correct, and location accuracy is proper.
- Quality audits: In-process inspection and testing are done to a statistically based sample of a production work order.
- Customer specific audits: Unique data gathering is often required by certain customers or within specific industries, especially those involving high-reliability applications. Specific features are verified or test data is generated to insure quality conformance. These requirements can be as varied as the applications within our wonderful world of electronics.

Printed circuit fabrication involves processing through a long list of sequential operations. Producing a completed part might involve drilling, imaging, etching, resist removal, cover film attachment, lamination, surface treatment, and many other individual processes. In many cases, fabrication involves 40 or more unique processing steps. A 99% yield at every process would result in a final lot yield of less than 67%, which would likely be too low to sustain the business. Yields of 100% at most processes are required for profitability, and good process controls are required to achieve this level of product robustness and predictability of the output. **PCB**

Dave Becker is vice president of sales and marketing at All Flex Flexible Circuits LLC. To view past columns or to reach Becker, click here.

THE POWER OF DATA:
The Most Important Questions Any Leader Must Ask

by Dave Dibble
NEW AGREEMENTS INC.

In the recently completed I-Connect007 survey of readers titled, "The Data Factor(y): The Power of Data," I had difficulty segmenting the results into useful categories. In other words, what were the issues that most concerned readers and customers? Responses seemed to flow toward a catchall bucket that I might describe as the following:

1. What are we supposed to be measuring?
2. How should we measure it?
3. How do we get people to respond properly once we have identified what and how to measure and implemented a robust data collection system?

You see, if we answer these three questions correctly, we are in good shape to become systems-based, more conscious leaders and managers and hence much better organizations.

What to Measure

I had the privilege to spend time with David Chambers, probably the country's most esteemed statistician who constantly reminded us, "Focus on what you measure and how you measure. If you get these right, everything else will follow. If you don't get these right, it's impossible to improve and control a system or process."

We don't want to measure everything. That's a trap that companies sometimes fall into, whereby excess time and effort collecting and evaluating data produces more frustration than valuable information. Generally, about 20% of the data will give us 80% of the benefits we need to control and improve our systems, both on the manufacturing floor and in service areas. Often, when we try to measure too many things, we become inundated with mostly useless data that obscures the important stuff we should be focused on. This is also where people stop looking at/acting on the data because it's simply too time-consuming and cumbersome

to guide anyone toward "right" action—the real purpose of good/meaningful data.

Identifying What to Measure

Our experience in the field indicates that a good starting point for deciding what to measure is to look at the systems that most impact your customers, your people, and your suppliers. These three areas are the three legs of the stool we call business. Importantly, you will want to identify the 20% of the systems in each area that are producing 80% of the problems or issues you are experiencing. Once these systems have been identified you can begin to create priorities. Remember, we can't fix everything all at once, nor should we try. One reliable way to identify stressed systems is to measure the stresses imparted onto people who work in or are directly affected by poor systems.

"One reliable way to identify stressed systems is to measure the stresses imparted onto people who work in or are directly affected by poor systems."

In setting priorities, look for systems that are "early" in the process. For example, fixing design or manufacturing engineering will generally produce greater overall benefit than fixing shipping. Functions early in the process will tend to leverage good stuff throughout the organization.

Second, look at the handoffs between departments, shifts, key employees and so forth. Normally you will see that your biggest problems are in the handoffs. This is because the first 15% of any system is the most critical to its function, both good and not so good. If you get the first 15% right, the rest will follow. In handoffs, whatever is handed off from a system is usually the first 15% (inputs) to the next system. If you don't get this right, there is no chance of fully optimizing the receiving system.

How to Measure

Even if you identify correctly what to measure, if you don't measure properly, the data will take you in the wrong direction, buoyed by faulty conclusions. While it takes a little more time on the front end to get your data collection correct, there is a huge payoff in your systems optimization efforts. I have a little saying I use to describe leaders and managers who are great firefighters: "No time to do it right; plenty of time to do it over." In quality and systems improvement, the slow road becomes the fast road and vice versa. It takes time to create a check sheet where the complexity is in the tool, not in the hands of the data collectors. Yet, once the proper data collection tool is created and people trained in its use, we get both the data we need and people using the tool correctly.

Now comes a critical question. Who is responsible for what and how we measure? This should be the people doing the work: frontline staff, marketing and customer service personnel, the receptionist, the guy sweeping the floors on third shift. You get the idea. If your quality or IT departments are responsible for what and how things are measured, you will get more of what you have now within a range. For sustainable quality and systems improvement, a systems-based approach for doing work must become the way you and your people work. Yes, for leaders and managers, too. Basically, the depth of change in any organization will be gated by the amount of growth in leaders and managers. No growth = little sustainable change.

Starting with Something Different than SPC

If you are Toyota, Honda, or another company that is steeped in systems-based leadership and management, forget about everything I'm about to share. However, if you're having difficulty creating and maintaining your quality culture and systems, what follows may be quite helpful.

Although I taught basic statistical process control (SPC) tools to my clients, I noticed that many people were fearful of learning to use these tools. This was especially true of non-technical workers and managers who didn't want to look foolish with their lack of mathematical background. Leaders too, in many cases, showed little desire to learn or use the tools. For some, English was a second language, making learning still more difficult. People do not learn well or easily when in fear.

We found that, in order for people to learn, use, and eventually own the tools, we had to reformat the tools, making them simple, user friendly and even fun. Once people realized they could be successful using the simplified tools, it was not unusual to have people up and doing good systems improvement work in only a day or two. Remember, if your front lines are not using the tools on a daily basis, you're not systems-based. When your organization is people-based, you are asking for the fires you put out yesterday to be burning brightly sometime in the near future, along with all the associated costs.

What and how you measure are the two most important criteria for your business in doing data collection for the purposes of improving systems and processes. If you get the what and how of data collection correct, you will be well on your way to solving your most intractable problems and creating ever better quality and customer service at ever lower cost—the ultimate competitive advantage.

As a consultant or trainer, I almost always work with people-based companies. Systems-based, data-driven companies probably have little need of my services. The calls I get are from companies that are usually experiencing recurring systems problems that are negatively affecting current and future financial performance or customer satisfaction. Just because you're collecting data or have implemented a systems-based quality program such as Six Sigma or Lean doesn't make you a systems-based organization, just as GM or Chrysler will never be Toyota or Honda.

Whether it is a PCB, assembly, design or other interconnect-related business that is having ongoing or recurring problems, the source of those problems is almost always systems based. However, the cultures of the companies is people-based and so puts on pedestals the best fire fighters. Also, these companies tend to look at technology as the source of solutions, which in many cases is, at best, only a partial solution.

If your company has recurring problems that significantly affect the quality and cost of your products and services, you'll want to learn how to identify what to measure and how to measure and take right action based upon that data. However, before you do all that, take a look in the mirror and examine the thinking that has brought you to this point in your business. It's not what you don't know that is hurting your business. It's what you "know" that isn't so. **PCB**

David Dibble is a keynote speaker, trainer, consultant, executive coach, and systems thinker. For more than 25 years he has consulted and trained in the workplace, with a focus on his systems-based book, *Four New Agreements for Leaders and Managers.*

Get Ready for the Transformation at 2015 HKPCA & IPC Show

In the "Electronics and Information Industry White Papers Series" (2015 Edition) that was released recently, a total of 20 white papers were published to track and analyze 20 industry segments and their respective developments in 2014.

Interim CEO Jeff McCreary Discusses Recent Changes at Isola

Isola's Interim President and CEO Jeff McCreary explains to Barry Matties the impetus for the personnel reduction taking place at Isola, the closing of their Northern California facility, and why there is no need to panic. He also shares his view of what the industry may expect from Isola going forward and what the company is looking for in a new CEO.

TUC Found to Infringe Isola Patents

Isola Group announced today that a jury in the U.S. District Court for District of Arizona found that Taiwan Union Technology Corporation (TUC) had directly and indirectly infringed key patents held by its U.S.-based subsidiary, ISOLA USA Corp. The products found to infringe were TUC's TU-872 laminate and prepreg products.

Cirexx Installs Second Excellon Laser

Cirexx International announced today that they have acquired and installed a second Excellon laser. The new machine is the Cobra-II Hybrid Laser equipped with Excellon's latest laser technology. It will drill holes, rout boards and micro-machine fine features.

Ucamco Launches 3 Wavelength Series of Ledia Direct Imaging Systems

Ucamco is delighted to announce the new 3 Wavelength series of Ledia Direct Imaging (DI) systems for the accurate, high-speed exposure of the industry's most demanding soldermask, inner-layer and outer-layer resists.

MacDermid Appoints Joe D'Ambrisi as VP, Global Electronics Solutions

MacDermid Electronics Solutions announces the appointment of Joe D'Ambrisi as vice president, Global Electronics Solutions. In his new capacity, D'Ambrisi will have global responsibility for all of MacDermid's electronic solutions operations including sales and technical support, research and development, marketing, OEM, and advanced electronics.

Matrix USA Holds Open House at Santa Clara Facility

Matrix USA featured an open house at their Santa Clara, California warehouse on September 15, 2015, held in conjunction with the PCB West Technical Conference and Exhibition at the Santa Clara Convention Center.

