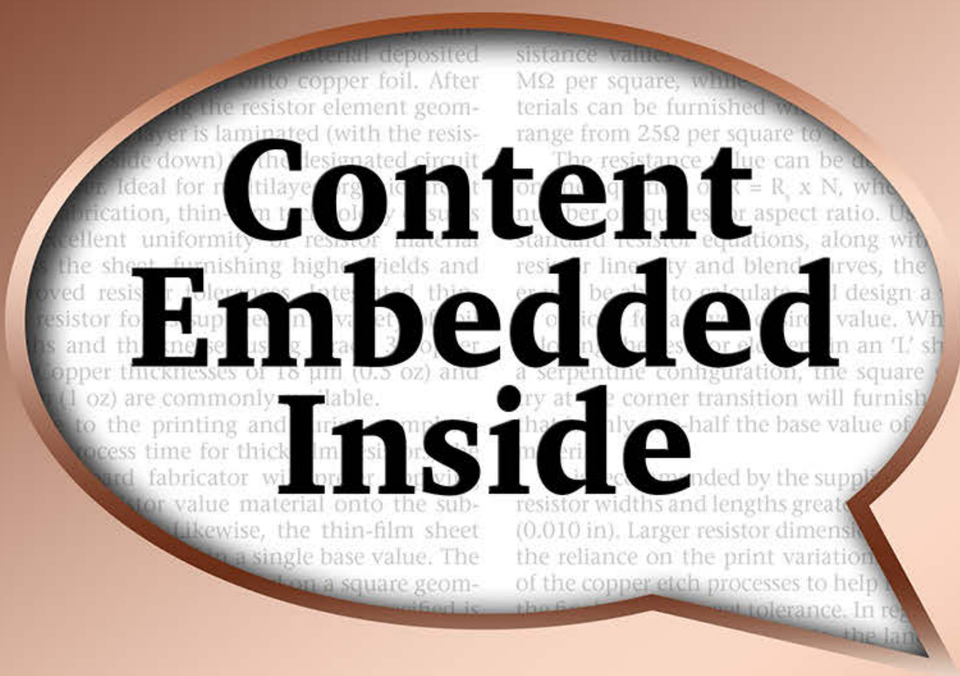
I-Connect007 Presents

June 2017

the pcb magazine



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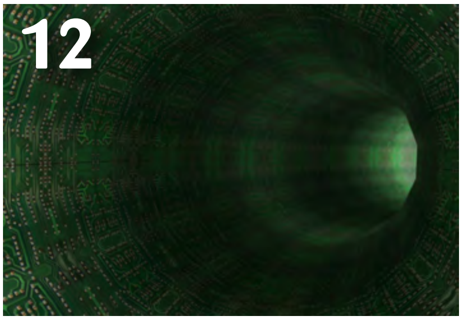

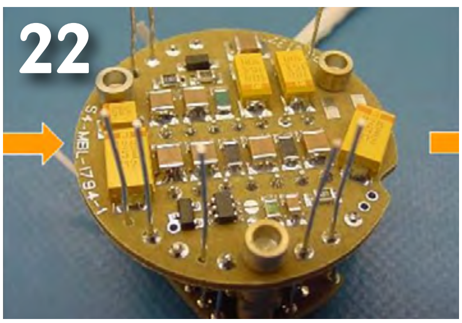

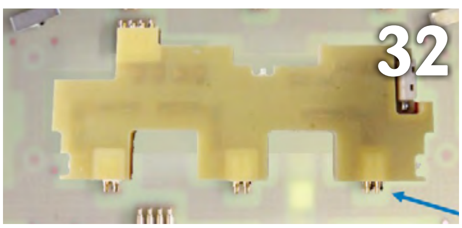

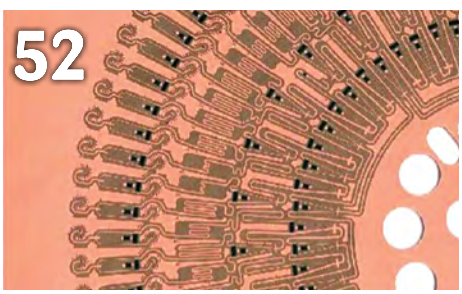

Embedded Components

Embedded technology seems finally to be coming into its own—thanks to Moore's Law and the ever-pressing need for more real estate on the circuit board surface. No longer just for the odd, expensive military product, buried components can be found in that most ubiquitous of consumer products, the smartphone, as you will learn in this issue. They are truly all around us!

FEATURES:

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June 2017

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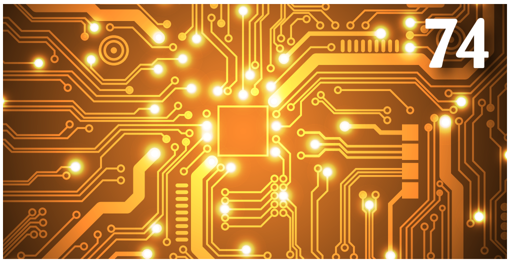
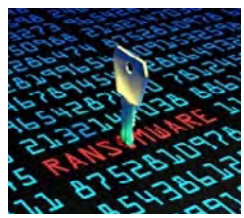


ARTICLE

COLUMNS

SHORTS



HIGHLIGHTS

DEPARTMENTS

Embedded Technology: It's All Around Us

by Patty Goldman
I-CONNECT007

In the early '80s, the PCB company I worked for was testing some of the first material for buried resistors. I can't recall what customer it was for, or how far along the project got, but over the years it seemed like the technology was slow to be adopted and perhaps ahead of its time. Now, a lot of years later, embedded technology seems to be finally coming into its own—thanks to Moore's Law and the ever-pressing need for more real estate on the circuit board surface. No longer just for the odd, expensive military product, buried components can be found in that most ubiquitous of consumer products, the smartphone, as you will learn in this issue. Who knew!

Back then, there were only buried resistors and from what I understand, the material was not cheap. Most uses involved either a need for extraordinary reliability or there was enough savings in reduced layers or improved abilities that would justify the cost. But there are other types of passives as well as buried active components. And the justifications are more complicated: signal integrity, greatly improved imaging capability which means more accurate resistive values, and always space, as in the required surface area of a circuit board.

We thought we would find out from our readers just how "popular" this technology really was. After all, as circuits get denser and lines/spaces get smaller, it stands to reason that burying components would be an increasing requirement and they would be part of every complicated multilayer. From our recent survey, we learned that more than half the respondents saw very little embedded technology work and about 5% worked with it a great deal (<75% of their work). So that leaves roughly 40% working with buried technology some amount of the time. When asked what type, the answers were fairly evenly divided between resistance, capacitance and active components.

We were curious as to the reasons for using embedded technology and got a wide variety of responses. The three main reasons were to free up board real estate, increase active circuit density, and to improve electrical performance. To improve reliability and to reduce cost were a little lower on the list but significant (Table 1).

Q: What is the main reason you or your customers utilize embeded technology?

PERCENT %	
62	Free up board real estate
61	Increase active circuit density
56	Improve electrical performance
35	Reduce cost
32	Improve reliability
6	Reduce package thickness or height
3	Security
9	Other

Table 1: Reasons for embedding components in PCBs.

We also asked about manufacturing challenges in an open-ended question. We saw some interesting responses like "poor yields if you choose the wrong material set" and "thin core movement during bonding" and "predictability of electrical values after processing" and "existing software tools" and (the painful) "getting it right the first time," along with a few complaints about supply: "limited," "insufficient," "finding it," "capable suppliers."

In this month's issue, we asked the "buried" experts to fill you in on some more details and perhaps answer your questions. We started with a veteran of this technology, columnist Vern Solberg. He gives a short overview then delves into some calculations on resistor geometry in this first part; the second part will appear in the June issue of *The PCB Design Magazine*, so you will only have to wait a few days to read it.

I asked Compunetics' Jesse Ward to give us a primer on buried capacitor technology since they use it extensively. Using illustrations from his suppliers, he clearly shows how space is saved on the board surface, plus he lists both mechanical and electrical benefits, along with applications.

Next, Manuel Herrera of Ohmega Technology delves into an application of resistor material—as thin film heater elements. He goes into detail on designing these, along with applications.

Getting further into applications is Thomas Hofmann of Hofmann Leiterplatten, a German PCB manufacturer that has developed a method of fabricating PCBs with embedded devices called AML. This paper was presented at the recent ECWC conference in Seoul, South Korea, and won a Best Paper award there. It is filled with practical information and an abundance of application examples.

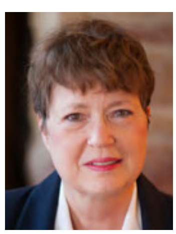
We here at I-Connect007 had a very lively discussion when preparing for this issue. We invited Dan Brandler and Manuel Herrera from Ohmega Technology, along with I-Connect007 Contributing Editor Happy Holden to talk with us about embedded components. It was quite a conversation! You will hear (read) it all: inside info on Ohmega, some history on the technology, more applications, how to do a cost justification, the significance of buried components for signal integrity (and hence why they are in your smartphone), how direct imaging has improved said technology, and much more!

We have an article by Thomas Jones, a research associate with Heriot-Watt University and soon to be conferred his PhD. His research on a megasonic treatment process for improved copper electrodepositon in vias was the subject for his doctorate and the subject of this article.

Rounding out this month's issue are a couple of columns that I particularly like. IPC's John Mitchell speaks to us on congressional site visits. What, you say? Yes, we mean inviting the guys who represent you in Washington to come visit your facility. It's not as complicated as you think and IPC will help set it up for you.

And lastly, Steve Williams, of The Right Approach Consulting, brings us a delightful barbershop story with a great message on delighting your customers.

Lots of meat in this issue, as I hope you find in all of them. Next month, we're all about the military industry and what's going on there. We hear business is up, but there are some new requirements coming that may make it difficult to participate. You need to know how this will affect your company so do tune in. The best way of course is to subscribe and get it delivered. Do it now! **PCB**



Patricia Goldman is managing editor of *The PCB Magazine.* To contact Goldman, click here.

Embedding Components, Part 1

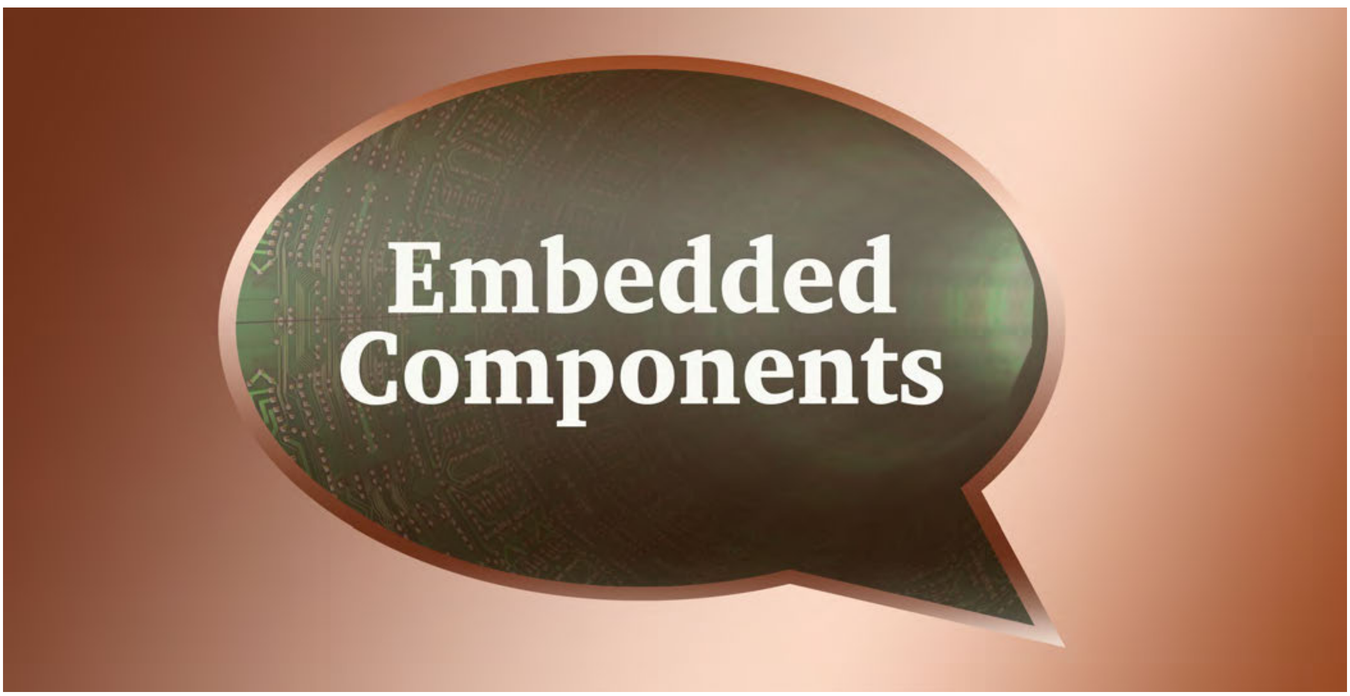
by Vern Solberg

The printed circuit has traditionally served as the platform for mounting and interconnecting active and passive components on the outer surfaces. Companies attempting to improve functionality and minimize space are now considering embedding a broad range of these components within the circuit structure. Both uncased active and passive component elements are candidates for embedding but the decision to embed components within the multilayer circuit structure must be made early in the design process.

Some components are easy candidates for integrating into the substrate while others may involve more complex processes and will be difficult to rationalize. Processes have evolved for embedding and interconnecting a range of common passive components: resistor, capacitor and inductor elements. Embedding formed resistor elements, however, is the most mature and economical process to implement. A formed resistor will have two copper lands with resistance material applied between the lands. The shape of the resistance material can be a simple rectangle, or a shape designed to maximize resistor element length while minimizing area. In each case, the resistance material must overlap the copper lands.

Formed resistor elements may be furnished as a printed thick-film composition or by employing a chemically etched thin-film process.

• *Thick-film* resistor materials are formulated to furnish a wide range of primary values. The resistor formulations are based on carbon-filled epoxy chemistry that enables screen printing the elements directly onto pre-patterned terminations on a designated circuit board layer followed by curing the product at temperatures in the range of 150°C. This carbon-filled epoxy thick film (TF) chemistry has been successfully used for a broad number of commercial applications. The process is generally employed where tolerances are less critical. Applications are varied and range from simple discrete potentiometers to pull-up and pull-down resistors.



Panasonic

Ultra-low Transmission Loss Multi-layer Circuit Board Materials for ICT Infrastructure Equipment

MEGTRON7

Laminate **R-5785(N)**
Prepreg **R-5680(N)**

H-VLP2 Cu and Low Dk Glass-Cloth Specifications

Features

- H-VLP2 copper foil and Low Dk glass-cloth allows for 30% loss improvement than MEGTRON 6
- Glass transition temperature (Tg): 200°C (DSC)
- Reduce process cost (Improve drill processability and ENIG (Electro-Nickel Immersion Gold))

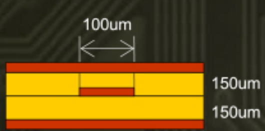
	Dk	Df
R-5785(N) + H-VLP2 Cu	3.4	0.002 @ 12GHz
R-5775	3.6	0.004 @ 12GHz

Applications

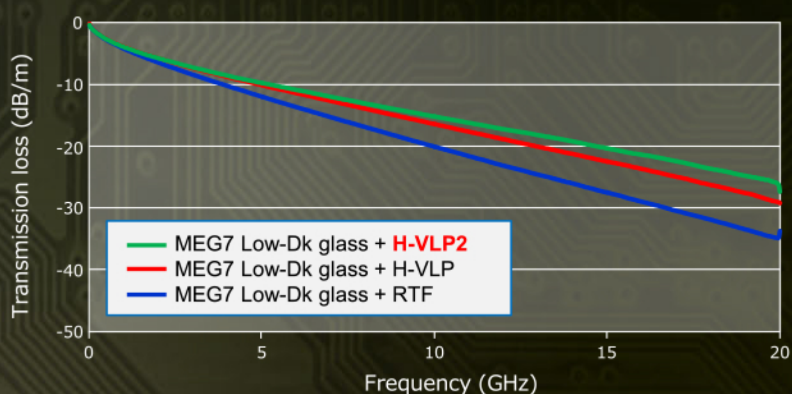
- High-end servers, High-end routers, Supercomputers, and other ICT infrastructure equipment, Antenna (Base station, Automotive millimeter-wave radar), etc.

Transmission Loss

- Evaluation Sample



Line Length	1000 mm
Impedance	50 Ω
Copper Thickness	18 μm
Inner Cu Treatment	No-surface Treatment
Core Type	#1078 (RC67%) x 2ply
Prepreg Type	#1078 x 2ply



Contact us

More information

• *Thin-film* resistors are formed using laminates coated with resistive material deposited using vapor deposition onto copper foil. After chemically defining the resistor element geometry, the sheet layer is laminated (with the resistor element side down) to the designated circuit board layer. Ideal for multilayer organic circuit board fabrication, thin-film technology ensures the excellent uniformity of resistor material across the sheet, furnishing higher yields and improved resistor tolerances. Integrated thin-film resistor foil is supplied in a variety of foil widths and thicknesses using Grade 3 copper foil. Copper thicknesses of 18 µm (0.5 oz) and 35 µm (1 oz) are commonly available.

Due to the printing and curing complexity and process time for thick-film resistors, the printed board fabricator will prefer applying only one resistor value material onto the substrate base layer. Likewise, the thin-film sheet material is furnished in a single base value. The resistor base values are based on a square geometry. For example, the resistor value specified is 2KΩ. The fabricator prepares a base value of 1 KΩ material. The geometry furnished on the design file to furnish the 2KΩ resistor element will be two squares in length. Likewise, a 2.5KΩ resistor element would require two and one-half squares. To maximize the number of resistor elements on the circuit layer, several techniques can be considered to achieve greater utilization of the process. For the more complex values the designer can string a number of squares together in either a single-line or serpentine configuration.

Calculating Resistor Geometry

Both thick-film and thin-film resistor materials are formulated to furnish a wide range of primary values. The resistance of a linear resistor is written as:

$$R = \varpi \times L/A = (\varpi/t) \times (L/w) = R_s\ (L/W)$$

Where, ϖ = resistivity
L = resistor length
W = resistor width
R_s = sheet resistance in %/sq
A = cross-section area
T = Film thickness

The thick-film materials are available in resistance values that range between 1Ω and 1 MΩ per square, while the thin-film sheet materials can be furnished with resist values that range from 25Ω per square to 1 KΩ per square.

The resistance value can be designed based on the equation of $R = R_s \times N$, where N is the number of squares, or aspect ratio. Using these standard resistor equations, along with actual resistor linearity and blend curves, the designer will be able to calculate and design a variety of options for a given desired value. When developing the resistor element in an 'L' shape or a serpentine configuration, the square geometry at the corner transition will furnish a value that is only one-half the base value of the resist material.

It is recommended by the suppliers to furnish resistor widths and lengths greater than 0.25 mm (0.010 in). Larger resistor dimensions will reduce the reliance on the print variations or accuracy of the copper etch processes to help in achieving the final resistor target tolerance. In regard to terminating the resistor elements, the land pattern geometry provided for the resistor termination should allow for a nominal 0.25 mm to 0.50 mm overlap of the resist material and consider allowances for fabrication process variables.

When higher power loading is required the resistor must be sized accordingly. Refer to the supplier's resistor calculator for resistor sizes based on power dissipation requirements. For greater detail regarding formed resistor design, material and process parameters refer to IPC-7092, IPC-2316 and IPC-4811 for additional information.

Part 2 of embedded component technology will focus on formed capacitor and inductor element design, and will appear in the June issue of *The PCB Design Magazine*. **PCB**

Vern Solberg is an independent technical consultant specializing in surface mount technology and microelectronics design and manufacturing technology. To read past columns or to contact the author, click here.

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A Brief Tutorial on Embedded Capacitors

by Jesse Ward
COMPUNETICS, INC.

Introduction

Compunetics has been operating in the embedded components market for more than 20 years. Initially driven by their parent company's need for high layer-count, high-density embedded capacitance cards for their OEM product offerings, technology and processes were developed which are mature and reliable. Embedded technology is integrated into PCBs using conventional processing techniques; the capacitive layers are drop-in replacements in the existing PCB stack. However, special processing is required to properly transport the extremely thin cores associated with embedded capacitance layers (three to 25 microns thick).

Embedded capacitors rely on utilization of planar copper-clad, thin-core laminate (Figure 1). These laminates replace decoupling capacitors which are normally mounted next to an IC. The IC is routed directly to the capacitive layer using vias. The laminates are drop-in replacements that use the existing PCB stack-up. Various dielectrics and core thicknesses are available. For example, DuPont HK04 material utilizes a 1-mil copper-clad polyimide core which functions as an ideal capacitor (Figure 2). Each clad layer of the core acts as opposing capacitor

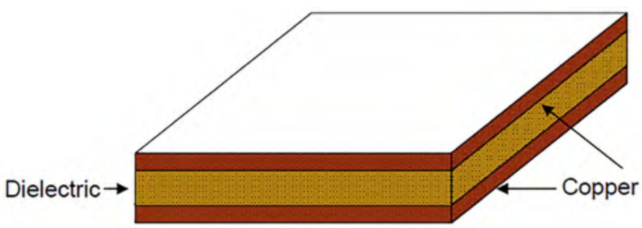


Figure 1: Basic construction of a capacitance layer: thin core (orange) and etched copper cladding (red). Source: Dupont.

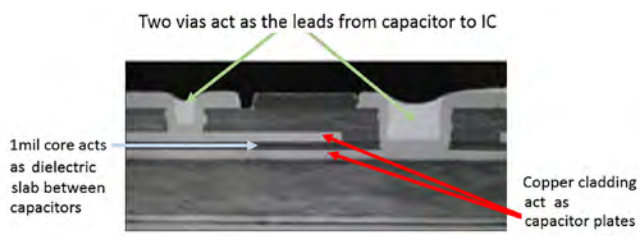
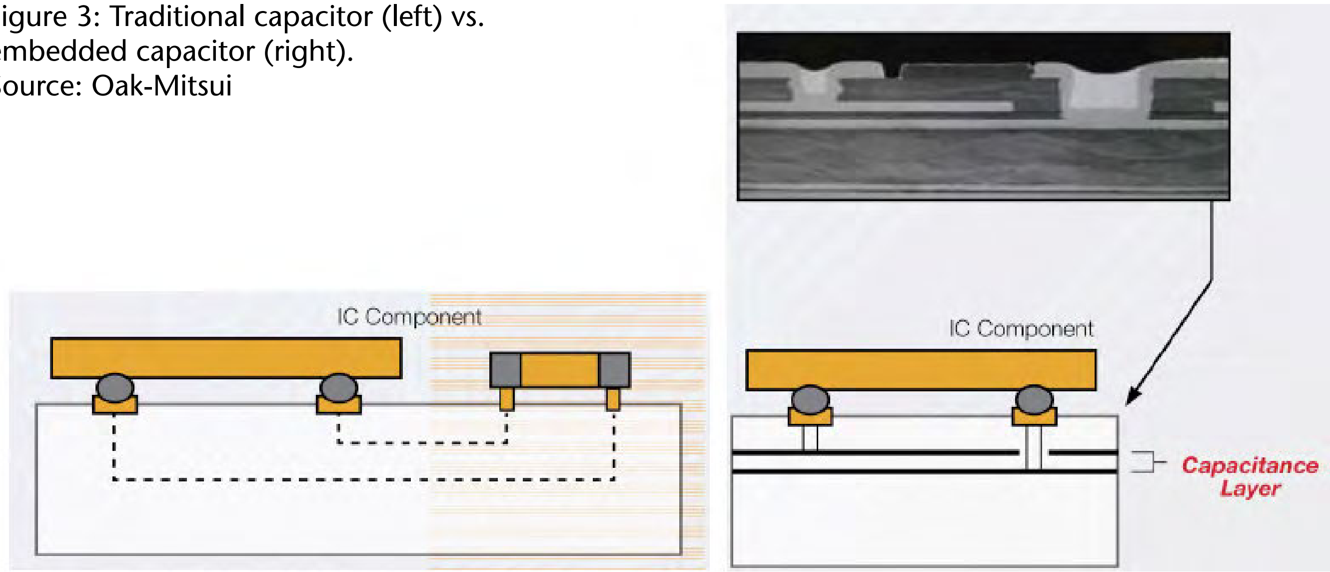


Figure 2: The technology addresses many issues with PCB design and power delivery at the same or lower cost, plus it's more reliable. Source: Oak-Mitsui

Figure 3: Traditional capacitor (left) vs. embedded capacitor (right). Source: Oak-Mitsui



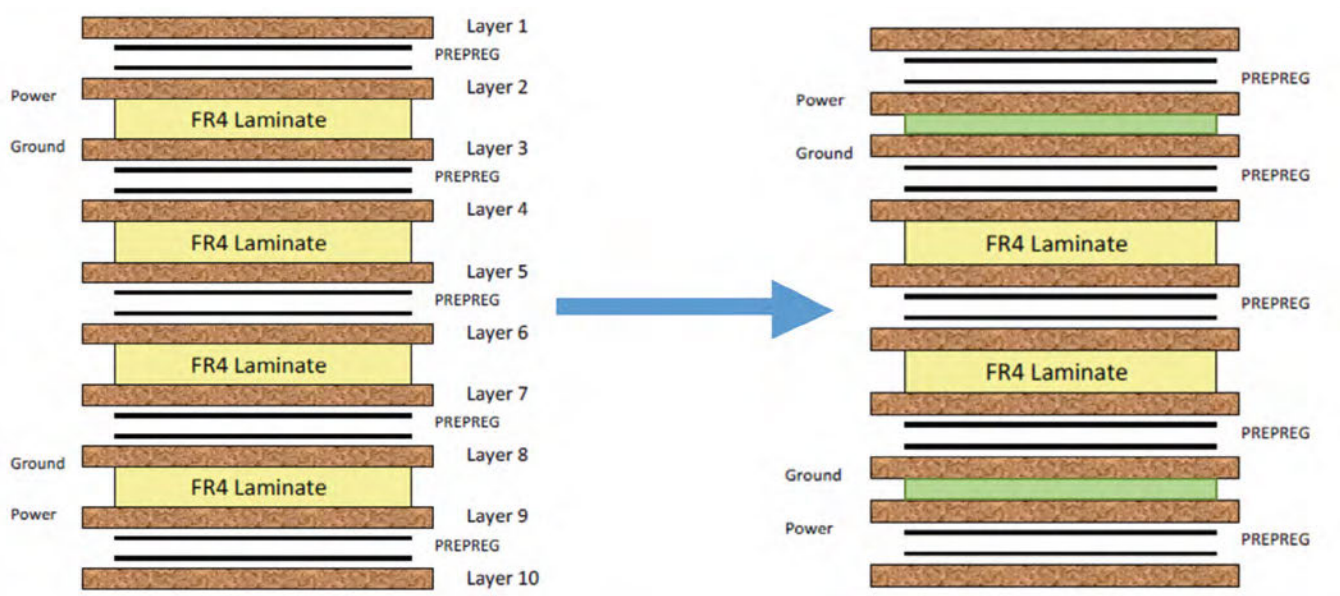


Figure 4: Capacitance copper clad cores directly substitute the outer cores (green). Source: Oak-Mitsui

plates: two blind vias (or through-holes) connect to either copper plane layer creating a capacitor. Some suppliers, such as 3M and Oak-Mitsui, offer epoxy-resin cores which provide high dielectric constants for applications such as MEMS microphones.

Figure 3 illustrates the difference between a traditional capacitor and an embedded one. Note the smaller footprint when the capacitor is embedded under the IC.

Drop-in Replacement

In general, place the capacitive layer on 2/3 and on (n-2)/(n-1) as shown in Figure 4. For high layer counts, there may be more capacitive layers.

There are three major brands of embedded capacitance material:

- 3M: ECM (very thin layer of ceramic-filled epoxy)

- DuPont Interra: HK04J (dielectric core composed exclusively of polyimide)
- Oak-Mitsui: FaradFlex (epoxy or other type of resin bonded to a high-performance polymer film)

Advantages of Using Embedded Materials

There are many benefits to incorporating embedded capacitors (as well as other embedded components) into a design. Besides mechanical or design benefits there are also electrical advantages.

Mechanical/Design Benefits

One of the major reasons to embed is to save space on outer layers; there will be fewer components to go on the surface of the multilayer. All decoupling capacitors can be eliminated (from the surface) as well as perhaps greater than 40% of bypass capacitors.

Saving real estate can result in a smaller size PCB which decreases weight and (possibly) thickness. This savings in board real estate could be utilized in other ways also; perhaps more capability can be designed in and extra layers be added without increasing overall thickness.

But with possible layer count reduction (and hence a thinner overall panel), the PTH aspect ratio will be reduced and the fewer surface components mean fewer PTH connections overall. Circuit routing capability will be improved. By solving noise issues early in the design cycle, not only is the cycle most likely shortened but specs can be simpler. All these benefits point to lower cost.

Electrical Benefits

Regardless of savings in materials, real estate, design turnaround time and the other benefits mentioned above, there are often other factors that make embedded capacitance a good approach. Chief among these is improved reliability with fewer connections overall. But there are numerous electrical design advantages that should also be recognized. These include:

- Significantly reduced power buss noise
- Decreased inductance
- Lower power-to-ground noise
- Reduced simultaneous switching noise
- Reduced interference from digital circuits to analog/RF circuits in mixed signal applications
- Reduced impedance and modal resonance
- Shorter routing path deliveries instantaneous charge when needed
- Decreased need for EMC measures such as metal shells, tapes, etc.
- No glass bundles, therefore no conductive anodic filament (CAF) concerns
- Improved trace routing capability

Applications

The improved tolerance, temperature voltage and frequency characteristics realized with embedded capacitors make these PCBs suitable for a wide range of applications, including:

- Routers
- Servers
- Telecom
- SSD storage
- MEMS microphones
- Commercial
- Wearable electronics
- Consumer electronics
- Organic capacitor chip diplexers
- RF filters
- Super computers
- Test and measurement equipment
- Medical applications
- Military/aerospace

Two applications are shown in Figures 5 and 6.

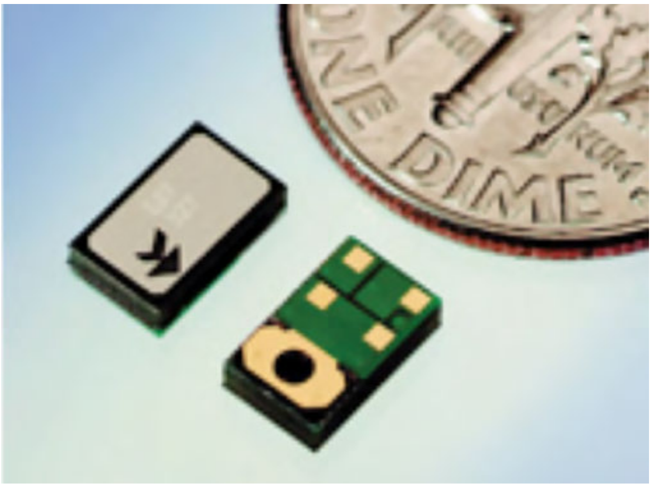


Figure 5: MEMS microphone. Source: 3M.

Figure 6: Servers such as these utilize buried capacitance in their PCBs. Source: Oak-Mitsui

Conclusion

Compunetics' parent company, Compunetix, Inc., is the leading manufacturer of multipoint collaboration equipment with the industry's largest worldwide deployment of digital conferencing systems in both the commercial and mission critical government markets. Their OEM products epitomize the benefits gained from employing buried capacitance layers. The circuit board's mass and profile are greatly reduced; the power delivered instantaneously from the capacitive layer otherwise wouldn't be supplied fast enough with conventional decoupling capacitors. Additionally, signal integrity is preserved and noise is minimized. These high-speed, reliable products facilitate mission-critical operations for the United States government, as well as preserve our national security. **PCB**

Jesse Ward is technical applications manager with Compunetics, Inc.

Fein-Lines: Virus, Phishing, Ransomware...Oh My!