AirBorn Flexible Circuits Names Matrix Electronics a Preferred Partner in Success

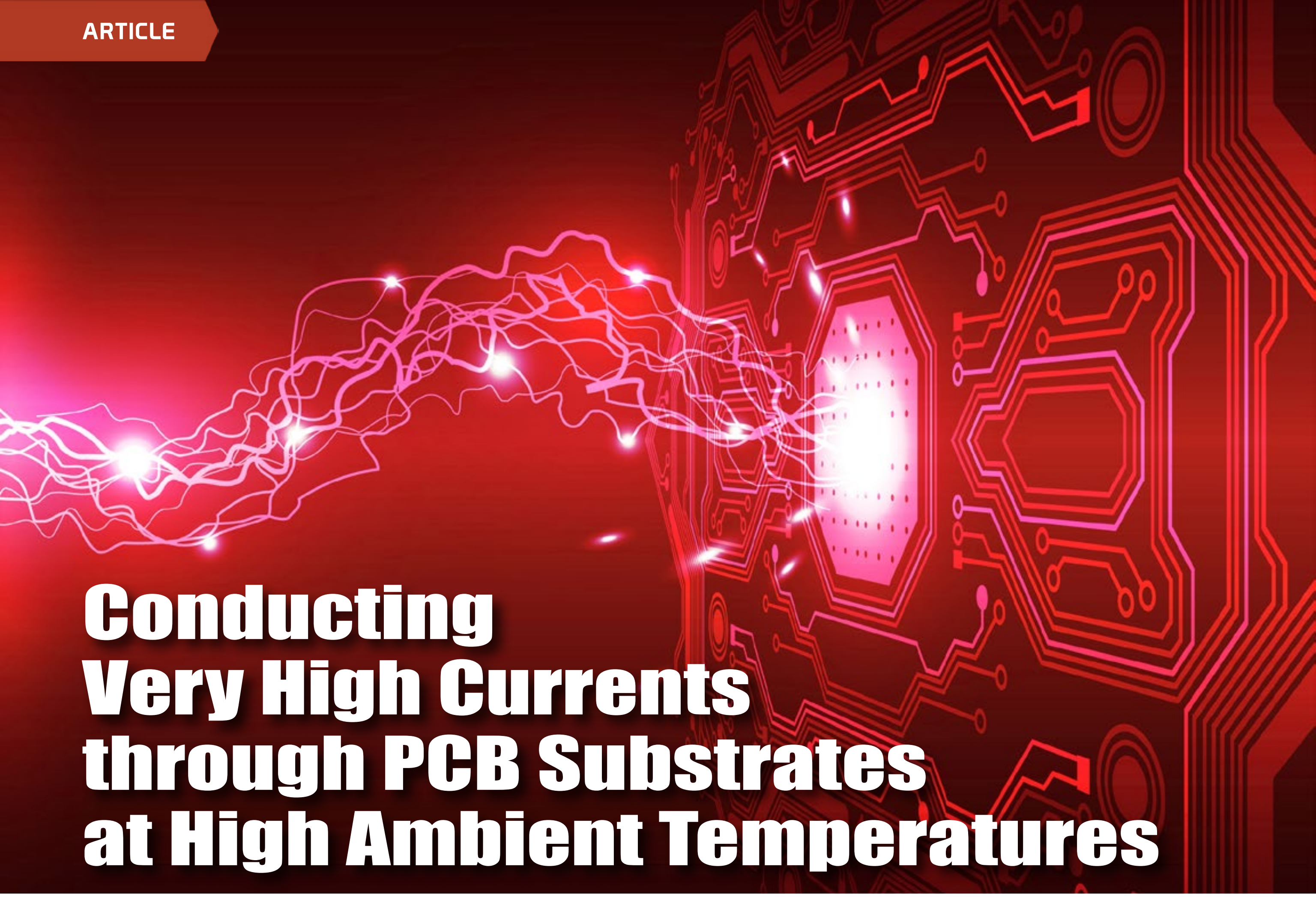
AirBorn Flexible Circuits Inc. named Matrix Electronics Limited as a PREFERRED SUPPLIER and a Partner in Success. Each year, this award is granted to the supplier who demonstrates an excellent track record for on-time delivery, quality and technical support.

Cipsa Circuits Installs Orbotech Fusion AOI and Sprint 120 Inkjet Systems

Orbotech Ltd. announced today that Cipsa Circuits, a European PCB manufacturer and long-time customer of Orbotech, has completed integration of two Orbotech Fusion AOI systems and one Orbotech Sprint 120 inkjet system, purchased in the first half of 2015, for their PCB production facilities in Spain.

Frontline PCB Solutions and Nanjing College Launch InCAM Excellence Academy

Frontline PCB Solutions and Nanjing College of Information Technology in Jiangsu Province, China, established an official training center—InCAM Excellence Academy. Successful graduates will be awarded a Frontline PCB Solutions InCAM certification qualification.



Conducting Very High Currents through PCB Substrates at High Ambient Temperatures

by Thomas Gottwald and Christian Rößle
SCHWEIZER ELECTRONIC AG

Introduction

One of the major challenges of our time is climate change and the associated need to reduce greenhouse gas emissions. The requirement to reduce CO_2 emissions has brought about significant changes in the area of power generation, and also in the area of mobility.

Supported by a favorable subsidy policy, the solar boom originated in Germany and quickly spread widely across Europe. Government policy has specified a sharp reduction of CO_2 emissions for the automotive industry as well, increasing the pressure to come up with new developments within the entire supply chain.

The advancing electrification of motor vehicles that currently takes place predominantly in the area of auxiliary units, and the demand for power inverters for renewable energy sources, have triggered a worldwide demand for power electronics components and led to significant development efforts towards efficient, cost-effective and reliable power electronics.

Challenges in Power Electronics

Anyone in the field of power electronics will quickly get involved in discussions about efficiency. On the one hand, the reasons result from technical requirements and, on the other hand, from purely economic considerations. For example, the efficiency of a solar power inverter to be purchased must be carefully considered as differences in efficiency of merely a fraction of one percent can greatly affect the yield of the entire system.

The efficiency is also a very important factor for the controllability of power electronics applications as every loss in efficiency also means power dissipation, which is directly converted into heat.

The higher the system performance, the higher the effort for removing the generated power dissipation. Higher power dissipation also means higher economic losses caused by the low efficiency of the entire system.

Challenges for Electronic Substrates

Electronic substrates for power electronics applications must support the requirement for a high efficiency of the entire system. Therefore, the losses on this level must be minimized.

The second requirement is the support for thermal management of the assembly, in which the electronic substrate often plays an important role.

In addition to that, electronic substrates in power electronics must obviously support all functions of electronic substrates in conventional electronics.

> "Electronic substrates for power electronics applications must support the requirement for a high efficiency of the entire system."

Impact of Materials

Losses in Metal Layers

Ohmic losses in metal layers that often consist of copper or copper alloys play an important role in power dissipation considerations for electronic substrates. Even though the intrinsic resistance of copper is low, it cannot be ignored if high currents are present, as it causes the conductor to heat up. This contributes to heat development in the entire system and must therefore be minimized.

Properties of Insulators

Another important factor in these considerations is the thermal conductivity of the substrate: The ampacity of a conductor is ultimately limited by the thermal destruction of the conductor. The better the heat dissipation of the conductor itself, the more current it can carry. Therefore, factors such as the specific thermal conductivity and thickness of the insulator play a crucial role.

Increasing Conductor Cross-sections

Increasing the conductor cross-section is an effective method to reduce the ohmic resistance. In many cases, there is no alternative to this. However, it must be considered that increasing the cross-section leads to additional weight, which is undesired in electric mobility applications as any increase in weight decreases the driving range of the electric vehicle. The conductor cross-section design must in turn satisfy the specifications regarding heat generation. The heat generation depends on the thermal conductivity of the substrate and its connection to a suitable heat sink. The higher the temperature stability of the insulator, the higher the permissible heat generation in the conductor for system design.

For these reasons, determining the required conductor cross-section has evolved into a complex task. The conventional methods and rules for layout design as described in IPC or FED can no longer be applied in many cases as they do not take these new boundary conditions into account.

Temperature Stability of Substrates

Another central aspect is the temperature stability of PCB substrates in power electronics. Power semiconductors can usually withstand junction temperatures of 175°C. This temperature range is increased further by new semiconductor technologies and is expected to reach 200°C or even 225°C within the next few years.

The full exploitation of this temperature range requires substrates that can be used in the mentioned temperature range.

Increasing the operating temperature also serves the purpose of minimizing efforts for the cooling system and hence minimizing system costs of the power electronics.

Ceramic substrates such as DCB/DBC substrates currently have a deep impact on power electronics as they combine excellent electrical insulation with high thermal stability. The downsides are the high costs of ceramic substrates and the limitation with regard to fine structures and number of substrate layers.

Organic PCB materials do not have these restrictions with regard to structure and number of layers, however, the thermal conductivity of the epoxy resins used is significantly lower than in ceramic materials.

A big advantage of PCB substrates is their significantly lower cost, which is why the use of ceramic substrates is limited to those power electronics that cannot be implemented without the properties of ceramic materials.

Assembly and Interconnection Technology for Power Electronics Systems

The conventional processing technology for PCBs is the fully automatic assembly of SMD components. The through-hole assembly is mostly limited to DC-link capacitors, if these have not yet been replaced by SMD components.

In ceramic substrates, the bottom side of bare semiconductors is connected to the substrate in the electrical, mechanical and thermal sense by means of conductive adhesives, soldering, silver sintering or diffusion soldering.

The conventional way of connecting the top side is via aluminum heavy-wire bonding, however, this technique is slowly being replaced by Cu wire bonding. After assembly, the bonds are often stabilized by sealing them with a highly viscous silicone gel.

The required logic control and driver electronics are implemented via a separate substrate (usually a PCB) and are often interconnected with the power electronics via press-fit contacts.

Most entire systems of power electronics applications have a large number of different assembly and interconnection technologies that must meet the required targets regarding reliability and costs on their own as well as in combination.

Reliability Aspects of Assemblies

Adjustment of the Expansion Coefficients

Due to their coefficient of expansion (CTE), organic PCBs are well-adjusted for components in housings such as QFP or DIP. Assembly of bare semiconductor components such as flip chips, however, is critical. Depending on their structural design, ceramic chip capacitors can also be critical as they have significantly lower CTEs.