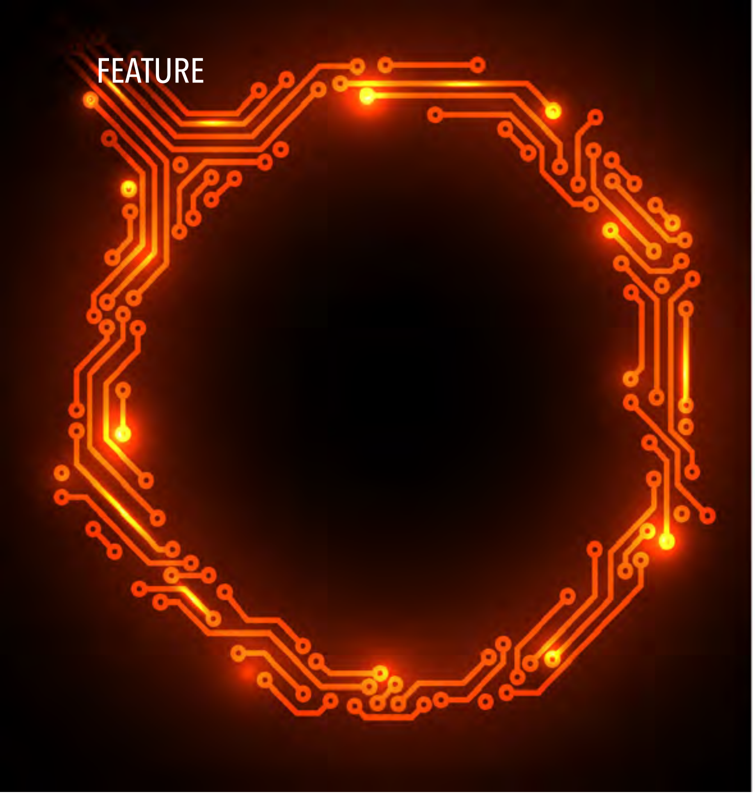
Malware, the collective name for viruses, Trojan horses and other malicious software, has been all over the news lately. Over the years, malware has evolved; it can affect smartphones and tablets as well as all computers. No matter what you hear from the fake news outlets, no computer, no brand, and no type is 100% safe. Malware on a computer is as old as the first computers. In fact, the first computer virus was called Elk Cloner and was found on an early Apple Mac in 1982.

Back in the day, a few years after I first started using a personal computer (an Apple II+ in 1979-80), the first virus strains were spread by infection obtained through inserting a contaminated floppy disk into your computer. Viruses spread globally but this took many months, sometimes years. Now we have the Internet and a zillion more PC users, and the incentive for those who produce malware is no longer mischief or experimentation. There is now a large financial incentive as seen with the explosion of the latest ransomware, the WannaCry malware.

I will cover malware in more depth overall in articles over the next few months, but for now, let's focus on the two most widely and commonly seen contaminations, and the most dangerous and expensive to eradicate today—at least once you have been infected—and the browser lock-up junior version which can be frightening but which is much easier to fix.

I know that all of you do back-ups of your computer's data on a regular basis, right? Right?

Click here to read the entire column.



Thin Film NiP Embedded Resistors in Heater Applications

Manuel Herrera
OHMEGA TECHNOLOGIES, INC.

Summary

There has been a growing adoption of NiP thin film resistors as heater elements from a diverse group of users including those in the aerospace, defense, high-end computing and the volume consumer electronics market. This has included interest and use from those responsible for validation and reliability testing. A novel application has now grown from the validation and reliability testing perspective. Using embedded resistors as heaters to do high-temperature or burn-in testing eliminating the need for thermal chambers.

Introduction

The idea of using embedded resistors as heaters in PCBs is not new. In the past embedded resistors as heaters have been used to raise the temperature of critical components on PCBs to optimum operating levels. A couple of examples include the semi-active laser (SAL) board in guided munitions and an X-ray spectrometer board in the ESA Mars Beagle II Lander[1].

Another recent space application required the melting of plastic fasteners. The plastic fasteners were used to secure folded solar panels during launch then deploy when the unit was in orbit. An embedded heater solution was designed to conform to the physical space, power and reliability metrics specified and selected based on its performance.

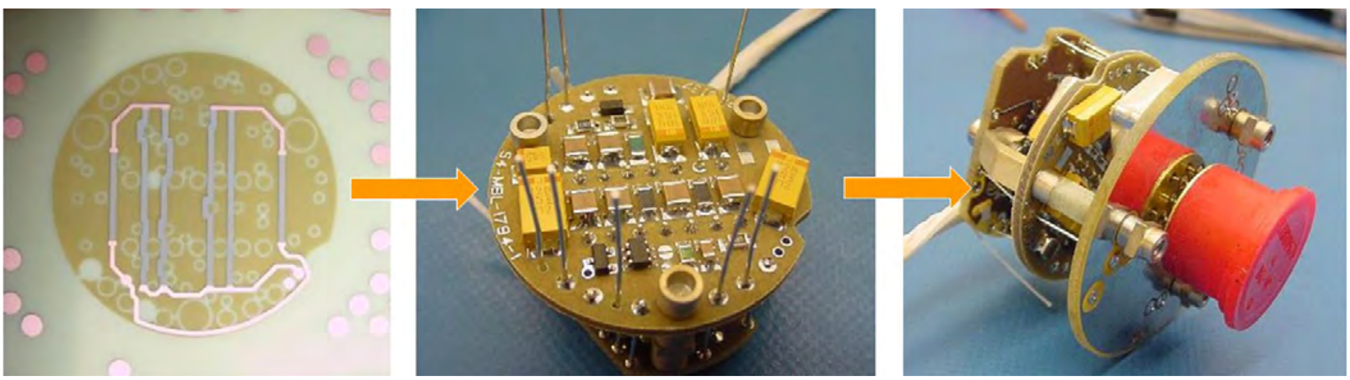


Figure 1: X-ray spectrometer board. (Image courtesy of the University of Leicester Space Research Centre and the Beagle2 Consortium.)

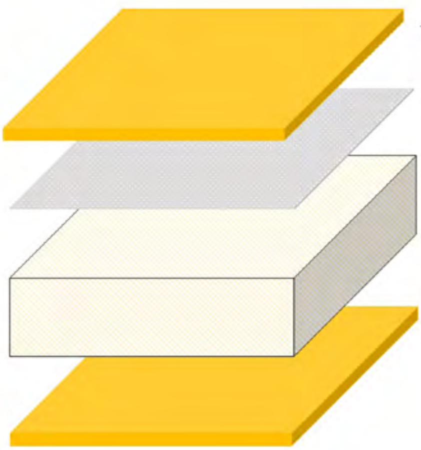


Figure 2: Illustration showing construction of resistive conductive material laminate.

Embedded Resistor/Heater Material

The thin film embedded resistor material is constructed by plating a thin layer of a nickel-phosphorous resistive alloy onto copper foil[1].

The resistive conductive material is subtractively processed (print/etch) to form the thin film embedded resistor elements that can be used as heaters. Using the resistive conductive material in a design does not require adding another layer to the circuit board as the formed resistors are typically added to an existing layer of a printed circuit board.

Designing Embedded Heaters in PCBs using Resistive Conductive Material

The first two bits of information needed to start the design of the heater are the power required and the area to heat. Once the required power and target area has been specified, the embedded heater can start to be designed.

The PCB substrate which acts as the conduit for the embedded heater needs to be considered. The main property is the substrate glass transition temperature commonly referred to as Tg. The surrounding substrate materials must be selected to handle the steady state operating temperature of the heater. If the heater needs to continuously operate at 200°C for example, the base material needs to be selected to handle this temperature. High Tg FR-4 materials are roughly rated to 170°C while polyimides and polyimide glass materials are roughly rated to 250°C[2]. Table 1 compares the Tg for a few different substrate materials. The PCB fabricator and laminators are a good resource for more information on the best dielectrics to use for a given application.

The next step to consider after suitable substrate material selection is the PCB stack-up. Locating the heater under the target on the surface of the board or on an innerlayer directly below ensures more of the heat energy is delivered and not lost in the surrounding materials. Inner or surface layers, substrate thicknesses, and copper planes/pours acting as heat sinks will have an impact on heater performance. For complex PCB stack-ups or heater systems with multiple material interfaces optimization may be best achieved using tools designed to model thermal dynamics.

The amount of power specified will determine the heater circuit size. The heaters need to be sized to one; handle the power required and two; fit in the space required. The NiP resistive

IPC Spec.	ReInforcement	Resin System	ID Ref.	Tg °C min.	Dk @ 1MHz
IPC-4101B/21	Woven E-Glass	Difunctional Epoxy (1) Multifunctional Epoxy (2), Flame Resistant	NEMA FR4, UL/ANSI FR-4/21, MIL-S-13949/04 GF/GFN/GFK/GFP/GFM	110°	5.4
IPC-4101B/24	Woven E-Glass	Epoxy (1), Multifunctional Epoxy (2), Flame Resistant	NEMA FR4, UL/ANSI FR-4/24, MIL-S-13949/04 GF/GFG/GFN	150°	5.4
IPC-4101B/26	Woven E-Glass	Epoxy (1), Multifunctional Epoxy (2), Flame Resistant	NEMA FR4, UL/ANSI FR-4/26, MIL-S-13949/04 GF/GFT	170°	5.4
IPC-4101B/40	Woven E-Glass	Polyimide	UL/ANSI GPY, MIL-S-13949/10 GI/GIN/GIJ/GIP/GIL	200°	5.4
IPC-4101B/41	Woven E-Glass	Polyimide	UL/ANSI GPY, MIL-S-13949/10 GIL/GIP	250°	5.4
IPC-4101B/42	Woven E-Glass	Polyimide (1), Epoxy (2),	UL/ANSI GPY, MIL-S-13949/10 GIJ	200°	5.4

(1) Resin System Primary, (2) Resin System Secondary, (3) Resin System Secondary 2

Table 1: Comparison table showing Tg for various substrates, excerpted from IPC-4101B reference chart[2].

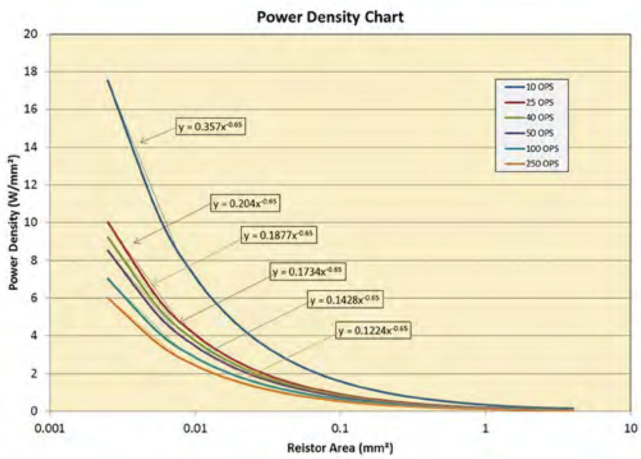


Figure 3: Power density plot for NiP resistive conductive material.

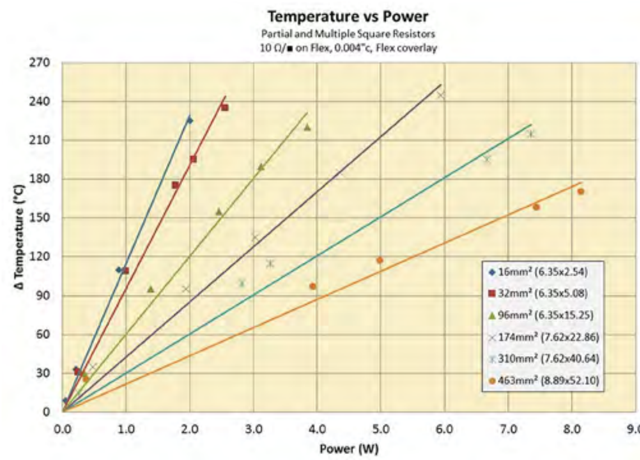


Figure 4: Temperature versus power for different size resistors/heater using 10 ohms per square.

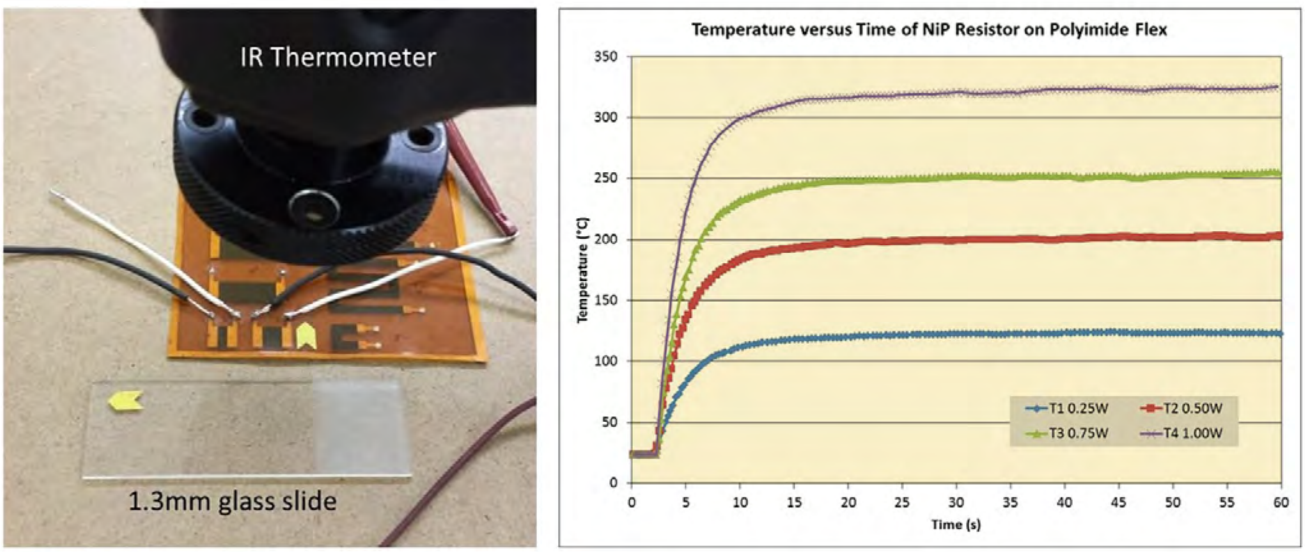


Figure 5: Temperature rise versus time for NiP resistor on polyimide flex substrate.

conductive material comes in various sheet resistivities. The sheet resistivities range from 10 ohms per square to 250 ohms per square[3]. Each sheet resistivity has an associated power density rating which is a rating of safe power per unit area. The chart below details typical power density data for the nickel phosphorus (NiP) resistive conductive material.

Figure 3 shows that lower sheet resistivities can operate at higher power densities. It is recommended to select sheet resistivities with the highest power density. Figure 4 illustrates how the resistor/heater size and power effect the temperature rise. The takeaway from the chart is that smaller areas get hotter for any given power. Notice also the linear relationship between temperature and power.

Figure 5 shows a test conducted to measure temperature rise versus time for a NiP resistor fabricated on polyimide flex material.

Let's take an example. Suppose 1 W is needed to heat a piece of silicon 12.7 mm by 12.7 mm (0.5 inch x 0.5 inch) with a thickness of 1 mm to 150°C in less than 60 seconds. The application has a fixed voltage source of 3.3V. Using the equations for power and Ohm's law, it is determined the heater needs to have a resistance of roughly 10 ohms. This can easily be designed using a resistive conductive material with a sheet resistivity of 10 ohms per square. The result would be a single square resistor 12.7 mm x 12.7 mm in size. As a comparison, to achieve the same temperature rise/power using a 0.254 mm (10 mil) wide trace of half-ounce copper would require a length of 2500 mm. Using an equal trace/space width would only allow approximately a quarter of the required length to fit in the target area.

Long Term Operation at High Temperature

A test was performed to measure the long-term effect of operating a thin film resistor in

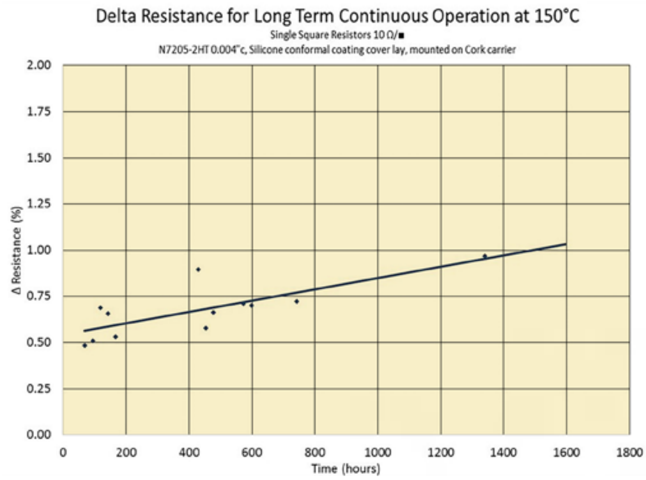


Figure 6: Long-term high-temperature resistor/heater operation.