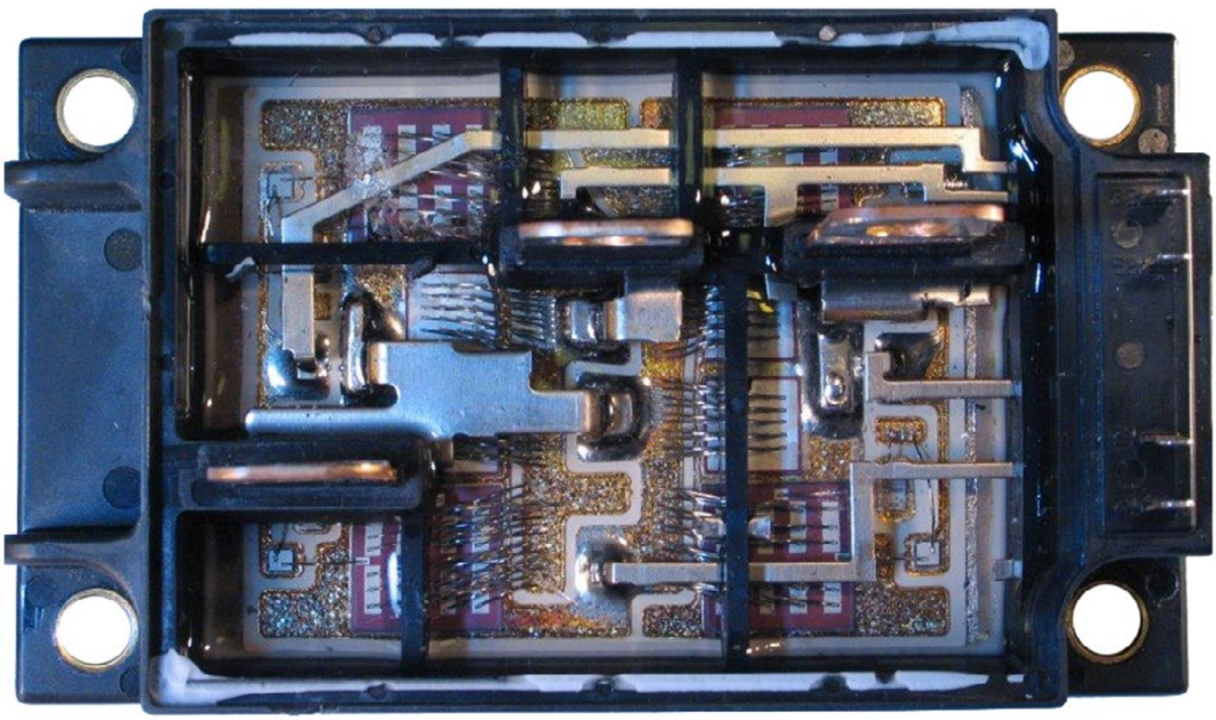
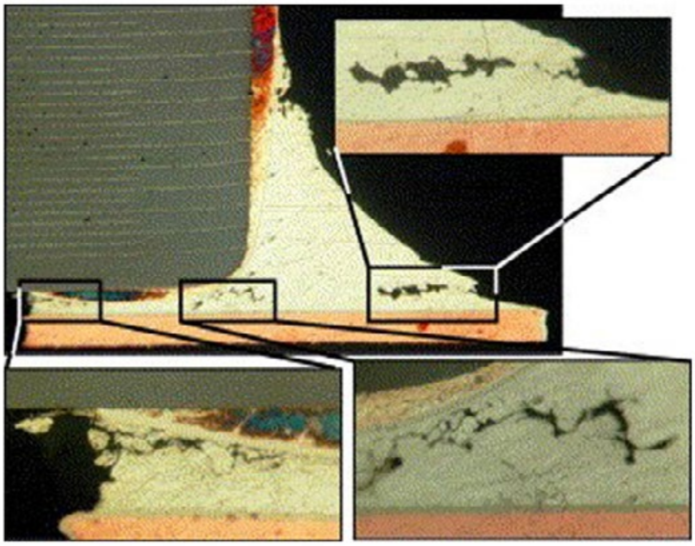
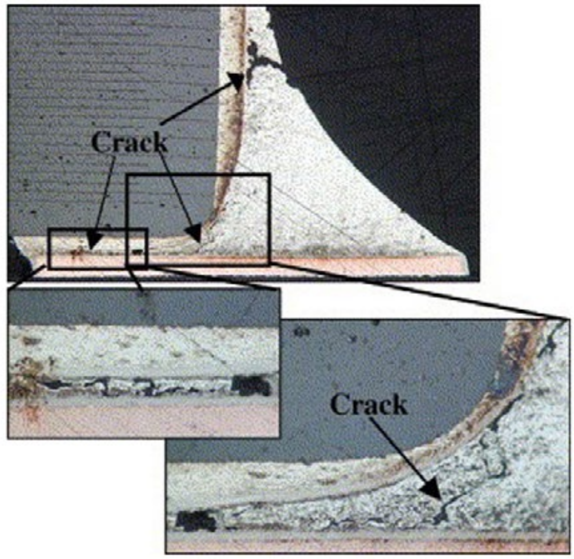


Figure 1: IGBT module power electronics based on DCB ceramics with power busbars in plastic housing. (Source: www.enacademic.com)





Figures 2 and 3: Soldered joint failure of a ceramic chip capacitor.

As opposed to that, DCB/DBC ceramics are assembled with bare power semiconductors. The lower coefficient of expansion of the ceramic base material leads to a better adjustment of the CTE between substrate and component in this scenario. The bare dies are then connected to the substrate and the terminals using wire bond technology. Due to their ampacity, heavy aluminum wires with a diameter of 500–600 µm are used for this.

Failure Mechanisms of Assemblies

The classic failure of assembled PCBs is failure of soldered joints in poorly adjusted components due to cyclic thermal loads. In the PCB itself, failure of interconnections has to be mentioned, due to the anisotropy of the CTE in x/y direction as compared to the z direction is common.

In ceramic assemblies, however, the classic failure case is bond lift-off from the power semiconductor caused by the large difference in the CTE between Si (2.7 ppm/K) and Al bond wire (24 ppm/K). Another mechanism is conchoidal fractures of ceramics induced by CTE differences of ceramics (approx. 7 ppm/K) and copper metallization (17 ppm/K).

Due to the aforementioned reasons, most power electronics systems use a mixture of ceramic substrates and PCBs that are interconnected by assembly and interconnection technologies that can be very sophisticated and complex at times. They are implemented by way of wire bonding, plug connectors, soldering or welding technologies, and modern power electronics systems often combine all available assembly and interconnection technologies in one single system.

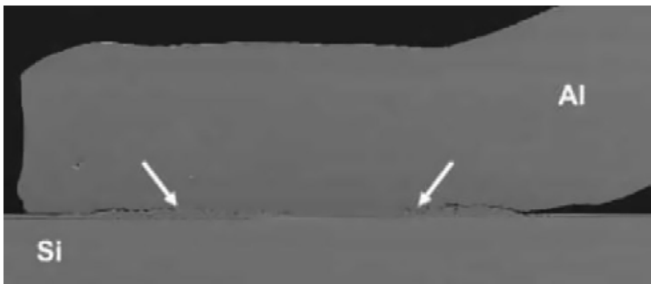


Figure 4: Cracks in a heavy wire bond on an IGBT (silicon) surface. (Source: www.powerguru.org)

Optimization of Power Electronics Systems

Therefore, the essential requirements for optimized substrates in power electronics systems are as follows:

- Increased ampacity
- Optimized thermal conductivity
- Increased temperature stability
- Reduced system complexity
- Increased system reliability
- Minimized costs

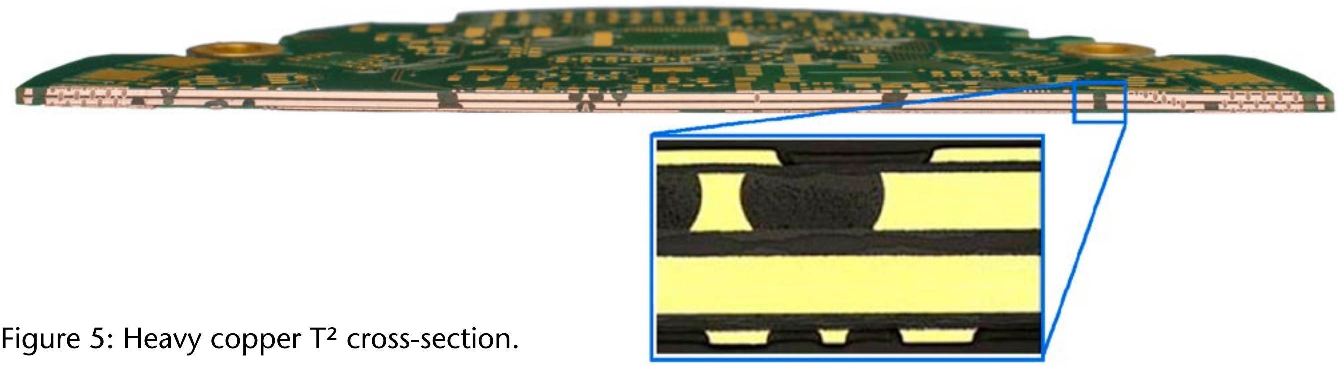


Figure 5: Heavy copper T² cross-section.

Solutions for Today's and Tomorrow's Requirements

Heavy Copper T²

Heavy Copper T² is based on conventional heavy copper technology. In conventional heavy copper technology, the PCB design is characterized mainly by etched areas that must be filled with large resin volumes released by the prepregs used during the lamination process. Due to the large amount of resin used, multiple prepregs must be used, leading to large insulation thickness between the outer layer and the inner heavy copper layer. This means that the microvia technologies such as laser-drilled blind holes could not be used with heavy copper technology due to the large insulation thickness. Furthermore, the insulation thickness increases the thermal resistance of the printed circuit board and decreases its reliability as interconnections of thicker circuits are subject to more stress during cyclic thermal loads.

Heavy Copper T² technology overcomes these disadvantages by filling the etched areas of heavy copper circuits in a special manufacturing step. Therefore, thin prepregs can be used in the subsequent lamination process. This results in the following advantages:

- Lower overall thickness of the printed circuit board
- Lower clearances between the copper layers
- Increased reliability in cyclic thermal loads
- Increased thermal conductivity in the Z-axis (through plane) of the design

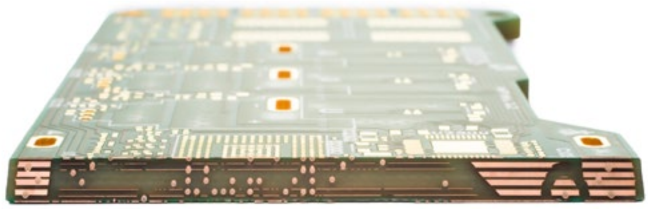


Figure 6: Cross-section of the Power Combi Board.

The Power Combi Board

The Power Combi Board uses a combined inner layer with heavy copper areas used for high-current conduction. However, the same level also has copper layers with a standard thickness of 18 or 35 µm that help to ease the routing for the use of complex components.

With this technology, the power and logic parts of an application can be implemented with just one circuit board, whereas previously, two circuit boards were necessary, which had to be connected with a plug connector.

The new solution helps increasing the reliability and making optimal use of the required installation space.

The Inlay Board

Printed circuit boards with pressed-in copper coins are well-known in the area of thermal management. The main disadvantage of this technology is the challenging thickness adjustment of the copper coins to the circuit board. While the coins have very low tolerances, multilayer circuit boards have a thickness tolerance of up to 10% due to the manufacturing processes. Therefore, flush fitting of the circuit board

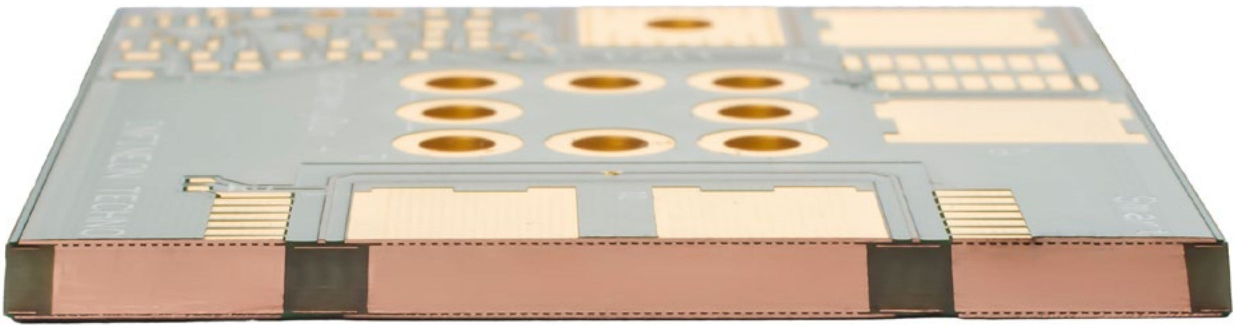


Figure 7: Inlay board with copper inlays of 2 mm thickness.

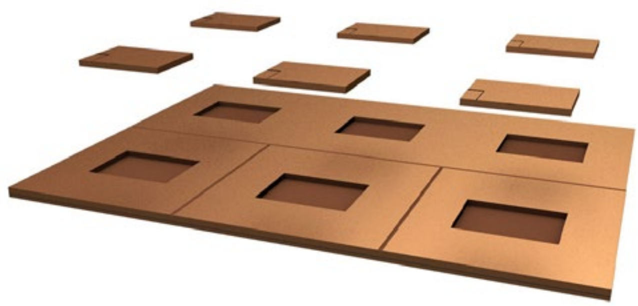


Figure 8: Lead frame with cavities for assembling power semiconductors.

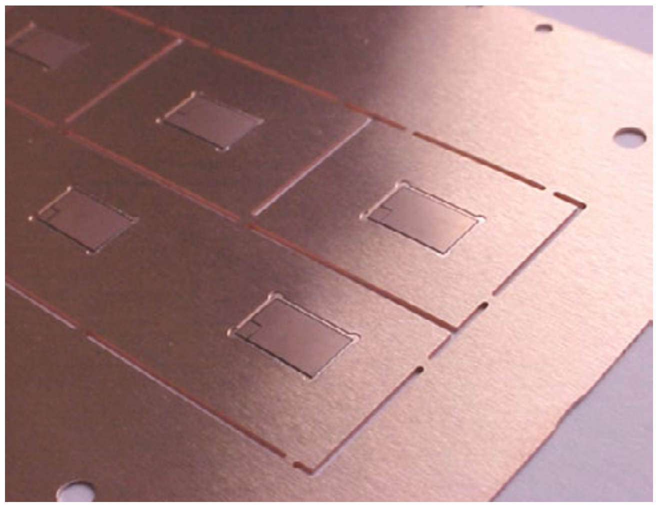


Figure 9: Lead frame with assembled MOFSETs.

surface with both sides of the inlay surface is only possible in a part of the manufactured lot. This can lead to varying thicknesses of the thermal interface material used during heat sink installation.

The inlay technology from Schweizer is different as the inlays are not pressed into a finished circuit board but are laminated into the assembly group as part of a multi-layer manufacturing process. In this process, the prepregs used equalize the occurring differences in thickness between inlay and circuit board.

The inlay can be entirely embedded in the matrix, leading to an electrically insulated inlay or it can be installed flush with one side of the entire structure of the circuit board, enabling it to be used for optimal thermal transition.

As the inlay is usually significantly wider than the component assembled on it, an immediate heat dissipation takes place within the inlay. This enlarged transition area at the heat sink leads to lower thermal resistances in the area of the thermal interface material.

Apart from thermal management, such inlay circuits can also be used for conducting high currents at low ohmic losses.

Most applications utilize the low ohmic losses as well as the optimized thermal interconnection to the heat sink, which is why the inlay board represents a high-end solution based on conventional printed circuit boards.

The Smart p² Pack

The precondition for miniaturization of high power electronics is a significant reduction of losses within the circuit and the efficient removal of power dissipation from the confined space. The p² Pack technology enables super-flat power modules with a thickness of 1–1.4 mm with reduced power dissipation and improved switching behavior as a result of using embed-

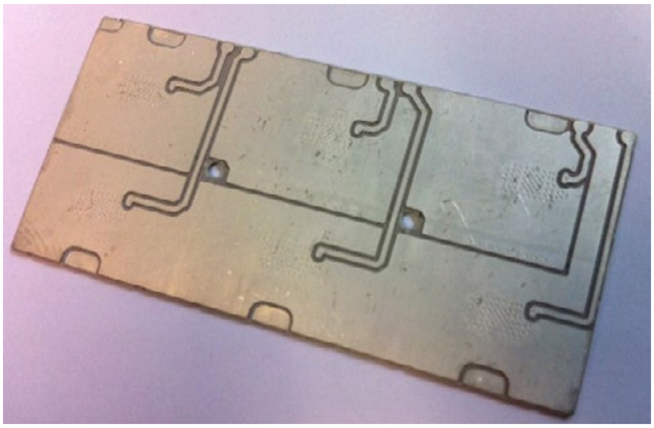


Figure 10: Connection of gate/source pads with conductor track structures.

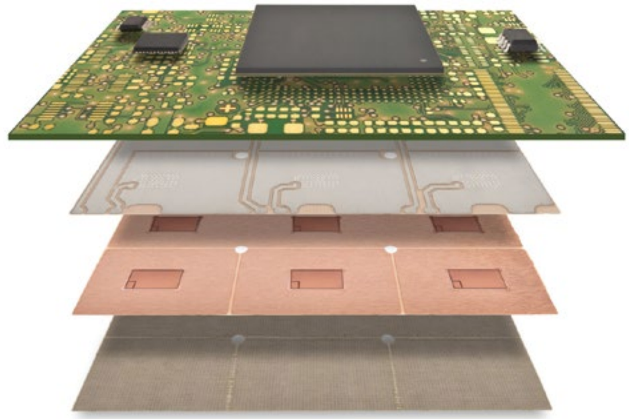


Figure 12: Exploded drawing of the Smart p² Pack functional layers.

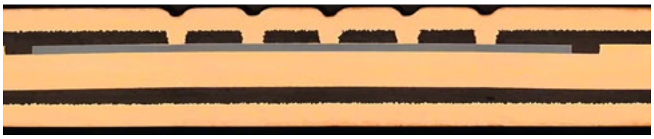


Figure 11: Cross-section of a p² Pack with Cu-filled microvias.

ding technology and processes from the printed circuit board industry.

With the p² Pack technology, an entirely new technology for manufacturing power modules has become available. So-called lead frames form the basis for this technology. These lead frames are machined to provide cavities for the assembly of power semiconductors.

In the next step, these cavities are assembled with power semiconductors. The goal is to position the surface of the semiconductors in one level with the lead frame.

The assembled lead frames are laminated with the help of conventional PCB processes to form a 3-layer structure. This way the bond wires are replaced by a circuit board wiring layer above the chip. The gate contact is implemented with conductor tracks and the source pads have a flat design in order to achieve an electrical connection as well as favorable thermal dissipation of the power.

Contacting the upper side of the chips is done galvanically by way of copper-filled blind holes penetrating through the dielectric on the upper side. The semiconductors must have a surface metallization that is compatible with these processes.

The design of the p² Pack is to be kept symmetric as it ensures a minimized pumping effect during thermal cycles. The solid Cu-layers above and beneath the lead frame are a design feature for double-sided cooling of the semiconductor while only the lower side must be connected to a heat sink. Depending on the lead frame thickness, up to 1/3 of the dissipated power can be distributed via the upper side and can be removed downwards through the package into the heat sink.

Smart p² Pack

The p² Pack itself can be combined with a logic control board to form a 1:1 substitute for a DCB substrate.

Due to the fact that the p² Pack has a height of only 1 to 1.4 mm, it can even be embedded in a logic control board. Very short connections between the gate driver and the gate contacts of the power semiconductors can be achieved this way. The driver module can be positioned on the control board directly above the power semiconductor while the connection to the gate is carried out with copper-filled interconnections from the outer layer to the p² Pack.

A heat sink can be mounted on the bottom of the Smart p² Pack using a thermal interface material.

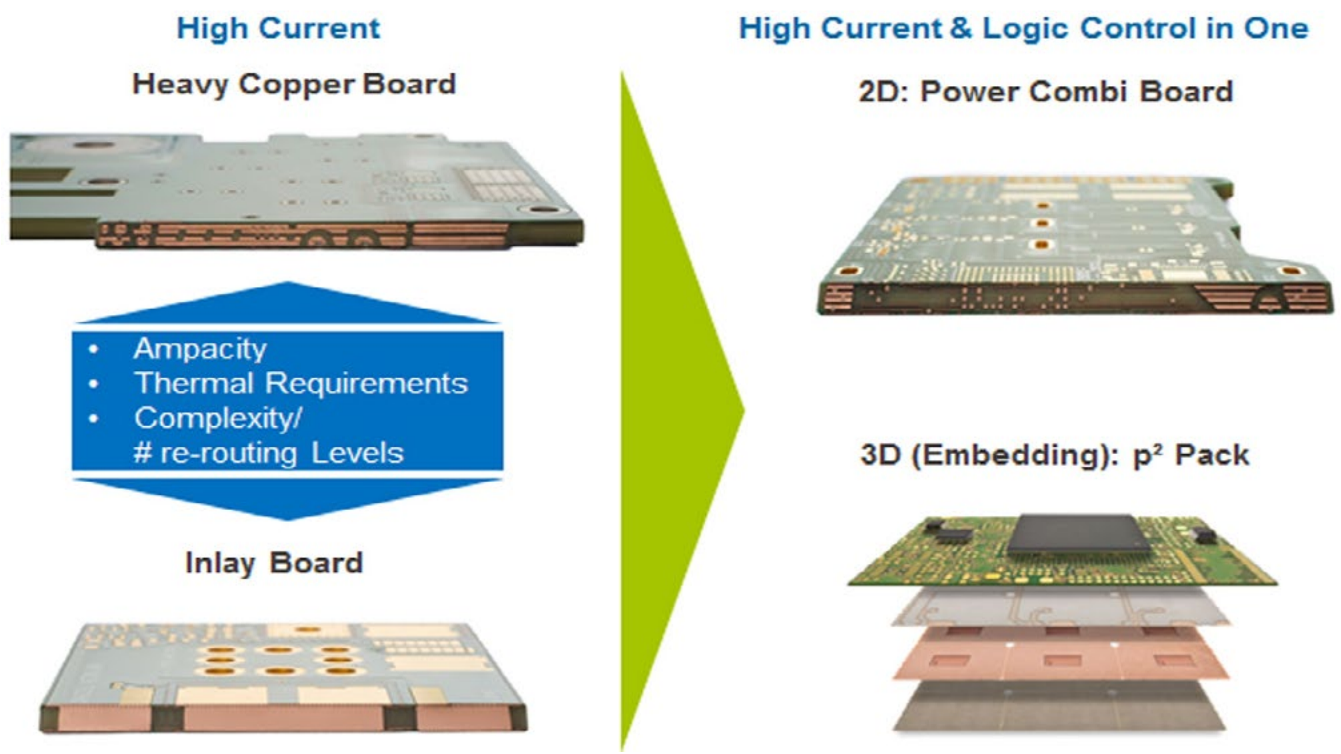


Figure 13: Overview of requirement and solution concepts.