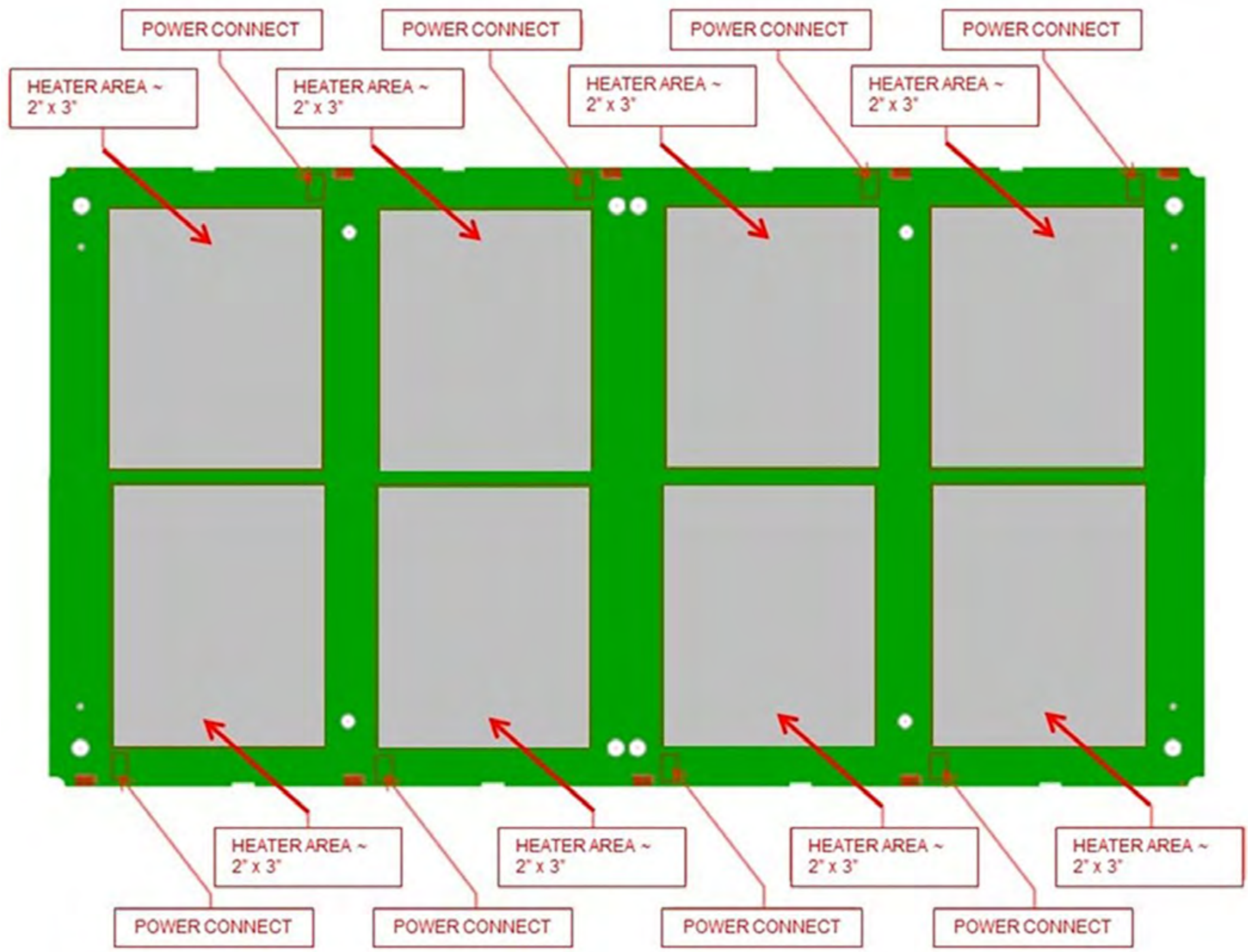


Figure 7: Example of a burn-in board.

a high temperature heater mode. The resistor was powered to reach a steady state temperature of 150°C and periodically measured over a period of 1200 hours to monitor any change in resistance. The change in resistance after the test period was less than 1%. The stability over long term operation validates the use in burn-in applications that require prolonged periods of stress on device under test.

Figure 7 shows an example of a burn-in board application. This example placed the heaters in an inner layer under the areas shaded in gray. Burn-in boards generally have the added benefit of a more flexible power budget as opposed to battery operated applications. Although, the heater areas in both portable and bench type applications will be primarily driven by the size of the device to heat.

Conclusion

Thin-film NiP resistors in heater applications are growing in popularity as they find new ways to provide solutions to the design engineer. These heaters can reliably produce temperature deltas of 30°C to 200°C+. There are many factors that will contribute to a successful heater design. In complex systems with multiple material interfaces it is recommended to employ simulation tools. For less complex systems, ballpark power estimates for desired temperature rises will work. **PCB**

References

1. Mahler, Bruce, "New Applications for Embedded Thin Film Heaters." Paper presented at BiTS Workshop, March 2017.

2. IPC-4101B "Specification for Base Materials for Rigid and Mulitlayer Printed Boards," IPC-4101B Reference Chart.

3. Brandler, Daniel, "The Performance of Embedded Resistors by Alloy Type and Film Thickness," *The PCB Magazine,* November 2011.

Manuel Herrera is the design and test engineer at Ohmega Technologies Inc., in Culver City, California.

Schweizer Presents Innovation at PCIM 2017

The Schweizer p² Pack allowing to embed power electronics semiconductors into the PCB is a preferred solution for future high current motor drives. This embedding technology saves valuable installation space and offers further system advantages such as: improved conduction losses (RDSon) of the power electronics, improved thermal resistance and thermal impedance (RTH und ZTH), a low-inductive design, improved switching characteristics, improved electromagnetic compatibility (EMC) and higher reliability.

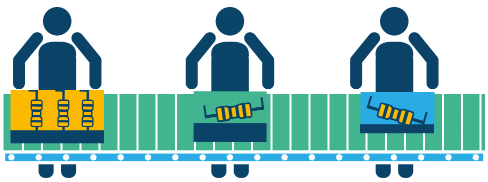
Schweizer Electronic AG now takes the next integration step by embedding shunts in combination with a half bridge for the first time, so the components 'thermal dissipation is optimised and further installation space can be saved, a considerable technical advantage in today's trend towards miniaturisation. First demonstrators of this innovation will be shown at the Schweizer booth (Hall 7, booth 240) on occasion of PCIM, taking place in Nuremberg from May 16–18, 2017.

Many power electronics applications (e.g., motors) use shunts for current measurement. A shunt is a low-resistance precision resistor that is applied for measuring electric currents. The current passing the shunt triggers a proportional voltage drop, which is then measured. Shunts so far have usually been mounted on the PCB. Consequently, the resulting heat has to be conducted through the substrate PCB first before reaching the cooling system.

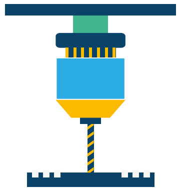
Technical details for embedded shunts Resistance values 0.05 up to 0.1 mΩ Currents: 0 – 300 A Voltage drop: 0.5 – 30 mV Dissipation: 4.5 – 9 W Temperature rise: 3 – 5 K Contact resistance: <1% of precision resistor.

IPC VALIDATION SERVICES STANDARDS GAP ANALYSIS (SGA)

- A Factory Driven Solution
  - Evaluate the Whole Manufacturing Process
  - Evaluate Areas of Concern



- How Well Do Your Processes Meet IPC Standards



- How Well Do Your Suppliers Meet IPC Standards

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Learn more about IPC Standards Gap Analysis (SGA) by contacting Randy Cherry, at RandyCherry@ipc.org or www.ipc.org/validation

Supply Lines
Highlights

Let's Talk Testing: You're in for a (Thermal) Shock!
Printed circuit board history stretches back to the early 1900s, with real promise shown in the industry after World War II. Through the 1940s, 1950s, and 1960s, PCB construction really started to progress.

Rogers Introduces Kappa 438 Thermoset Laminates
Rogers Corporation is pleased to introduce Kappa 438 laminates. These glass-reinforced thermoset laminates were developed for wireless circuit designers looking for a better performing and more reliable alternative to FR-4 laminates.

Copper Foil Maker Co-Tech Positive About 2017 Outlook
Co-Tech Copper Foil has expressed optimism about its performance during 2017 citing robust copper foil demand.

SAE Circuits Express Installs New NTO Lead Free Hot Air Level Machine
SAE Circuits Express has installed a new NTO 2424-LF lead-free hot-air solder leveling machine.

Orbotech Presents mSAP-Enabling PCB Production Solutions for Advanced HDI at CTEX 2017
Orbotech Ltd. is demonstrating a selection of its newest, most innovative, mass-production PCB manufacturing solutions at CTEX 2017, May 17–19 in Suzhou, China.

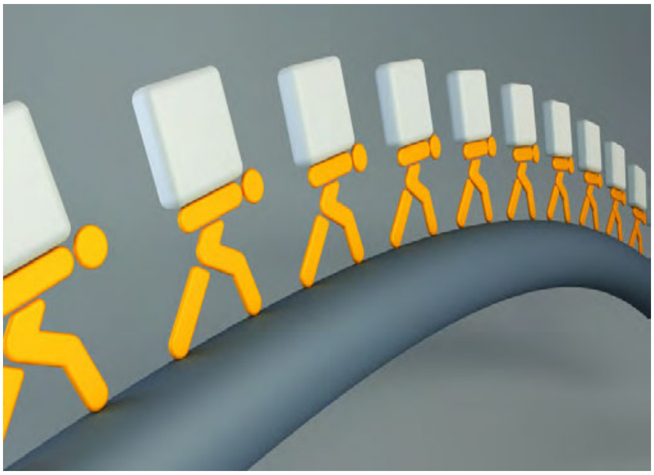
MacDermid Enthone Welcomes Four Industry Experts
MacDermid Enthone Electronics Solutions, a MacDermid Performance Solutions business, has appointed four PCB experts to their North America Sales and Service team.

Trouble in Your Tank: The Desmear Defect Guide
Inadequate or excessive desmear will lead to several PTH defects and failures. Resin smear, ineffective texturing of the resin, and even overly aggressive desmear will contribute to poor plating, adhesion failures and a myriad of other non-conforming defects.

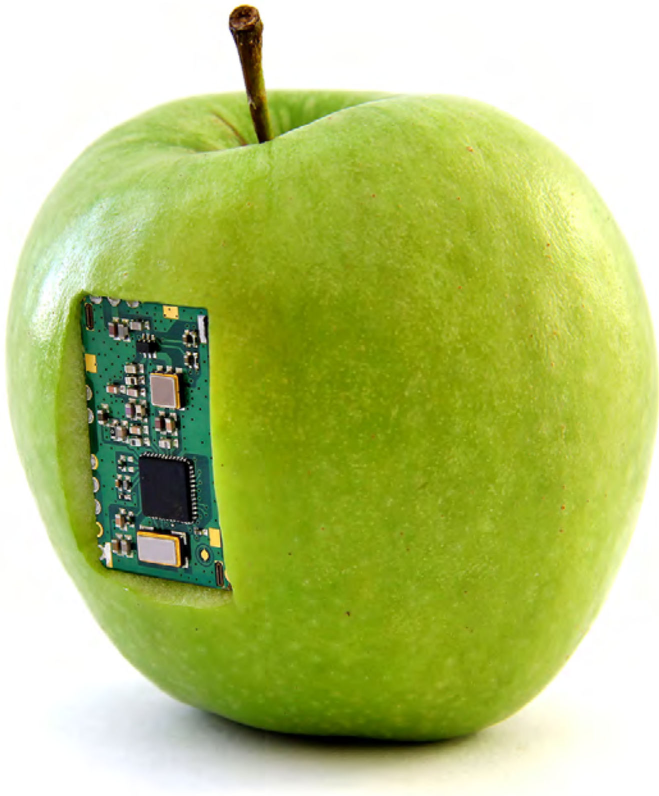
Insulectro Adds DuPont Pyralux Laminates to the Ready-to-Ship PumaFast Inventory Program
Insulectro, the largest distributor of materials for use in printed circuit boards and printed electronics, has just added popular constructions of DuPont's flexible laminates to its PumaFast stocking inventories.

Sierra Proto Express Installs atg S-Technology Flying Probe System for HDI Electrical Test
Sierra Proto Express has installed a new atg Luther & Maelzer GmbH S2-16DS, a 16-head, double-sided, high-speed, high-accuracy flying probe test system. The atg S2-16DS dual shuttle testers utilize 16 test heads, multiple optical recognition systems, and a wide variety of advanced, high-speed electrical test measurement techniques to electrically test all types of PCBs for continuity and isolation.

Ventec International Appoints Kyle Pattie as Account Manager, Eastern USA
Ventec International Group has appointed Kyle Pattie account manager for the U.S. Eastern region, selling and supporting all product lines to help the company further develop its presence in the region.



Embedding Active and Passive Components in Organic PCBs for More Reliability and Miniaturization



by Thomas Hofmann
HOFMANN LEITERPLATTEN GMBH

Abstract

Hofmann Leiterplatten GmbH has developed a wide range of products during in 25 years. New manufacturing know-how has been developed in fabricating organic PCB with embedded devices. A special name "AML®" (Active Multi Layer)[1] was created to differentiate the surface mount devices (SMD) and the device embedded technology (DET) PCBs. Manufacturing processes that are not typical for standard PCB fabrication shops has been developed.

The paper explains typical applications where PCBs with embedded devices are used today. In addition, products with improved reliability will be shown and what are the benefits for the industry and the end user.

The last section in the paper will focus on future trends and the option for systems in PCBs (SiPCB®)[2]. This enabling technology will open advanced production possibilities for improved reliability of high power electronics and harsh environment technology solutions. The paper will share specific knowledge applied in the production of products with embedded devices in PCBs more than 20 years. Important patents in Europe have expired. This will open a great opportunity for device embedded technology in PCBs as an excellent future potential for designers, PCB fabricators, EMS companies and OEMs.

Introduction

Thomas Hofmann founded Hofmann Leiterplatten GmbH in 1989. The objective was to provide special technology solutions based on printed circuit board technology to the electronics industry in Regensburg in Germany. During this time, many OEMs in Europe closed their in-house PCB fabrication sites to streamline the electronic equipment fabrication process. PCBs became commodities like standard passive and active components. The goal of the newly formed PCB factory started by Thomas Hofmann was to create innovative fabrication support for electronic designers and development engineers for large OEMs and EMS companies like Siemens, Osram, Infineon and many others in the Regensburg area.

PCB fabrication technology was selected because this includes the widest range of fabrication technologies. Here are some examples of

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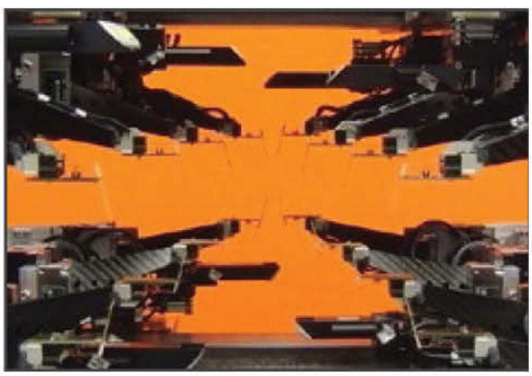
Introducing the atg A8-16a with 16 test probes at an unrivaled test speed of up to 250 measurements per second and full “lights out” Automation.



Test area:	610 mm x 620 mm (24.0” x 24.4”)
Number of test heads:	16 (8 top + 8 bottom side)
Smallest pad / pitch :	35 μm (1.4 mil) / 80 μm (3.2mil)
Test voltage:	Up to 1000V
Max. measurements / minute:	Up to 15000 measurements /min. *
Loading capacity:	390 mm , max. 80 kg weight
Max board weight:	20 lbs
Marking option:	Barcode label

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typical processes: mechanical drilling, mechanical and chemical milling, routing, photoimaging, screen printing, electroless and electroplating of different metals, and etching. These are considered as the enabling steps to produce a wide range of products. As a result, many innovative solutions are offered for various industries such as automotive and industrial electronics, lighting technology, measurement and medical technology, as well as the home automation sector.

The following typical products are manufactured:

- Conventional printed circuit boards (PCBs)
- Active Multi Layer (AML)
- Active and passive front plates
- Printed board assemblies
- Metal core substrates (MCPCB or IMS)
- Printed circuit boards with embedded components
- Mechanical components and mechatronics
- Conventional front panel applications, front panels with integrated components (intelligent front panel)

The Trend in Device Embedding Technology

Embedding of passive components has been used in ceramic hybrid circuits since this technology was introduced in the beginning of the 1970s. Polymer thick film paste was used. Ohmega-Ply® a resistor foil was available for PCBs as well. However, in mass production, only hybrid circuits are used. From the material point of view, this is an expensive technology selection. In cases where it is needed for reliability reasons, the higher cost has been justified. In mass production, the industry is looking for a more cost-effective solution based on organic PCB technology. Here the PCB fabrication technology has a clear advantage. Large panel production and standard multilayer processes offer an outstanding technology basis for embedding active and or passive components in the organic FR-4 material.

Figure 1: View of the factory—28 years of quality made in Regensburg.

As technology has evolved, smaller components made it easier to embed active and or passive components inside of PCBs by using the standards soldering or other component attachment technologies like gluing, sintering or plating.

In 2011, the integration of embedded connector was evaluated by Hofmann Leiterplatten in Germany and introduced in the standard production of the latest design for device embedded technology. Examples are shown in Figures 16, 18 and 19.

The Process for Fabricating Device Embedding Technology PCBs

The surface mount device technology was an enabling way to place SMD parts on the surface of FR-4 CCL material on solder land layer of the PCB. This was then the important step to take the surface mount components to the inside of printed circuit boards (Figure 3, Step 1).

For this process, a thin core CCL (0.36 mm) is used for mechanical stiffness during component placement. Thinner FR-4.0 and FR-4.1 laminate can be used. In our company, we have experience with both brominated flame retardant that is used in FR-4.0 and the different flame retardant that are used in FR-4.1. We have gained experience with the resin flow, press condition and curing behavior of the important resin systems used in FR-4.0 and FR-4.1 CCL.

By placing the components inside the PCB, the electronic components and the conductors are better protected against mechanical damage, shock, dust impact and the influence of humidity and of any liquids like water, cleaning agents, solvents, oil and others liquids that could dam-

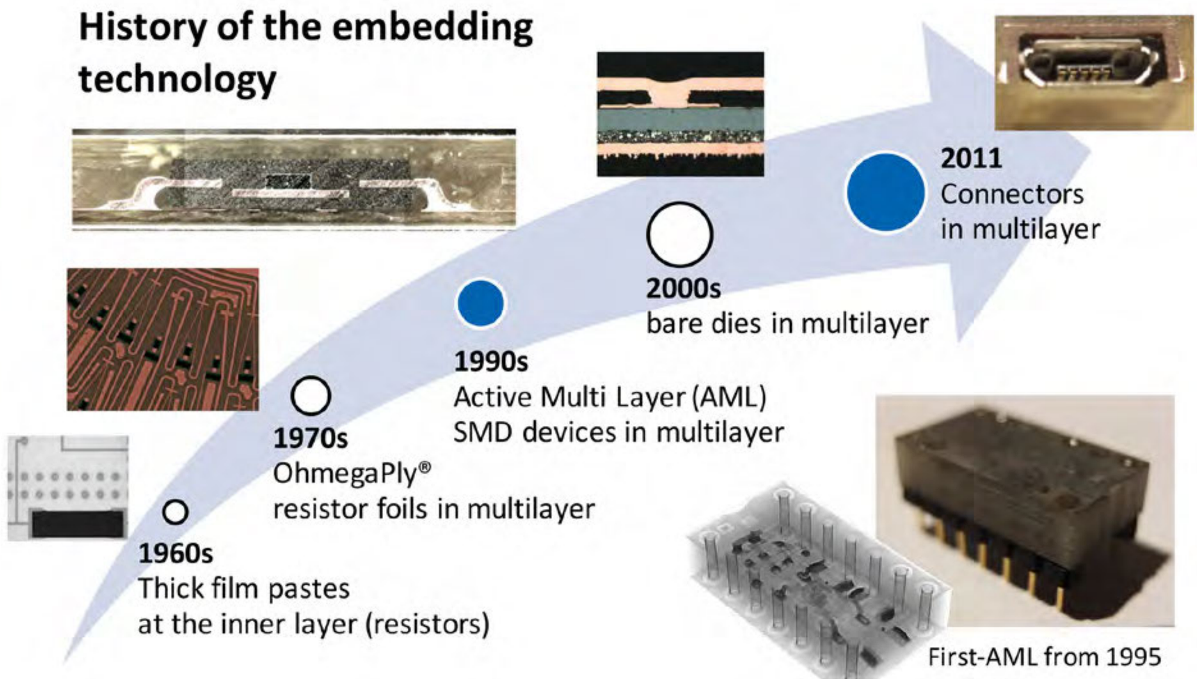

Figure 2: A typical roadmap for embedded devices used by Hofmann Leiterplatten.

age components or would result in conductive surface contamination between the conductor and the solder lands. In addition, compared to air, the epoxy glass-reinforced CCL has a more than 10x better heat dissipation. This allows the components to operate at lower temperatures.

Important Note

To achieve these benefits, an excellent co-operation between the printed circuit board fabricators, the electrical designer, the PC board layout engineer, the laminate fabricators and the component suppliers, as well as the assembly specialist and test engineers is mandatory to achieve high first-pass yield. In addition, it is required to manage the supply chain and to get new components and known good bare dies. The total information sharing from design rules and expected innovative results may impact the total supply chain and will influence the miniaturization potential and the yield and reliability of the electronic devices with embedded device technology. To achieve these goals to our and the end user´s satisfaction, it was required to establish our in-house assembly department with the capability of handling thin core PCBs and

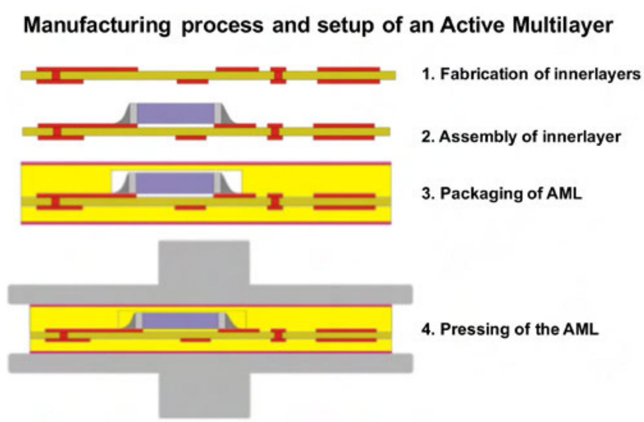

Figure 3: The fabrication process for embedding devices in PCBs, Part 1.

very small devices during the total fabrication process.

Application Examples

Thermal management heat dissipation

In-house test at Hofmann Leiterplatten factory has shown that the temperature at of MOSFET components assembled on the outside sur-

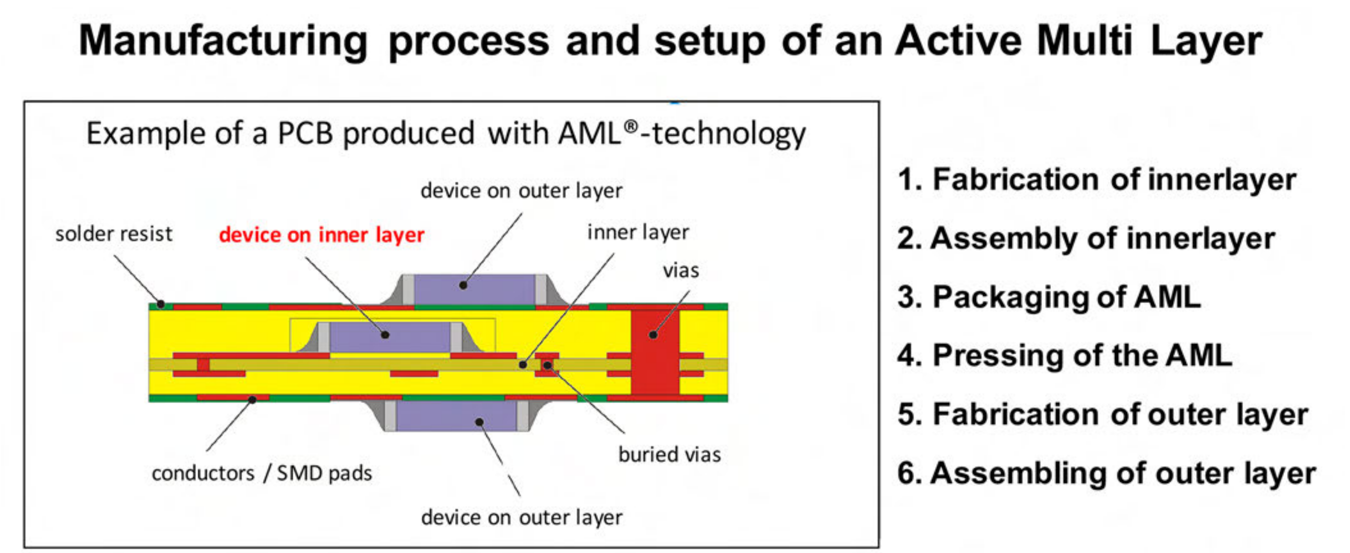

Figure 4: The fabrication process for embedding devices in PCBs, Part 2.

face in standard technology on the surface of the PCB measured 188.5°C at the component hot spot. By placing the same MOSFET type components inside of the PCB construction, the temperature was reduced by 106°C to an operating temperature of 82.5°C. The thermal heat from the component was distributed over the total area of the PCB. For an electronic engineer, this could impact the total layout of a PCB and it could also help in miniaturisation of electronic devices and equipment. Cost reduction could also be achieved if no external cooling is needed. The photographs and the temperature measurements were taken by a thermal camera. The impact on heat conductivity factor of the epoxy resin (0.35 W(m.k) and the glass fibre (1.05 W(m.k) in the PCB material provides a more than 10x improved thermal conductivity compared to air (0.024 W(m.k).

Resistance to water and other liquids

In Figure 6 an example is shown that demonstrates LEDs embedded in a CCL material used in fabrication of PCBs. These materials are resistant to many liquids. These strips are connected to power and have been lighting partially in water partially in air since more than five years. In some applications, this CCL with embedded devices is used in hot oil and other hot liquids. Embedded electronic devices in CCL are also used in gearboxes to manage the electrical functionality at the gearbox temperature. The exposure to hot gearbox oil is of no issue for the device embedded technology PCBs.

These sensor modules (Figure 7) are placed in small areas. They must be cost-effective in manufacturing. Embedding components is an outstanding way to miniaturise surface area of the unit through an effective design for manufacturing. Small unit designs manufactured using large panel processes offer an opportunity to lower manufacturing cost. At the same time, high product reliability is achieved as all electronic components have excellent protection against humidity, oil, shock, temperature and EMC impact by other uncontrolled radiation and frequencies.

Manufacturing PCBs with Embedded Devices

Over the last 20 years, many tests have been conducted. This was needed to define reasonable design rules that will enable the use of standard packaged components as well as to allow sufficient epoxy resin for a reliable bond strength during the press cycle. In addition, air entrapments or voids must be avoided. This could have an impact on signal speed and insulation characteristics of the dielectric material.

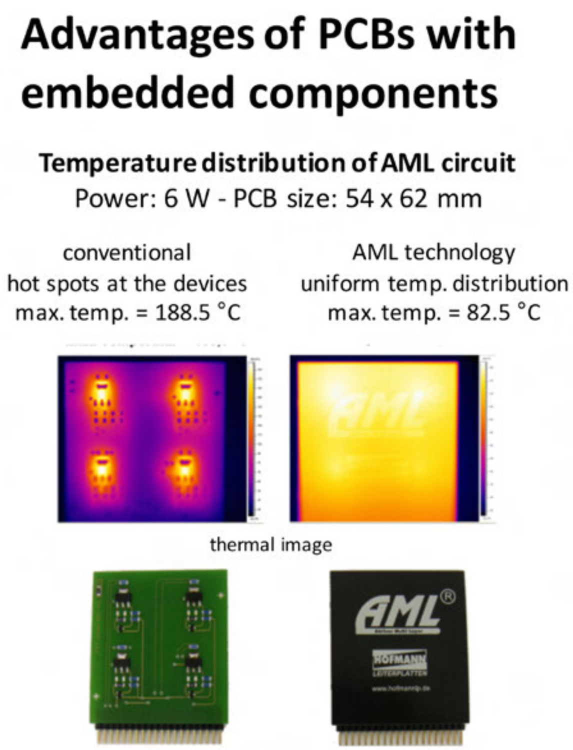

Figure 5: Heat dissipation improvement using device embedded technology.

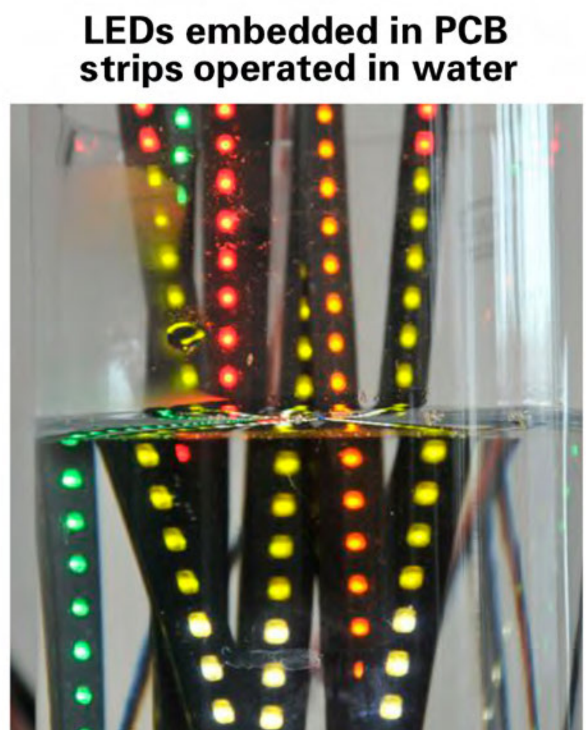

Figure 6: Device embedded components are resistant to any liquids that are resistant to standard PCB CCL based on epoxy resin.

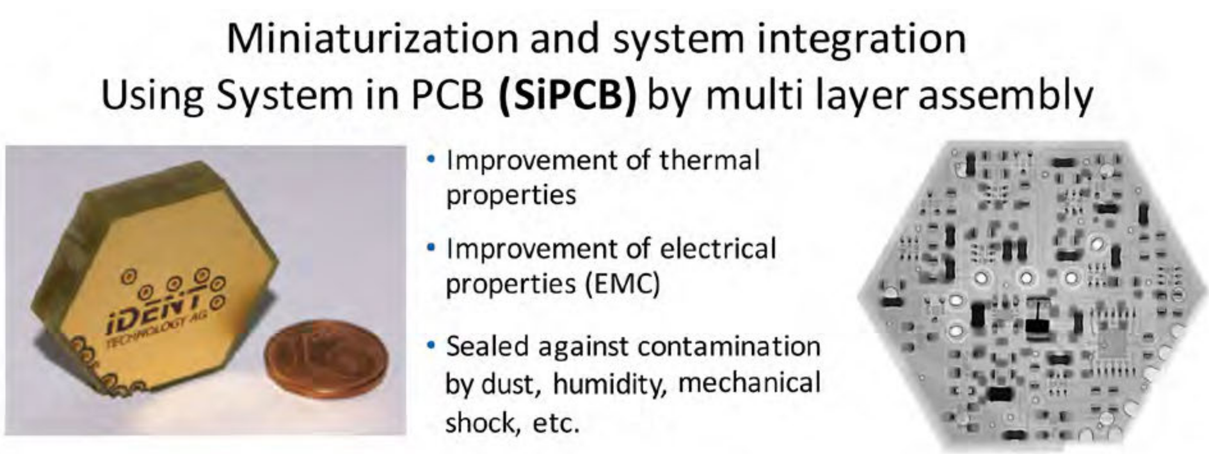

Figure 7: A sensor PCB with two layers of embedded components.

Holes and vias

In the case of an AML PCB, it should be noted that no through-holes or vias are placed in the areas of the components. For vias or holes, a distance of at least 0.5 mm from the periphery of the drilling to the SMD land of the adjacent component should be maintained.

Distance from components and package density

When designing the layout, please note that the component areas, the surfaces intended for the inner layer assembly, occupy only a maximum of 40% of the circuit board area. The component area is defined by the component,

Recommended design rules!