Which technology is suitable for which task?

The technology to be used is determined by the requirements of the application.

For example, the number of grids carrying high currents determines whether a heavy copper board (many grids) or an inlay board (few grids) will be used.

If a combination of logic and power circuitry is to be implemented in a single circuit board, the Power Combi Board is available for this purpose.

The Smart p² Pack is the perfect solution if very limited installation space is available, circuit losses must be minimized and maximum electric and thermal performance is required in limited space.

Summary

Power electronics have entered the high-volume market as a result of increased electrification of the power train and auxiliary units in motor vehicles. This has pushed the demand for miniaturization and cost reduction as an electric drive has to be installed in addition to the combustion engine and as many useful additional electric auxiliary units must be installed in the installation space that has always been very limited.

This trend requires electronic substrates capable of handling very high electric power at very low losses. Due to the limited installation space, locations with high ambient temperatures must be used as well, resulting in more demanding temperature requirements.

With the new highly temperature-resistant materials and high-current technologies described, future applications can be increasingly based on circuit board technology. **PCB**

Thomas Gottwald is director of innovation at Schweizer Electronic AG.

Christian Rößle is vice president, sales & marketing, and director of embedding/systems with Schweizer Electronic AG.

MilAero007 Highlights

Liquid Cooling Moves onto the Chip for Denser Electronics

Using microfluidic passages cut directly into the backsides of production field-programmable gate array (FPGA) devices, Georgia Institute of Technology researchers are putting liquid cooling right where it's needed the most—a few hundred microns away from where the transistors are operating.

Robots and Us

If you follow technology news—or even if you don't—you have probably heard that numerous companies have been trying to develop driverless cars for a decade or more. These fully automated vehicles could potentially be safer than regular cars, and might add various efficiencies to our roads, like smoother-flowing traffic.

Lockheed Martin Delivers First Upgrade PAC-3 Missile Interceptors

The U.S. Army significantly upgraded its missile defense capabilities today as it accepted the first PAC-3 Missile Segment Enhancement (MSE) interceptors built by Lockheed Martin. With improved mobility and range, the new interceptors will defend against evolving threats around the globe.

The Real Martian Spinoffs Part 3: Harnessing the Power

More powerful than the mighty Saturn V that took humans to the moon, the Space Launch System (SLS), NASA's newest rocket currently under development, will have the capability to send astronauts deeper into space than ever before. With SLS and the Orion capsule, humans will no longer have to dream of walking on Mars—they finally will do it.

Electronic Interconnect Improves Customer Service with Addition of TS16949 and AS9100 Certifications

In an effort to bring a more stringent system into place, PCB fabricator Electronic Interconnect has received both their TS16949 and AS9100 certifications.

Lockheed Martin to Open Submarine Combat System Laboratory

Lockheed Martin Australia will open a submarine combat system laboratory in Mawson Lakes in November to support the company's pursuit of the Royal Australian Navy's Future Submarine project SEA 1000 Phase 1. Construction began at Mawson Lakes on July 27, 2015 and is expected to open in November. An expanded Phase 2 with a secure area is scheduled to open in the third quarter of 2016.

FTG's Circuits' Segment Posts 31% Sales Growth in Q3

The circuits' segment sales were up $3.3M or 31% in Q3 2015 versus Q3 2014. All facilities reported increased revenues. On a year-to-date basis, circuits' sales were up $7.4M or 23%.

Epec Hires Todd Barham as Military & Aerospace Business Development Manager

Epec Engineered Technologies recently announced the hiring of Todd Barham as Military and Aerospace Business Development Manager. Todd's main role with Epec will be to help grow the company's market share in the military and aerospace sectors.

The Application of Advanced Ultrasonics in Metal Plating Processes

Most surface modification chemical treatments by their very nature contain hazardous and oxidising chemicals, and there is a major concern that these chemicals are used maliciously with the intent to manufacture explosives or formulate poisons to harm the public. Cyanide-based plating solutions and high concentrations of hydrogen peroxide used in current techniques are a significant use of these materials in industry.

UAV Market to Reach $10B Mark by 2024

The global defense and security market for unmanned aerial vehicles will expand at 5.5% per year over this decade, from the current figure of $6.4 billion, to $10.4 billion by 2024, according to IHS.

Digital Imaging Revisited

by Karl Dietz
KARL DIETZ CONSULTING LLC

The advantages of digital circuitization techniques have been described in detail by suppliers of equipment and photoresist. Since phototool generation and conditioning are omitted, there is the advantage of shorter lead time. Small lots can be customized at no extra cost (e.g., with added date and lot number information). There may be an advantage in fine-line imaging of surfaces with poor co-planarity because of the depth of focus of the laser beam. But the biggest advantage may be the ability to "scale" (i.e., to change the dimension of each individual exposure for best fit to reference points on an underlying pattern of a multilayer structure). However, early digital imaging systems had substantial drawbacks, such as Orbotech's DP100, which used an argon ion laser with limited radiation power, high power usage, and high cooling requirements.

For years, laser direct imaging (LDI) was synonymous with digital imaging. While most early, commercially successful digital processes involved the use of lasers, other more recent processes use non-laser light sources such as LEDs (light emitting diodes), or various types of mercury lamps, making use of more than one wavelength. Others use inkjet technology to build image patterns such as legend print, soldermask or etch resist. They all have in common the building of a pattern, pixel by pixel, and they employ digital on/off switches to form the pattern. The switch might be an optical modulator or an array of LCPs (liquid crystal polymer cells) that can be rendered translucent or opaque by addressing it with an electrical pulse.

Or the switch might be micro-mirrors on a chip, such as Texas Instruments' Digital Micromirror Device™ (DMD), whereby tiny

mirrors are addressed with an electric pulse so that the mirror is either tilted to direct the light to the substrate or away from the substrate. Or, in the case of ink jetting, it could be a piezoelectric membrane that changes its shape upon receiving an electrical pulse, thus causing the formation of an ink droplet, or it could be a digitally modulated electrical field that selectively deviates electrically charged ink droplets from a continuous stream of droplets.

> "They all have in common the building of a pattern, pixel by pixel, and they employ digital on/off switches to form the pattern."

More recently, additional developmental and commercial digital imaging systems have been marketed.

The French supplier of imaging systems, Altix-Automata-Tech, first introduced its ADIX-System at productronica 2013. It is based on an advanced high-power LED radiation source (ALDS), a dual multi-wavelength UV-LED, and DMDs. The system is suitable for rigid and flex substrates and has automatic handling options. Earlier systems using DMDs include:

- ORC's DI-Impact (formerly by Pentax)
- Hitachi's DE imagers DE-H, DE-S, and DE-F series
- MIVA Technologies GmbH, Germany, Miva 2600X Direct Imager
- Maskless Lithography's DMD-based system (USA), using a mercury arc light source
- Aiscent Technologies Inc. (Canada)

The Korean company AJUHITEK entered the market with its EP digital imager series that is using a laser diode radiation source with the wavelength of 405 nm.

HAN's Laser is the only Chinese supplier of direct imagers to the best of my knowledge.

The Japanese direct imager suppliers ADTEC, DNS, ORC and Via Mechanics continue to introduce improved systems.

The Swiss supplier PrintProcess introduced its Apollon DI-A11 direct imager that offers automated loading and unloading. It offers automatic image scaling and resolves reliably 1 mil features.

KLEO Halbleitertechnik GmbH, Germany, has supplied direct imagers since 2009, with systems in production in Germany and Switzerland. The KLEO-LDI-System CB20HV-Twinstage uses a 405 nm wavelength laser diode. The 405 nm radiation source is dominant in Asia. Photoresists (dry film and liquid) suitable of exposure at 405 nm are available from Hitachi, DuPont, Atotech, Eternal, Kolon and Elga Europe.

The UV-P100 UV-LED direct imager by Limata GmbH (Germany) was developed for prototype and short run production. It can use conventional dry film and soldermask. Light source life exceeds10,000 hours. Max panel size is 650 x 540 mm^2. Resolution of 50 micron features is obtained. Automated load/unload is available, and side-to-side registration is achieved with cameras and registration target holes.

Orbotech's Nuvogo DI System is designed for mass production of advanced HDI/flex and rigid-flex applications, according to Orbotech. The Nuvogo™ 800 is compatible with nearly all resist types. The MultiWave Laser Technology™ uses a multi wavelength laser beam of high intensity so that lower cost resist with standard photosensitivity can be used for high throughput (up to 7,000 panels/day/line) with optimal line structure. **PCB**

Karl Dietz is president of Karl Dietz Consulting LLC. He offers consulting services and tutorials in the field of circuit board & substrate fabrication technology. To view past columns or to reach Dietz, click here. Dietz may also be reached by phone at (001) 919-870-6230.

Electronics Industry News
Market Highlights

Highly Flexible, Wearable Tactile Sensor for Robotics, Electronics and Healthcare Applications

A team of scientists from the National University of Singapore (NUS) Faculty of Engineering has developed a wearable liquid-based microfluidic tactile sensor that is small, thin, highly flexible and durable. Simple and cost-effective to produce, this novel device is very suitable for applications such as soft robotics, wearable consumer electronics, smart medical prosthetic devices, as well as real-time healthcare monitoring.

Singapore PC Market Growth Driven by Mobile PCs in 1H of 2015

PC shipments in Singapore totaled 588,300 units in the first half of 2015, a 12% increase over the same period last year, according to Gartner Inc.

Outsourcing Manufacturing to China Results in High CO2 Emissions

Despite the increasingly fervent debate regarding the trade relationship between China and the United States and its implications for the global political environment, it is evident that manufacturing goods in China and shipping them to developed countries has real-world consequences, particularly for the environment.

Copper Clad Laminate Industry has Entered New Round of Growth

The CCL industry has entered a new round of growth in recent years, and two regions in Asia—China and Southeast Asia—have become the fastest-growing. Relevant manufacturers have successively taken measures like capacity expansion and acquisitions to strengthen their CCL business.

Car OEM Telematics Leads IoT Segments, Generates $60B of Service Revenues in 2020

While 4G networks would be preferred by automakers to power the connected car, 3G networks will carry the data driving the majority of its global telematics and infotainment services revenues. In fact, it will be after 2020 that 4G becomes the leading connection technology for OEM telematics revenues.

Survey Reveals IoT Opportunity

While the Internet of Things (IoT) continues to evolve and expand, moving from the planning stage to execution, the momentum is quantifiable. According to a new survey from IDC, 73% of respondents have already deployed IoT solutions or plan to deploy in the next 12 months.

New Color Technology Displays to Comprise 25% of Total Display Shipment Area in 2020

Wide-color gamut flat-panel displays are expected to grow from 3% in 2015 to 25% of the display market in terms of area by 2020, according to IHS. Color gamut refers to the ability of a digital display to reproduce colors as they are seen by the naked eye.

Microcontroller Market Growth Tied to Rise in IoT Applications

The market for MCUs used in connected cars, wearable electronics, building automation and other IoT applications is expected to grow at an overall CAGR of 11%, from $1.7 billion in 2014 to $2.8 billion in 2019, according to IHS.

Chinese Handset OEMs to Increase Demand for Smartphone Sensors

Chinese OEMs have proved willing to try any new technology that allows them to compete more successfully. Of the many Chinese handset manufacturers, Xiaomi will consume the greatest number of sensors in 2019, according to IHS.

Researchers Take First Steps to Create Biodegradable Displays for Electronics

University of Missouri researchers are on the path to creating biodegradable electronics by using organic components in screen displays. The researchers' advancements could one day help reduce electronic waste in the world's landfills.

ARTICLE

As Vias Shrink, Opportunities for Laser Drilling Expand

by Dirk Müller, Ph.D.
COHERENT INC.

While lasers have long been employed for via drilling in PCB fabrication, mechanical drilling still remains the predominant production technology. However, as via diameters shrink to support various advanced packaging techniques, mechanical drilling becomes more expensive, and ultimately technologically unfeasible. A variety of laser technologies are now poised to step in to extend production via drilling down to the micron level. This article reviews the various laser sources that are available to support the latest packaging technologies as they become more widely adopted, and describes the characteristics and capabilities of each.

CO_2 Lasers

Carbon dioxide (CO_2) lasers have been used in PCB via drilling for more than two decades and currently service about 20% of the market. The reason for this relatively low market penetration is simple. Even though CO_2 lasers are a non-contact method that eliminates the need for frequent tool replacement, their sweet spot is at hole diameters around 100 µm diameter and below. As the industry transitions to smaller vias, mechanical drill replacement costs start to increase exponentially, and the use of CO_2 lasers will expand significantly to cater to the growing demand for ever smaller micro-vias.

CO_2 lasers drill vias through a thermal interaction. That is, the material absorbs the infrared light output of the CO_2 laser, which heats it until it vaporizes. Many dielectrics absorb well in the far infrared, while nearly all metals are highly reflective at these wavelengths. As a result, copper layers act as a natural stop when drilling with a CO_2 laser. In order to drill through copper (such as a top clad layer), it must first be oxidized to create a dark patina which absorbs the laser light.

While the CO_2 laser can readily produce a smaller via than a mechanical drill, there are limitations on the smallest via diameter it can reach. One limit is caused by light diffraction. Specifically, the smallest focused spot size to which a laser beam can be focused is directly related to its wavelength. Longer (e.g., far infrared) wavelengths, cannot be focused as finely as visible or ultraviolet wavelengths. Also, the thermal nature of the light/material interaction produces a small heat affected zone (HAZ)

around the drilled hole, limiting how close it can be placed to other features. As a result, the practical lower limit on via diameters for CO_2 lasers is about 70 µm. But what if the hole diameter needs to be smaller than 70 µm?

CO Lasers

This is where carbon monoxide (CO) lasers come in. This type of laser was first developed about 50 years ago, but lifetime and reliability issues prevented this technology from becoming commercially viable. However, in the past year, the advent of new technology is making CO lasers practical, yielding products with very high output powers, and which demonstrate lifetimes in the thousands of hours range. The reason that CO lasers are of interest is that they output over the 5–6 µm spectral range, or about half the CO_2 wavelength of 10.6 µm, allowing for a smaller focused spot.

For via drilling, this shorter wavelength provides several important advantages. For example, it lowers the minimum via diameter that can be produced down to about 35 µm (due to diffraction). But even when producing larger diameter vias, the CO laser has an edge over CO_2. Specifically, the focusing lens used to achieve a 70 µm diameter via with a CO laser has twice the focal length of the lens required to achieve the same via size with a CO_2 laser. This longer focal lens provides greater depth of focus, which increases the field of view. The longer focal length and increased depth of field facilitate an increase in scanning speed, and therefore faster via production, with the shorter wavelength CO laser.

Because the CO laser can be focused to a smaller spot, it's easier to reach higher power densities with it than with a longer wavelength CO_2 laser of the same power. (Since the CO laser has roughly half the wavelength of the CO_2, it forms a spot size that is half as big, and which therefore has one-quarter the area, or four times the power density.) Conversely, achieving a given power density requires only one-fourth the total output power with a CO laser as with a CO_2 laser. Depending upon the exact parameters of a particular via drilling task, this makes it possible to use a much lower power CO laser for a specific job. This lowers the cost of the laser and the cost of the electricity and reduces the carbon footprint for the process.

In addition to the optical benefits, there are also differences in light absorption characteristics at the shorter wavelengths. This can be especially true in the case of polymers, which have an infrared absorption spectrum that consists of numerous sharp peaks. As a result, some polymers exhibit high absorption at 10.6 µm, and much less in the 5 µm to 6 µm band, and vice versa.

Another important material which exhibits very different absorption characteristics at 10.6 µm and 5 µm is glass, a material now of great interest for interposers in 2.5D and 3D advanced packaging techniques. Specifically, although glass has much lower absorption at the shorter wavelength, the use of the shorter wavelength actually produces superior results. This is because the lower absorption enables the CO laser beam to penetrate farther into the material. Together with the superior focusing ability of the 5 µm wavelength, this enables very small holes with high aspect ratios to be drilled in glass with precise depth control. The photo shows 35 µm diameter vias drilled in glass. Vias of this size and quality simply couldn't be produced with a CO_2 laser in glass.

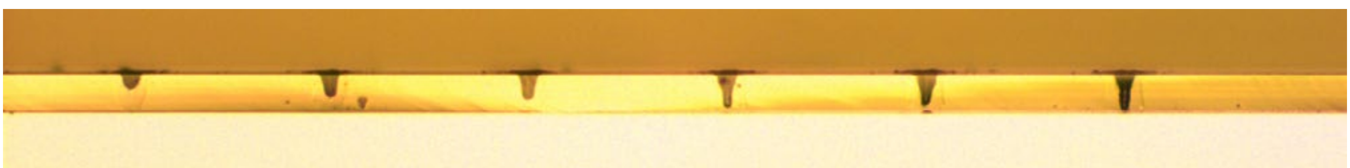


Figure 1: A 50 µm-thick glass substrate drilled with successively more pulses from a CO laser demonstrates the ability of this source to drill glass interposers. CO_2 drilling of this material typically results in heat-related cracking.

UV Solid State Lasers

In addition to CO_2 lasers, diode-pumped solid-state (DPSS) lasers operating in the ultraviolet (UV) at 355 nm are a well-established source for drilling microvias, and are employed in other microelectronic fabrication tasks, such as wafer and micro-SD card singulation. The UV output of these lasers delivers two important benefits for micro-via drilling applications. First, with a wavelength that is over ten times smaller than CO_2 and CO lasers, plus their excellent beam quality, these lasers can be focused down to even smaller spot sizes. Second, shorter wavelengths are absorbed more strongly than infrared light by the vast majority of materials, including both metals and dielectrics. Because they don't penetrate as far into the bulk material during processing, they deliver the ability to more precisely control the depth of the removed material, and produce a much smaller heat affected zone (HAZ).

Together, these factors make UV DPSS lasers the first choice for producing microvias in the 25–35 µm diameter range. These applications also benefit from the ability of the UV laser to drill both copper and composite lasers. They are generally not used for vias above about 70 µm, since these lasers typically have a higher cost of ownership than infrared (CO and CO_2) lasers.

One major limiting factor in the overall lifetime and service frequency for UV DPSS lasers is the frequency tripling crystal. Specifically, this is the non-linear optical element that converts the native, near infrared output of the solid-state laser crystal (typically at about 1 µm wavelength) into the UV. There are two basic configurations in which this crystal can be used. It can be placed intracavity (within the laser resonator) or external to the laser cavity. Intracavity frequency tripling more readily delivers high output power than external cavity tripling. However, exposing the crystal to the higher optical powers experienced within the cavity also significantly shortens its lifetime and reduces service intervals for a given power rating. Instead, Coherent UV DPSS lasers for microvia drilling use external cavity tripling in order to ensure the highest possible reliability. Using this approach, Coherent is able to supply UV lasers with up to 40W of power that operate for more than 10,000 hours without a crystal change, which is more than sufficient for current microelectronics processing tasks.

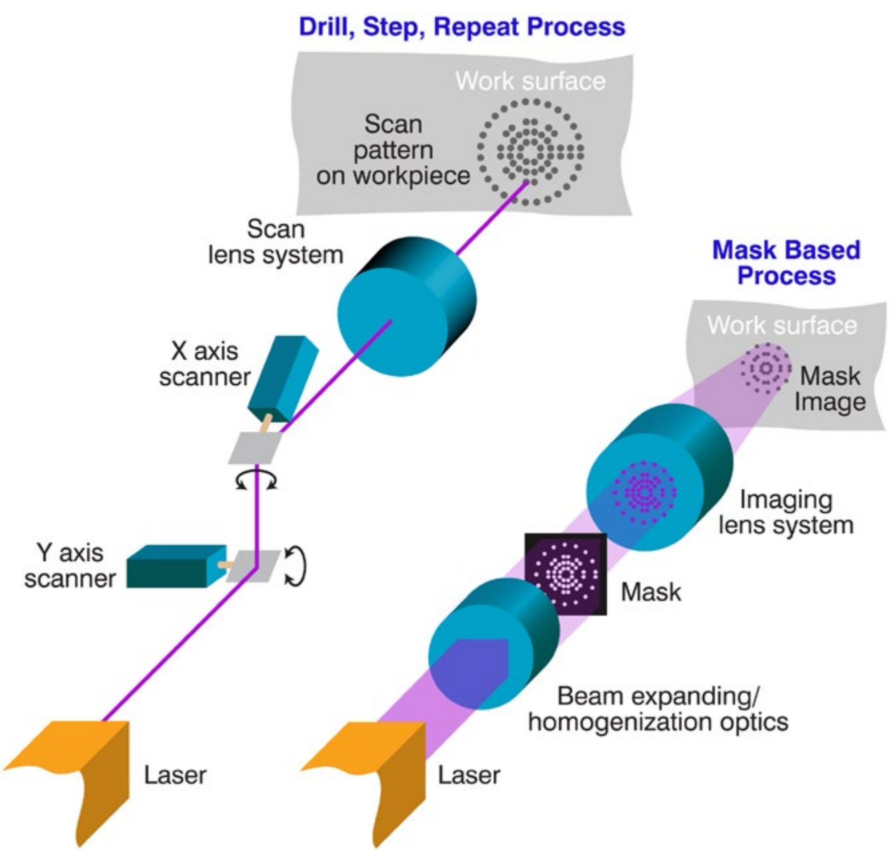


Figure 2: Schematic illustrating the difference between the direct write and mask-based writing technique for laser via drilling.