- Devices suitable for embedding technology
- Distance between vias and devices
- Distance between the components
- Package density (component area on maximum 40 % of the innerlayer)
- Thickness of the PCB

label	distance between	space
A	PCB edge to component	> 1 mm
B	component (pad to pad)	> 1 mm
C	single components	> 1 mm
D	component group	> 2 mm
E	SMD pad and drill / via	> 0.5 mm

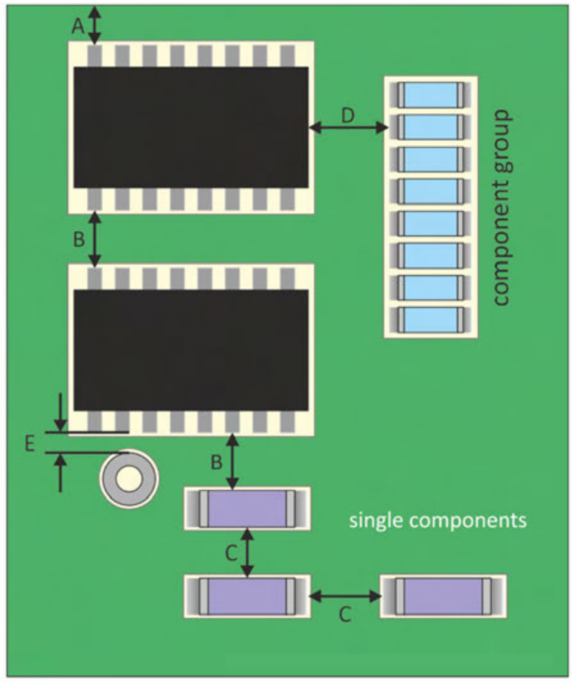

Figure 8: Design guidelines are important for success.

including the land for the solder joints. A uniform distribution of these areas across the circuit board area is advantageous when embedding devices.

Circuit board thickness

The final thickness of the printed circuit board results essentially from the thickness of the embedded components. The maximum component height is decisive.

The design for manufacturing (DFM) strategy is key for the success of the device embedding technology. When this technology was started, design software did not exist. Today, many of the large CAD companies offer support. However, not many PCB fabricators have the experience to support the PCB fabrication for an effective design for manufacturing. Cooperation with the customer at the earliest possible time is needed to establish the foundation for a successful partnership and for a functional and innovative product. It is also the basis for cost-effective planning for a long-term strategy in the case that the product shall be in mass production and shall be used in a global marketplace.

The device embedding technology is driven by the cost-performance relationship. However, the components define the functionality performance characteristics of the product. Also, the availability of these devices will be key for the development of the technology of device embedding PCBs.

As indicated in Figure 9, there are some limiting factors that are driven by the components, the manufacturing process and/or the use of the materials that are not suitable for an effective device embedding fabrication process.

New options must be considered. Here, metal core PCBs (MC-PCB) with standard epoxy resins may be used. This could replace the need for thermal vias and/or expensive highly thermally conductive materials in conjunction with standards surface mount attachment technology PCBs.

With the new option of MC-PCBs, relatively inexpensive constructions can be realised. This is possible by using a highly thermally conductive dielectric layer between the aluminium support and the conductor/components layers. From our experience, this build-up construction has proven excellent heat dissipation capabili-

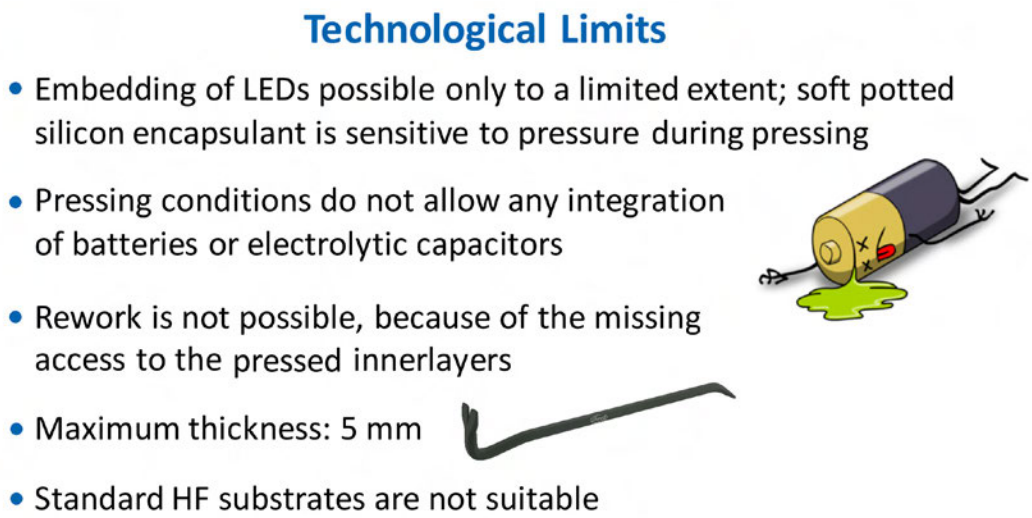

Figure 9: Present technology limitations of the AML technology.

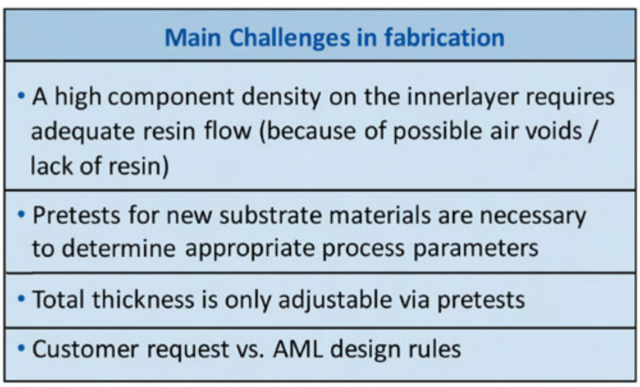

Figure 10: Primary AML fabrication challenges.

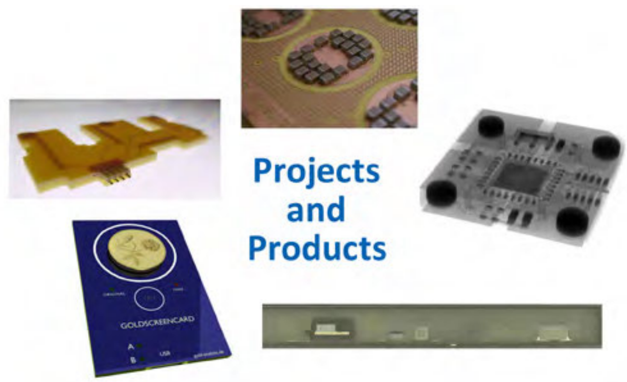

Figure 11: Products using the device embedding fabrication technology by Hofmann Leiterplatten GmbH.

ties for a cost-effective PCB used in conjunction with electronic components with high power application.

Each component has its own geometrical shape and dimension, each resin has its own flow characteristic and each multilayer press and press cycle has its own press profile and heat dissipation. Therefore, it is necessary to understand the epoxy resin flow properties and the capability to encapsulate the components with a homogeneous epoxy embedding resin.

Projects Utilizing the AML Device Embedding Technology

Some products that have been manufactured are not under any non-disclosure agreement (NDA). Most of the present new developments are under NDAs with our key customers. As our company is focusing on new technology based on PCB fabrication technology, we must get involved in many new projects at a very early stage of the product development process. Confidentiality is a key element in joint product development for the success of our customers and our company.

In the beginning, we very much depended on a friendly EMS fabricator to assemble our components to the thin core CCL innerlayers. When components were large, this was still an option. However, when components became smaller and delivery times for development projects were under a tight time frame, we installed our own component assembly capability, as well as soldering and test know-how, in our factory in Regensburg. This enables our product development team to get involved in advanced products with unique product performance, product features and application at reasonable cost. Also, the time to market enabled our team to become a valuable resource for our European customers.

In addition, the in-house manufacturing capabilities enabled us to participate in joint industry projects that are partially sponsored by funds provided by:

- Local authorities in Bavaria
- German government
- European Union funding from the EU commission in Brussels

Project Examples

The ZIM 3D microsystem[3] (Figure 12) was an innovative three-dimensional stack of individual sensor modules that are connected by magnets. This was a model for the electronics industry to create technology demonstration modules that enable development engineers to test different functions and application in new product development laboratories. This enables development engineers, for example, to test out interface options in new product developments without soldering components to a test board. For the highly-connected industry, this can be a helpful tool to shorten development time in automotive and industrial electronics.

In Figure 13, a new project for the automotive industry in Europe is shown. Within the framework of a BMBF collaborative project, research will focus on the areas of performance, cooling, miniaturization and reliability in automotive and lighting applications.

System integration technologies for highly integrated power logic modules use the example of drive and lighting technology—in the project "ProPower"[4].

The next generation of electro-mobility very much depends on cost-effective and high-reliability solutions that meet the very high performance criteria of the automotive industry.

In this context is important to understand that flammability and electrical safety are key factors that will be considered in the projects as well. Automotive electronics is not made for a national or a European market. These standards must be compliant with global safety specifi-

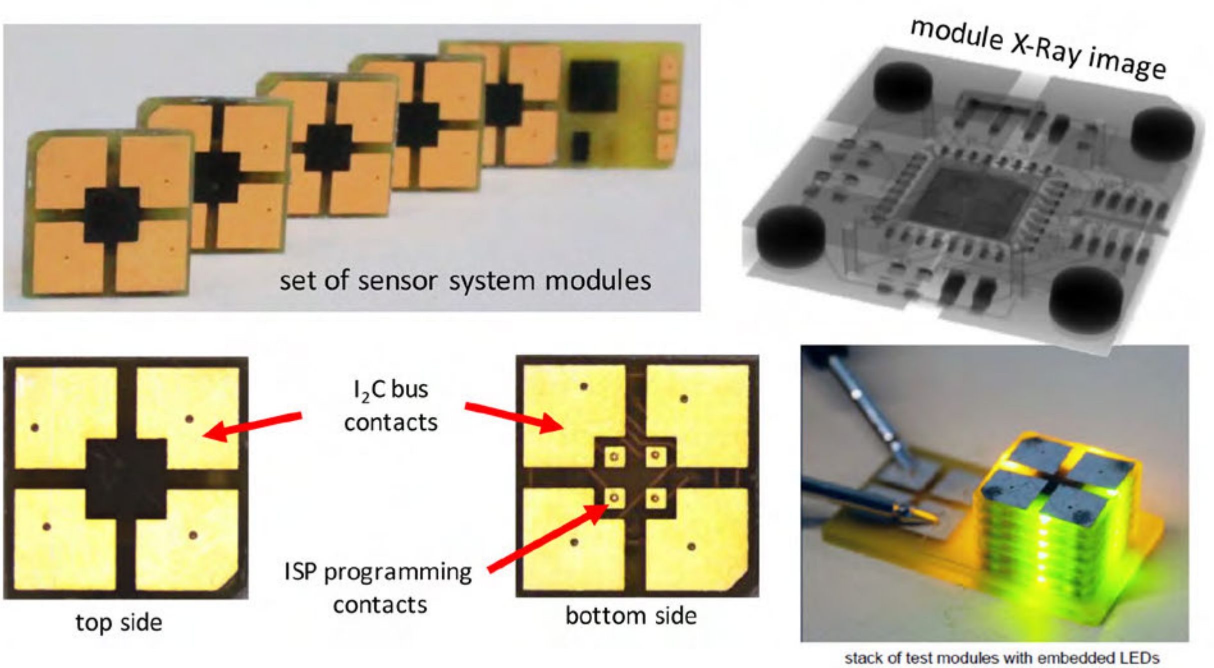

Figure 12: Demonstrator made for the ZIM3D microsystem project.

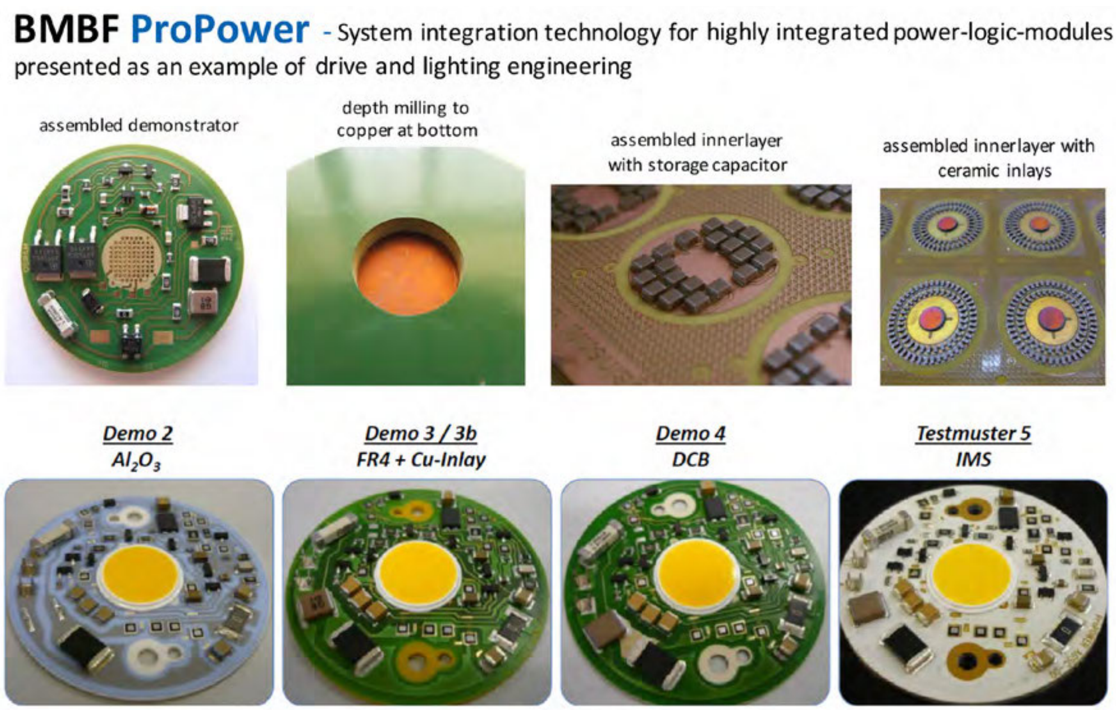

Figure 13: Advanced project for the automotive industry to meet technical, safety and cost-effective requirements.

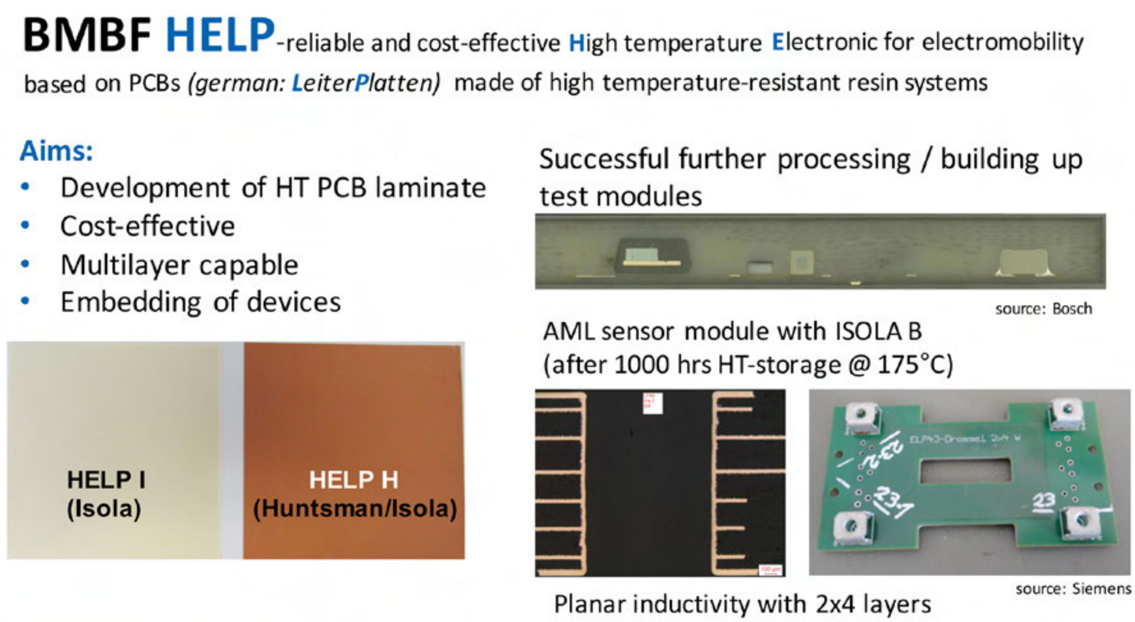

Figure 14: Project HELP[5] is defined to develop material selection tools for high temperature PCBs in E-mobility application.

cation and needs. Therefore, it is well understood that the safety aspect, as well as technical functionality and cost-effectiveness, are key for these projects.