Excimer Lasers

Excimer lasers are another, even deeper UV source (usually at 308 nm or 248 nm), although they have vastly different output characteristics than DPSS lasers, leading them to be employed for microvia drilling in a very different manner. Specifically, the pencil-shaped beam

from a DPSS UV laser is typically utilized in a drill, step, and repeat mode. In this mode, the focused laser beam is moved to a desired hole location, the laser drills the hole and, once finished, the laser beam is moved to the next hole location, all in sequence. In this approach, the throughput is linearly dependent on the number of vias being drilled.

In contrast, excimer lasers produce a large rectangular-shaped beam that is ideal for use in a mask-based writing process. A photomask containing the pattern of vias for a panel, or region of a panel, is illuminated with the laser. This photomask is then re-imaged onto the work surface, and all holes within the beam section are drilled simultaneously.

In mask-based writing, laser fluence and pulse frequency dictate the maximum field size that can be exposed at once, but not the total number of holes that can be produced within this field. Thus, as pitch size decreases (and the number of holes produced in a given area increases), parallel, mask-based drilling becomes increasingly efficient. In fact, the parallel drilling rate increases with the square of the pitch size. This makes it an increasingly attractive alternative as feature size and spacing decreases, and tends to "future proof" the technique as via diameter and pitch decrease over time. Because of the higher capital cost of excimer lasers, these tools typically make economic sense at production rates around 50–100 panels per hour or higher, or if the desired feature sizes get down to 5–10 µm.

Because of their short wavelength output, excimer lasers have similar processing characteristics to UV DPSS lasers. Specifically, there is strong absorption by most materials, both metal and dielectrics, which allows them to produce micron-scale feature sizes with nearly zero HAZ.

Our laboratory has also investigated the use of excimer lasers for via drilling in glass interposers. In these tests, 25 µm diameter holes, with a pitch (hole-to-hole spacing) of 50 µm, were produced in glass substrates ranging in thickness from 100–300 µm. The laser wavelength of 193 nm was used, with a 600 mJ pulse energy, in a mask-based process that produced a fluence of 7 J/cm² at the work surface. The 193 nm wavelength was chosen because glass exhibits strong absorption at this wavelength.

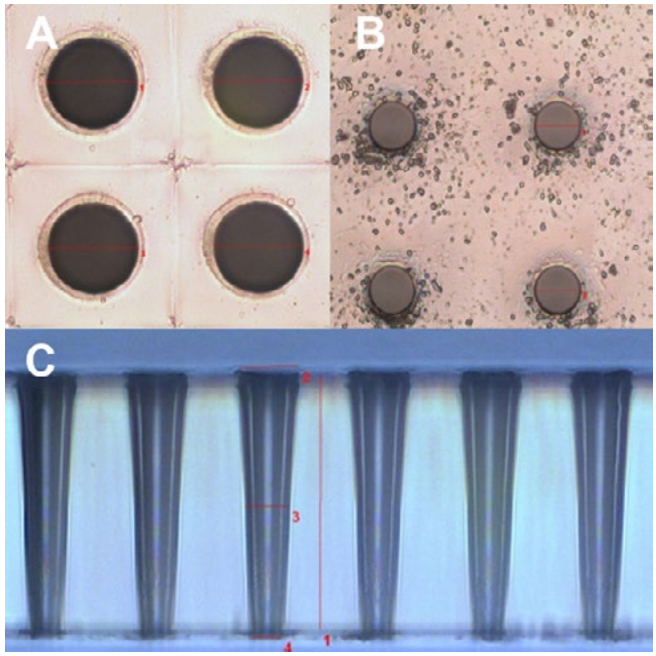


Figure 3: Excimer laser (193 nm) vias drilled into glass. A) The 25 µm diameter entrance hole; B) the exit hole; and C) the cross-sectional view.

Clean, round, symmetric vias were successfully produced in all the thicknesses tested using a total of 700 pulses or less. Hole taper was seen in the higher thicknesses, but sequential drilling from both sides of the glass reduced this effect substantially. This is relatively easy, since the transparent glass makes it easy to register fiducial marks on one side of the glass when it is flipped over for drilling from the second side. Overall, this testing showed that vias down to 5 µm diameter could be successfully produced.

In addition, mask-based excimer laser ablation provides excellent control of feature depth and wall angle. Unlike CO_2 laser via drilling, which usually takes just three laser pulses, excimer laser drilling utilizes numerous pulses, each of which removes just a small amount of material. Thus, via depth is precisely controlled by varying the number of laser pulses delivered. Wall angle is highly dependent upon laser fluence, so this parameter can also be varied to produce exactly the desired results.

In conclusion, most of the advanced packaging techniques that are currently on line, or becoming popular, require microvias that are beyond the capabilities of mechanical drills. In

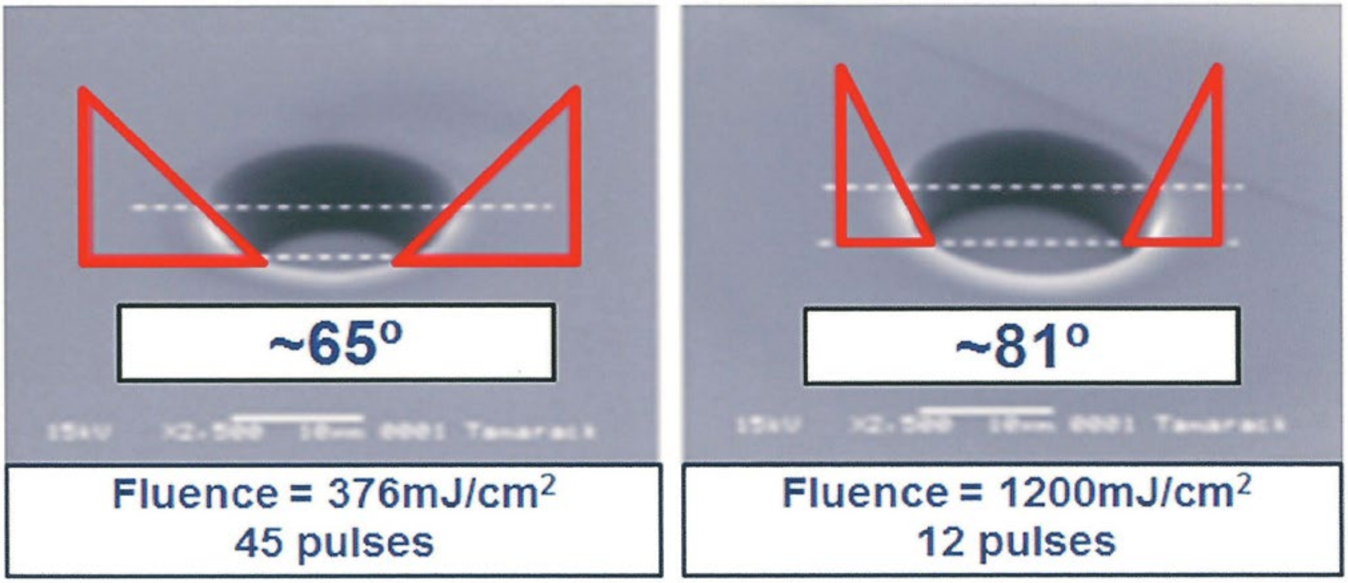


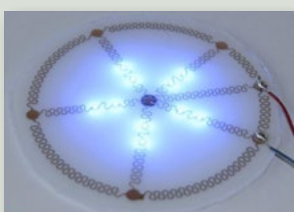
Figure 4: Varying laser fluence enables manipulation of feature side-wall angles, which can be important in subsequent deposition steps.

response to this need, laser manufacturers have already developed a variety of tools to optimally support next generation PCBs, substrates and interposers for today's advanced packages, and which deliver the performance overhead to support expected miniaturization trends in all these areas for the foreseeable future. **PCB**

Dirk Müller, Ph.D. is director of marketing at Coherent Inc. To reach the author, click here.

Imec and Ghent University Present Thermoplastically Deformable Electronic Circuits

At the recent meeting of the International Microelectronics Assembly and Packaging Society (IMAPS 2015), imec and CMST (imec's associated lab at Ghent University) presented a novel technology for thermoplastically deformable electronics enabling low-cost 2.5D free-form rigid electronic objects. The technology is under evaluation in Philips LED lamp carriers, a downlight luminaire and an omnidirectional light source, to demonstrate the potential of this technology in innovative lighting applications.



Thanks to its energy-efficiency, excellent light quality, and high output power, light emitting diode (LED) technology is becoming the sustainable light source for the 21st century. But in addition, it also allows to design unprecedented, innovative lighting solutions. Imec and CMST's new thermoplastically deformable electronic circuits now add a new dimension to the possibilities to fabricate novel lamp designs as well as smart applications in ambient intelligence and wearables.

The production process was developed in collaboration between the industrial and academic partners involved in the FP7 project TERASEL: imec, CMST (Ghent University), ACB, Holst Centre, Niebling Formtechnologie; Sintex NP and Philips Lighting BV. TERASEL is a European effort focusing on the development, industrial implementation and application of large-area, cost-effective, randomly shaped electronics and sensor circuit technologies.

ARTICLE

CAN TECHNOLOGY BE TOO DISRUPTIVE?

by Doug Bathauer
INTEGRAL TECHNOLOGIES

Steve Jobs said, “Innovation distinguishes between a leader and a follower.” The procession of new technologies continues at a breakneck pace, resulting in a world that is more connected than ever. From the Internet, smartphones, hybrid cars, and autonomous vehicles, to 3D printing, energy storage and so much more, innovation disrupts and advances our world.

“But since the Industrial Revolution of the late 18th and early 19th centuries, technology has had a unique role in powering growth and transforming economies,” reports McKinsey Global Institute in a report titled, *Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy*. “Technology represents new ways of doing things, and, once mastered, creates lasting change, which businesses and cultures do not unlearn. Adopted technology becomes embodied in capital, whether physical or human, and it allows economies to create more value with less input. At the same time, technology often disrupts, supplanting older ways of doing things and rendering old skills and organizational approaches irrelevant.”