In Figure 14, a framework of a BMBF collaborative project is in focus. Test methods for new materials and for different components are evaluated. Test samples will be made and new

test methods will be established, as this has to do with the way to manufacture cost-effective products that are operated at high temperatures. The important factor is that PCB material is the first selected based on facts. In addition, global safety standards must be fulfilled.

An additional BMBF PCB 4.0[6] (Figure 15) is targeted to the electronics that is needed for Industry 4.0. In this project, machines will talk to machines. The computer will take this input data and will analyse and store this information for future traceability. This is a requirement of the industry that must be fulfilled as the requirements and the implementation of Industry 4.0. The need for documentation and sharing of process data with the customers in the supply chain is the objective. This will be done with a new interfaces technology and sensor technics. This device must be reliable and highly flexible in terms of robustness against all kinds of environmental impacts like temperatures, vibration and mechanical shock, humidity, gases, solvents, light and others. The device embedding technology is an effective way of considering this to provide effective industry solutions. As the fabricators in Europe very much depend on innovation in conjunction with miniaturization, the BMBF 4.0 project is mandatory for future industry systems and robotics.

Product and Process Developments: Device Embedding and Application Technology

Embedding devices are mainly regarded as placing active and or passive components inside a PCB. However, processed digital or analogue signals will not stay forever inside the specific PCB. An interphase is needed to connect the data to the outside world. This can be wireless with Bluetooth, NFC or WLAN or other standard interphases like USB, Thunderbolt or any other connector-based technology.

Now there is a way to integrate the connector as a part of the technology of the embedded device that is used inside the PCB (Figure 16). The process is done simultaneously with embedding the other SMT devices.

In the racing car, weight saving and improved functionality are key elements for a high chance to be first in class. The device embedding technology, using the AML technology

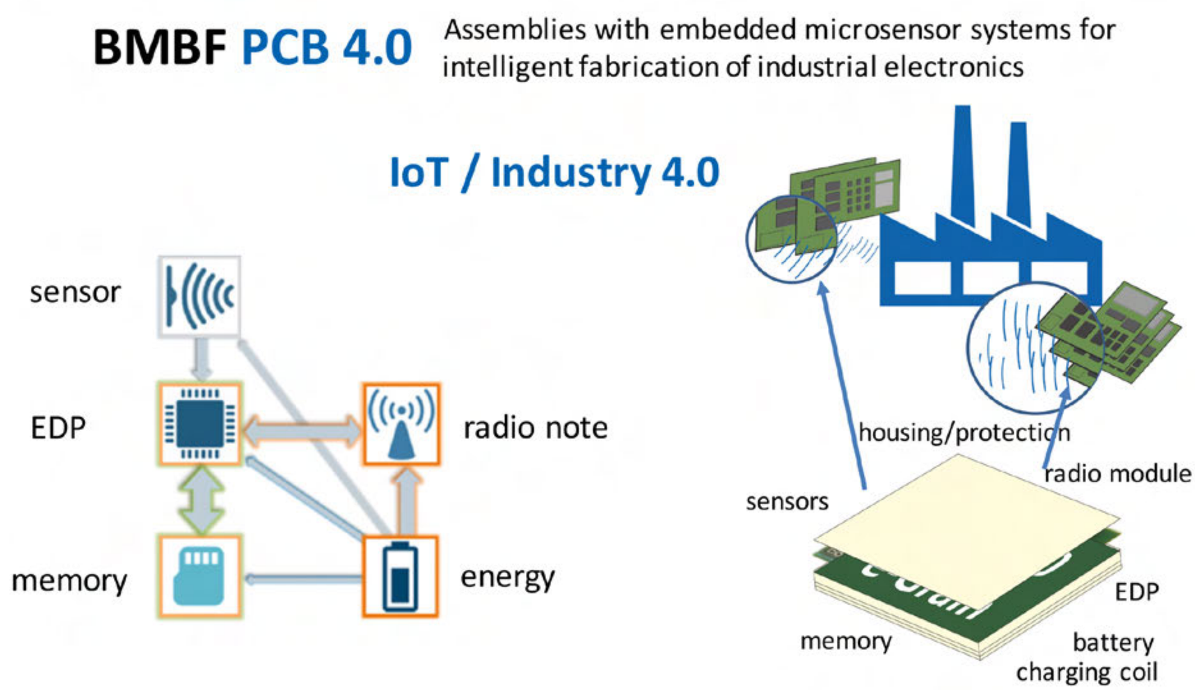

Figure 15: Sensor technology for Industry 4.0 using embedding technology to enable automatic data collection and sharing.

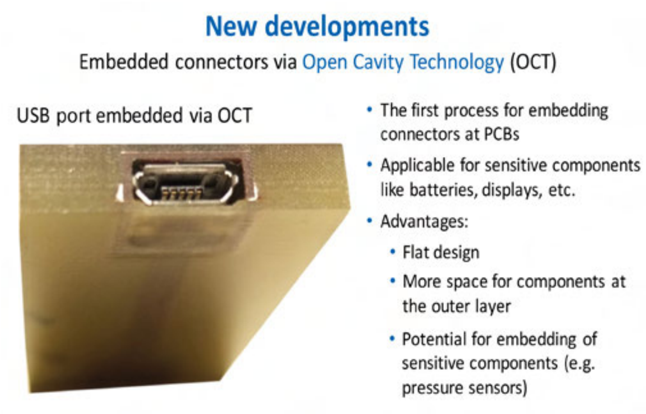

Figure 16: Integrated connector inside a PCB with embedded devices.

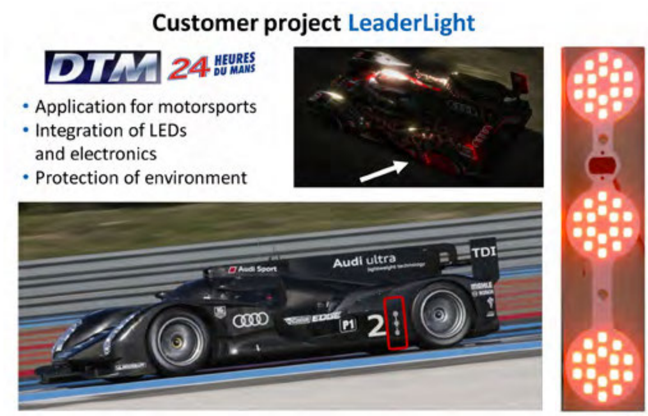

Figure 17: Embedded LEDs in racing cars reduce weight and improve functionality and safety.

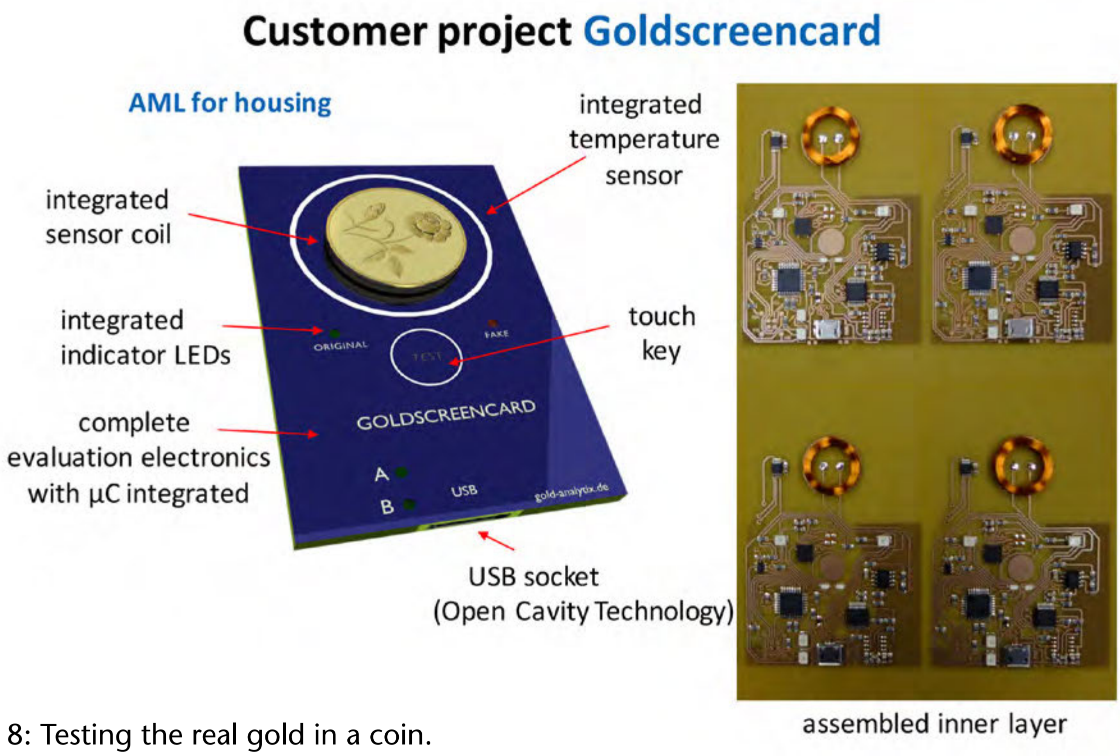

Figure 18: Testing the real gold in a coin.

processes, is used very successfully in this application. Opportunities for standard car application are under evaluation. As these are mainly cost-driven functions, time will tell when high-end cars will install embedded devices for more robustness and higher functionality.

Gold coins are one of the traditional methods to save money and to avoid devaluation of any currency. Gold coins are also traded when cash is needed. However, it is not easy to define whether the gold content is according to the book value of the coin. Many traditional test methods are taking the gold coins in water to define the volume. The volume of water and then multiplied with the specific gravity of gold. Although this is a traditional process, it takes time and experience of applying it.

A company in Germany has developed an electronic unit (Figure 18) to define the pure gold content of a coin. An inductive test meth-

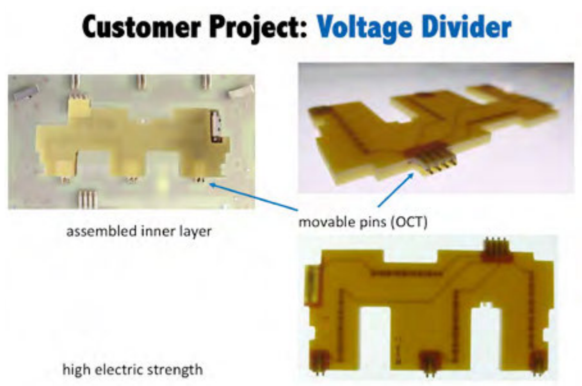

Figure 19: Voltage divider unit made by using embedded devices including spring-loaded connection devices.

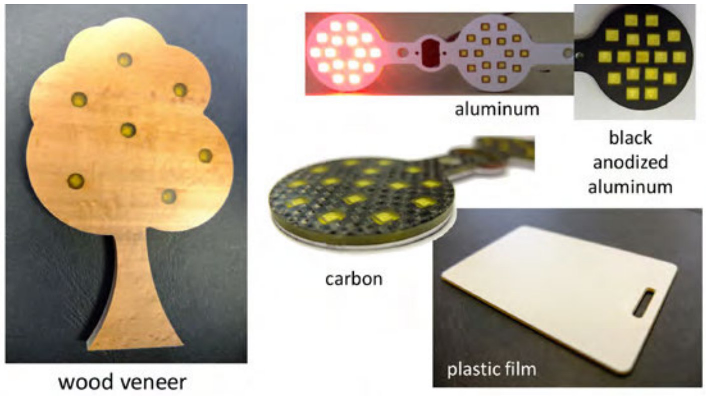

Figure 20: Decorative application with surfaces like wood, carbon, plastic film and black anodized aluminum.

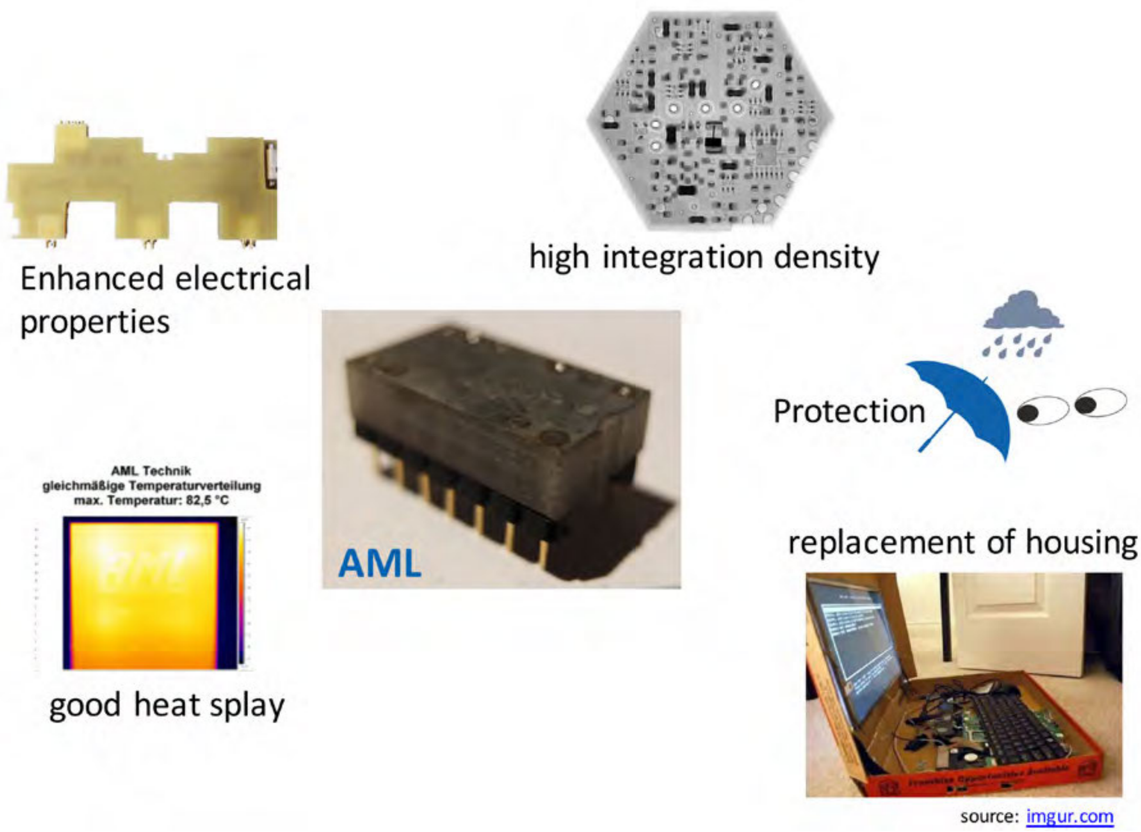

Figure 21: Opportunities for high value-added products used in the electronics industry.

od is used to define whether the coin is the type of gold it should have according to the books specification. This gold test unit is made completely by using the AML technology to embed devices. Interferences with the calibration of the device will result in destroying the unit. This enables to minimise the risk for counterfeit measurements and wrong product definition.

Dividing voltage in a power electronic switching station often requires rewiring and or very expensive switching systems. The use of predefined templates, with spring-loaded con-

nections, allows a fast way to change the way of dividing the flow of current (Figure 19).

Specific for this product is the approval by interactional electrical and safety standards for global utilisation of the product with embedded connectors and devices. Therefore, the approvals for high-voltage product application by the Underwriters Laboratories (UL) in the USA, were required. These also include the performance requirements in accordance with IEC regulation for high power application. The use of specific materials was needed to meet the safety standards of the customer, the industry segment. This was also certified by UL. High-voltage strength, normally not needed for standard PCBs, has been fulfilled by using this technical solution.

Electronic devices as part of a decorative solution is also a new need by product designers and marketing experts. Besides functionality, aesthetic solutions are required by the industry that is specialised in high added value products. This is needed to satisfy the demand of a specific individual clientele group. Electronic functionality inside of wooden plates, or a plastic or an alumina-based housing are additional requirements by a specific end user. The device embedding technology meets many of these specific requirements by the electronics industry the OEMs or even by the individual consumer.