Recent history is full of major companies and sectors that were met and leveled by disruptive technology. Just a few examples include the video rental business usurped by digital streaming, the traditional print publishing world disrupted by online publishing and the conventional power industry challenged by the rapid growth of the solar and energy storage sector.

But when is new technology *too* disruptive? Does new technology ever debut before its time? In the book, “The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail,” by Clayton M. Christensen, the author writes that “outstanding companies can do everything right and still lose their market leadership—or worse, disappear altogether.” Focusing on “disruptive technology,” Christensen’s book is about the “failure of companies to stay atop their industries when they confront certain types of market and technological change” and why many companies miss out on new waves of innovation. Whether in electronics or retailing, a successful company with established products will get pushed aside unless managers know when to abandon traditional business practices.

Outside of the plastics sector, the world of conductive plastics/polymers, first produced several decades ago, is not widely acknowledged

as disruptive, but there is no doubt that breakthrough technologies and novel usage of conductive polymers is occurring. Conductive plastics conduct electricity in comparison to normal insulating plastics. Conductive plastics are used in countless applications in many industries because they are easy to extrude or injection mold into desired shapes and sizes.

"Conductive polymers are already used in fuel cells, computer displays and microsurgical tools, and are now finding applications in the field of biomaterials," reports *Acta Biomaterialia* magazine. "These versatile polymers can be synthesized alone, as hydrogels, combined into composites or electrospun into microfibres. They can be created to be biocompatible and biodegradable. Conductive polymers are being used as biomaterial for tissue engineering. "Their conductive nature allows cells or tissue cultured upon them to be stimulated, the polymers' own physical properties to be influenced post-synthesis and the drugs bound in them released, through the application of an electrical signal. It is little wonder that these polymers are becoming very important materials for biosensors, neural implants, drug delivery devices and tissue engineering scaffolds."

> "The automobile companies that will thrive in the coming decades are the ones that embrace technological advances. Consumers now crave a vehicle loaded with all the electronic goodies it can hold."

To date, conductive polymers have had few large-scale applications; however, advances in the technological development of conductive polymers are leading to their incorporation in batteries, super capacitors, biomaterial, solar cells, flexible transparent displays, electromagnetic shielding, stealth aircraft coatings and more.

The automotive industry has been subject to dramatic disruptions since the first steam powered automobile debuted in 1768. A prime example of a disruptive trend is the Ford Model T. When the Model T was first available to the public in 1908, the market for horse-drawn carriages diminished, and the market for automobiles took off. Today an average new car has 30 computer processors with assisted parking, voice recognition, and GPS functions more and more common. Hybrid and electric cars are on the rise and automotive design is benefitting from modern materials and improved metals.

The automobile companies that will thrive in the coming decades are the ones that embrace technological advances. Consumers now crave a vehicle loaded with all the electronic goodies it can hold. To satisfy this craving, manufacturers have been loading up even standard models with on-board GPS systems, hands-free phone consoles, wireless Internet, satellite radio, cameras and DVD monitors. In the process, they are also packing on the pounds. At the Consumer Electronics Show, Ford CEO Mark Fields said "we view ourselves not just as a car and truck company but also as a mobility company."

Today, the trend of lightweighting holds heavyweight importance. Analysts predict that lightweighting, the process of reducing weight for improving performance and improving fuel efficiencies, will become a $300 billion annual market as global trends point to CO_2 reduction and resource efficiencies as being vital to meeting regulatory and industry mandates in the transportation sector. New materials development will be the driver in this trend.

For example, Ford's 2015 model F-150, which accounts for 1 in 20 cars sold in the U.S., is now 700 pounds lighter than its 2014 model with aluminum alloy replacing the heavier steel frame. The federal government's new Corporate Average Fuel Economy standards (CAFE) require automakers to raise the average fuel efficiency of new cars and trucks to 54.5 mpg by 2025.

The electrically assisted vehicle can certainly meet or exceed the CAFE requirements, but these vehicles carry their own weight issues, as

batteries and electrical systems add hundreds of pounds to the vehicle.

More electronics add another problem that needs to be addressed: electromagnetic interference (EMI). Conductive resins will play an ever increasing role in the lightweighting industry. Certain companies are fighting automobile obesity by utilizing conductive hybrid plastics as EMI shielding solutions. Integral Technology's patented material utilizes long fiber technology shields high-voltage components and has also developed numerous applications for connectors, covers, and enclosures. Other measures are the joint development of shielded cable with Delphi Automotive. We are able to provide the same shield effectiveness as the aluminum or cast aluminum parts while providing on average a 60% weight savings. Who says you can't have your Bluetooth cake and eat it too?

Evangelos Simoudis, managing director at Trident Capital, in an article on Enterprise Irregulars, states that "in the next 10 years we will create more innovations that will impact the automotive industry than we have created in the previous 100" and that these "disruptive innovations are coming from companies outside the traditional automotive ecosystem. The car as a computer on wheels is disruptive and enables the emergence of a completely new ecosystem and value chain."

Disruptive innovation creates new markets, disrupts existing markets and replaces prior technology, thereby enabling existing markets to be productive, sustaining and value-driven. While new technology disrupts the status quo, technology can never be too disruptive. As President Obama said, "Change will not come if we wait for some other person or some other time. We are the ones we've been waiting for. We are the change that we seek." **PCB**

Doug Bathauer is CEO of Integral Technologies.

Walking Robot Developed at Oregon State University

A study by engineers at Oregon State University suggests that they have achieved the most realistic robotic implementation of human walking dynamics that has ever been done, which may ultimately allow human-like versatility and performance.

The system is based on a concept called "spring-mass" walking that was theorized less than a decade ago, and combines passive dynamics of a mechanical system with computer control. It provides the ability to blindly react to rough terrain, maintain balance, retain an efficiency of motion and essentially walk like humans do.

As such, this approach to robots that can walk and run like humans opens the door to entire new industries, jobs and mechanized systems that do not today exist.

The findings on spring-mass walking have been reported for the first time in IEEE Transactions on Robotics, by engineers from OSU and Germany. The work has been supported by the National Science Foundation, the Defense Advanced Research Projects Agency and the Human Frontier Science Program.

The technologies developed at OSU have evolved from intense studies of both human and animal walking and running, to learn how animals achieve a fluidity of motion with a high degree of energy efficiency. Animals combine a sensory input from nerves, vision, muscles and tendons to create locomotion that researchers have now translated into a working robotic system.

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Recent Highlights from PCB007

1 TTM Technologies Consolidates Manufacturing Operations

TTM Technologies Inc., a major global printed circuit board manufacturer, today announced that it plans to close three facilities in order to improve total plant utilization, operational performance and customer focus.

2 The Re-industrialisation of Europe

With an inquisitive mind and a head for challenges, besides the ability to think outside the box and the courage to dare to be different and strive to be first, Spirit Circuits MD Steve Driver can be relied upon to grab the attention of an audience of PCB professionals. As keynote speaker at the Institute of Circuit Technology Hayling Island Seminar, he lived up to his reputation with a motivational presentation, the two themes of which exemplified his latest entrepreneurial venture.

3 Inaugural Boards, Chips and Packaging IMPACT Conference Adds 15 Industry Experts to Presentation List

Isola Group and Semico Research announced today that the inaugural event, "Board, Chips and Packaging: Designing to Maximize Results Conference" is garnering significant interest from the embedded design community with the addition of 15 industry experts added to the agenda.

4 World PCB Production in 2014 Estimated at $60.2B

The world market for PCBs reached an estimated $60.2 billion in value in 2014, growing just 0.7% in real terms, according to IPC's World PCB Production Report for the Year 2014. Production growth in China, Thailand and Vietnam compensated for declining PCB production in most other regions.

5 AT&S Highlights the Future of PCB Industry

Miniaturisation and performance enhancement are leading trends not only for mobile devices such as smartphones; applications in the automotive sector and in medical technology are also getting progressively smaller, more efficient and more powerful.

6 N.A. PCB Book-to-Bill Ratio Reaches Five-year High in August

Total North American PCB shipments increased 1.5% in August 2015 compared to August 2014. Year-to-date shipment growth stood at -0.1, reflecting the negative sales growth rates seen earlier this year. Compared to the previous month, PCB shipments were up 3.6%.

7 Final Surface Finishes for Automotive: No One-Size-Fits-All Solution

Regardless of whether your application is automotive, medical or military, there are many factors to consider when selecting a final surface finish. Cost, lead or lead-free requirements, end environment, shelf life, fine-pitch components, RF applications, probe-ability, thermal resistance and shock and drop resistance, to name a few. There is not a one-size-fits-all finish. Understanding the advantages and disadvantages of each surface finish allows the designer to select the finish that best fits each particular application.

8 Becoming an Automotive Supplier—Proceed with Caution

Possibly further fueling a growing desire in our industry towards participating in the automotive electronics sector have been further technology advancements in automobiles, as well as a tear in Tesla's stock price and headlines.

9 All Flex Now Offers High Temp Flexible Circuits & Heaters

All Flex, manufacturer of flexible printed circuits and heaters, has developed a polyimide-based material set specifically targeting the market for high temperature flexible circuits and flexible heaters. Increasing demands for high temperature applications have driven the development process at All Flex over the past 18 months.

10 Testing Flexible Circuits, Part 2: Raw Materials and Components

Even though the raw materials may individually meet certain specifications, it is important to determine if the final product configuration meets those specs, which means that testing done at the finished circuit level is also needed.

EVENTS

For the IPC Calendar of Events, click here.

For the SMTA Calendar of Events, click here.

For the iNEMI Calendar of Events, click here.

For the complete PCB007 Calendar of Events, click here.

LA/Orange County Expo & Tech Forum
November 5, 2015
Long Beach, California, USA

CEA Innovate!
November 8–10, 2015
New York City, New York, USA

productronica 2015
November 10–13, 2015
Munich, Germany

2015 EFRA-CEFIC Workshop
November 11, 2015
Munich, Germany

Space Coast Expo & Tech Forum
November 12, 2015
Melbourne, Florida, USA

Indiana Fall Forum & Expo
November 13, 2015
Columbus, Indiana, USA

LED Assembly, Reliability & Testing Symposium
November 17–19, 2015
Atlanta, Georgia, USA

Rapid Oven Setup & PCB Profiling – Seminar
November 24, 2015
Warwickshire, UK

2015 International Printed Circuit & APEX South China Fair
December 2–4, 2015
Shenzhen, China

IPC APEX EXPO Conference & Exhibition 2016
March 15–17, 2016
Las Vegas, Nevada, USA

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Coming Soon to *The PCB Magazine:*

December:
Associations and 2016 Events

January:
Medical Electronics: Getting the Vitals