Summary and Future Opportunities

Over the last 20+ years, we have seen a lot of benefits for the total supply chain and the end-user for electronic equipment with embedded devices. However, to fully benefit from the features of the embedding device technology, the supply chain needs to be restructured.

Key Items:

- Product designer must be involved at the concept stage of the new development
- PCB fabricators must be capable of manufacturing device embedded PCBs
- Assembly operation should be directly connected with the PCB fabricator; an in-house assembly facility is beneficial
- Solderless connection as attachment technologies shall be considered (e.g., gluing, plating or sintering)
- OEMs should understand the value of the miniaturization potential by using the device embedding technology in PCBs
- Consider the cost-reduction potential offered through miniaturization and encapsulation of all components in a material combination of epoxy resin reinforced by woven glass structures
- Avoiding special housings for the PCB with embedded devices opens additional potential for new cost-effective products
- Resistance to liquids and an excellent thermal dissipation offer new application in automotive, mining and other industrial environments fields

The device embedding technology in PCBs should not be regarded as a disruptive PCB technology. It is an evolution of existing PCB fabrication technologies combined with new design, fabrication, assembly and testing methods. **PCB**

References

1. German Trademark "AML" DE39607556 German Patent DE19627543[2] German Trade Mark "SiPCB" DE302013018045[3] ZIM R&D Project "3D Microsysteme" 2010–2012[4] BMBF R&D Project "ProPower" 2011–2014[5] BMBF R&D Project "HELP" 2011–2014[6] BMBF R&D Project "PCB 4.0" 2016–2019.
2. German Trademark "SiPCB" DE3020130-18045.
3. ZIM R&D Project "3D Microsysteme" 2010–2012.
4. BMBF R&D Project "ProPower" 2011–2014.
5. BMBF R&D Project "HELP" 2011–2014.
6. BMBF R&D Project "PCB 4.0" 2016–2019.

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Thomas Hofmann is president of Hofmann Leiterplatten GmbH.

Electronics Industry News
Market Highlights

Flexible, Organic and Biodegradable: Stanford Researchers Develop New Wave of Electronics

A new semiconductor developed by Stanford researchers is as flexible as skin and easily degradable. It could have diverse medical and environmental applications, without adding to the mounting pile of global electronic waste.

Floating Fields for Fine Fabrication

Magnetic levitation (Maglev) is well known for its use in high-speed rail networks, but could also be applied at smaller scales in medicine and electronics. To do so, researchers must be able to precisely control electromagnetic fields so that they can move and rotate objects without touching them.

The Importance of Lithium and Cobalt in Today's Energy Market

Lithium-ion batteries are an efficient source of energy for rechargeable storage devices, capable of expanding battery durability and leading to an increasing power source for consumer electronics, including hybrid and electric vehicles.

Global Smart Manufacturing Market: Players Need to Explore New Markets

The global market for smart manufacturing is characterized by the presence of numerous companies. This makes the landscape fragmented and highly competitive. The competition is being dictated by the demand for huge investments in infrastructure and development of technologies.

Global Collaborative Robot Market: Modest Price and Impressive Return on Investment Allure Demand

The global collaborative robot market has been anticipated to be characterized by a trend where larger companies could engage in the acquisition of smaller and local automation firms to enlarge their operative base.

Conductive Paper Could Enable Future Flexible Electronics

Researchers have made an ionic gel paper with long-term bendable electrical robustness. This process could be used for flexible electroluminescent devices such as roll-up computer screens and other flexible electronics. We are getting closer to reality as scientists improve upon a growing number of components that can bend and stretch.

Paper-Based Biosensor with Smartphone Readout

Researchers at the ICN2 Nanobioelectronics and Biosensors group led by ICREA Research Prof. Dr Arben Merkoçi have infused paper strips with graphene quantum dots and combined them with smartphone technology to develop an intuitive, portable and disposable biosensing system.

Demand for PCBs in Consumer Electronics to Drive Global SMT Equipment Market

Transparency Market Research estimates that the global surface mount technology equipment market was valued at US$4845.7 mn in 2016 and is anticipated to reach US$7075.8 mn by 2025, exhibiting a CAGR of 4.4% from 2017 to 2025.

Gartner Survey: 42% of CEOs Have Begun Digital Business Transformation

An unsettled global political environment has not shifted CEOs' focus on profits and growth in 2017. Growth is the first business priority for 58% of CEOs, according to a recent survey* of 388 CEOs by Gartner Inc.

3.4 Billion Smartphones Ready for Apple Pay, Samsung Pay and Android Pay by End of 2017

According to new analysis from IHS Markit, 3.4 billion smartphones will be ready for Apple Pay, Samsung Pay and Android Pay by the end of 2017, and the number is expected to increase to 5.3 billion by 2021.

A DEEP LOOK INTO EMBEDDED TECHNOLOGY

by Barry Matties and Patty Goldman
I-CONNECT007

In preparation for this month's magazine, we set up a conference call with the goal of uncovering the challenges and opportunities related to embedded technology. Invited were a handful of the industry's heavy hitters in the embedded world: Retired technologist and I-Connect007 Contributing Editor Happy Holden, and Ohmega's Technical Director Daniel Brandler and Design & Test Engineer Manuel Herrera. This informative, comprehensive discussion focuses on the state of embedded materials and components, today and into the future, as well as a variety of promising processes.

Patty Goldman: Gentlemen, thanks for joining us. Some of the things we want to learn are: What's going on? What's the latest? Additionally, what are some of the things that you think that your customers want to know?

Dan, Ohmega Technology has been doing embedded components for over 30 years. Can you provide an overview of that work?

Dan Brandler: Ohmega Technology primarily makes materials used in embedding resistors, planar resistors, even surface resistors under the solder mask, but mostly it's a multilayer structure. We electrically deposit a nickel-phosphorous alloy, which is the resistor material. It's been around since World War II, so it's a very well established material. We electrically deposit it on standard ED copper foil of different levels of roughness, which will be discussed later in the conversation, and we supply that material to either laminators for PCB or microwave applications or to board shops who make their own laminate and PCBs with the embedded resistors. In some cases, we subcontract laminates out to companies. But our primary business is just applying the resistive copper foil and we've been doing that for a long time. We're not the only ones doing it; there are other alloys out there like Nichrome, but we're the oldest.

About 30–40% of our business is aerospace defense, things like power dividers, microwave applications for satellites, phased array antennas, and microwave absorbers. That didn't used to be the case, but the majority now for commercial use is mainly for sensor technology, particularly in cell phones. I would guess almost all of you or at least certainly half of you I'm speaking to right now will probably have cellphones with you with our resistors in it. Our resistor material is in the largest American cellphone manufacturer's products. I'm not supposed to


PCB systems FORUM

use their name, but we're designing their next model. As these phones increase they use more and more microphones. The original microphone was designed to listen to your voice, but there are microphones to listen to noise, and there are microphones in the speakers and in earbuds. All of these sensors are MEMS modules that use resistors.

They're simple boards, basically two- to six-layer boards that have one or two layers of Ohmega in our case. These are used as part of filters which means they have capacitors embedded as well and most of the time, I'd say the clear majority of it, you will have different layers. Let's say we have a resistor layer and a capacitive layer, and the capacitive layer might be in a separate core. However, we do have a joint patent with Oak Mitsui for a combined product, which means the same core has both the embedded capacitor and the resistance. There are some advantages to that. The reason it's not more widely used is that it's a more expensive product and therefore the economics are rather working against us. Plus, there are some difficulties in the way you test capacitors; it's a lot different than the way you test resistors.

"So for now, most of these applications, particularly in cellphones, is at the capacitive embedded layers and the resistive embedded layers are separate and can be handled and processed separately and then all laminated together."

So for now, most of these applications, particularly in cellphones, the capacitive embedded layers and the resistive embedded layers are separate and can be handled and processed separately and then all laminated together. This totally blindsided us 10 years ago, by the way, and that has become the biggest part of our business. Originally our core technology was the high-end, very expensive military aerospace. Telecom and advanced high-end file servers would be the main part of our business. But what has happened is that suddenly these low-frequency applications came along, and then the audio. With 100 million cellphones, that became the largest part of our business, mostly being exported to China. Our materials are shipping to the Far East all the time because there are so many board shops and so much assembly work done in the Far East. We export primarily to China, but also Taiwan and Malaysia and various Pacific Rim countries.

The technology is well-established although the applications are new; it's standard print-and-etch technology. Board shops already have almost all the equipment, although there are a couple that might need a nickel strip tank, or their testers would have to be different. But basically, it's the same print-and-etch technology that they all use. The first etcher we don't care, they might use cupric chloride which they would have to use if they used Nichrome. Also, the big thing in miniaturization is using laser direct imaging. Almost none of our PCBs are laser trimmed. Close to 90+% is "as is," which means they have very precision printing and etching which is sufficient to hold the necessary tolerances. We're not a big fan of laser trimming; on the other hand, we love direct imaging, either laser or LED technology.

The imaging technology has improved and our product has improved to allow very miniature resistors like 50-micron (2 mils) wide resistors, 2 mils by 4 mils or 8 mils and holding a reasonable tolerance. That's the new, biggest thing. We saw this coming, but seeing it didn't necessarily mean we had all the answers to it. There were two worlds: there was the world of high-speed digital and there was the world of RF microwave. In the world of microwave, the gigahertz technology needed very smooth conductors because of skin effects, and the smooth conductors lowered the resistance. Since we control sheet resistivity, that's why it's about resistance, not thickness. What happens is the conductors get smoother and smoother and that drives down the thickness of the resistor material, so it becomes thinner.

The identical alloy that you had 10 or 20 years ago, say at 25 ohms per square cm, would be 0.4 microns thick; now it's down to 0.2 microns and on its way down to 0.15 microns. The only difference is the surfaces are very smooth and it's driving down resistivity. At the same time the question is: how do you improve the bond strength? Because when you get these very smooth surfaces, the bond strength starts dropping and then you're subjecting the PCB to thermal shock and so forth. The lower bond strength then turns into a reliability issue, so these two worlds are kind of colliding. The high-speed digital is getting faster and so is the RF. Basically the bottom line is we all know about Moore's Law, but there's also this frequency thing. If frequency is increasing, it is inevitably driving down the thicknesses of these embedded layers because of the need for smoother and smoother conductors.

And that's where we are now. We're looking at copper foils that we're going to be plating on and we're looking at chemical solutions, because it's not going to be mechanical, for improving bonds so that we can use these very smooth conductors. We have an R&D program now directed at that, and it's what we think is the next big thing coming along.

Meanwhile we are very busy; 2015 was our record year. There was a slight downtick last year, but this year we think we'll beat that. Certainly, year-to-date, we're in record territory in terms of business, mostly driven by the combination of aerospace defense increases and the commercial has also increased. It's not that they're going to sell that many more cellphones, but we're in the China market as well as the U.S. market, and they're using more microphones per phone. Plus they're using more layers, like going from one to two, but to go from one to two layers per PCB doubles it right there. We're really seeing a huge upswing in these applications.

Matties: For the increase, if I'm hearing you right, you're saying that people are coming in and doubling up on your material in the same application for the same board?

Brandler: Yes, two things are happening: more microphones for noise cancellation to improve sound fidelity; and second, more layers for the same reason of resistive layers and capacitors. And we're still pushing on the combined product I mentioned, although most of the capacitive layers and resistive layers are separate. But what you must have is both capacitors and resistors to create a filter and part of the problem of miniaturization is, if you look at a laptop, the high-speed end of it is rather far away from whatever audio stuff is going on, and the digital is in the middle. But as you then squeeze it down to the cellphone size, things get a lot closer together, and if you squeeze it down further to an ear bud, now they're right on top of each other. And all that RF interference is going right through the digital circuits.

You must have a way of dealing with that and one of the ways is to put the capacitive layer right below the resistive layer to eliminate noise. This is where signal integrity, this is where the fact that things are all on top of each other at very high frequencies, there's all this crosstalk and parasitics going on that must be dealt with. As a result, the inevitable drive for higher densities and higher frequencies has caused the need for more applications of these embedded paths and layers, both resistive and conductive and capacitive. So it's really a design thing.

“This is where signal integrity, this is where the fact that things are all on top of each other at very high frequencies, there's all this crosstalk and parasitics going on that must be dealt with.”

I would say the driver for us now is higher frequency, smoother copper. There are also some issues in the supply chain. The standard coppers are available in the States, but some of these ultra-smooth coppers are not made here. We have to go to Asia to get some of these super-fine things, and we're competing. The problem we see in the marketplace with getting copper foils is that the lead times are starting to lengthen and what our suppliers tell us is that fine line etching is really using up the thinner material.

But even more so, these energy storage batteries, not just for cars but for homes, for storing solar energy or whatever energy require a lot of copper. They're sucking up all the copper in the industry and now we're seeing lead times out 6–8 weeks where before it was a couple of weeks. The lead times are going up at the same time that our volumes are going up. I don't know where that's going to end, but every time Tesla builds a new megaplant somewhere, believe me, they're going to use a lot more copper. I don't have an answer to that question except that so far, we're dealing with it and we're keeping up with the demand. We'll see how that goes.

Matties: What sort of increase in copper price do you expect we'll see this year, 30%?

Brandler: I have no idea. What we've seen so far is an increase in delivery and the lead time is being pushed out. But you're asking the wrong guy, I'm the technical guy. I don't really get involved in economics but you asked the right question. I think it's inevitable that's going to happen. But the lead times being pushed out tells me they're struggling with capacity issues which means the price is going to start climbing.

Matties: Thank you very much. Happy, do you have any thoughts or questions on this?

Happy Holden: Well, it's an interesting topic that's been around a long time. One of the problems I always felt with the material supplier is that they always had the cart in front of the horse. In other words, they were always introducing and pushing new and better materials but had failed to establish any kind of cost tradeoff. The first step is always providing some cost trade off. In other words, everybody asks how much is this going to save us or what benefit is this? And since they never really produced any kind of model or software to allow people to do a cost tradeoff, those that experiment with it got burned severely when they found out how expensive it was versus conventional surface mount and even embedded surface mount.

So the industry still has the fundamental problem with the question of "how do I benefit from this?" There are some companies like in the aerospace industry, because of reliability and temperature and/or size or weight, they have to use that and they've been a user for 35 years. The mobile phone people are using it for the same reason and that is size and weight as well as performance advantage. But that's not the North American market too much or the rest of the world. Everybody is still standing around waiting and saying, "Show me the benefits." And I don't mean a whole bunch of bullets about how great it is, because we know that's only part of the picture. Show me the cost model.

Prof. Peter Sandborn at the University of Maryland developed software for MCC and Savantage Inc. that does cost tradeoffs of embedding components, either discreet or process. And it does it iteratively as it redesigns the board to find the sweet spot, where if you do it this way, you have this many resistors or this many capacitors or this size, you can reduce the size so that the material cost drops and you'll make money. But that's not available, or nobody's commercialized that or made it available for free. We're all still stuck with that first question. Then comes the second question: What are the characteristics available of the material? Then comes, how do I design this, what are the design tools out there, and how do I use them? The fourth question is, how do I fabricate this? Is it a drop-in, or do you have to add special processes and things like that?

I've put embedded ICs into active production and shipped tens of millions of the units. The fabrication of some of these things is a lot more difficult than many times what's advertised, especially if you're doing active ICs not just passive devices. He still actively uses that software, which means an article by him or him describing the software, since most people don't know it exists, might inspire others to produce a spreadsheet or base thing that we can have on the web that allows people to put in their numbers, like cost of surface mount components, number of solder joints, layers, size, etc., in order to see if there is an opportunity to embed it [illustrated in Figures 1, 2 and 3]. Once you find an opportunity then there's a lot more interest in the second and the third step.

Brandler: I definitely have a different point of view from Happy. Ten or 15 years ago, when I first came here I would agree with what Happy said. I think that was right, there was certainly a cost issue and tradeoff and how many resistors per square inch you need to replace surface mounts, but I think we've moved on. Let me address some of the issues he raised. First I want to be clear, our intent was never to sell Ohmega-Ply as a way of saving money on surface mount components. That model would not fly. Our main thing had to do with performance and density and miniaturization and signal integrity, and so forth. Yes, there were some cost adders at the worst possible place—with the material, because we're basically a material supplier. The reason we're still here, being the most expensive product at that time, was because of other technical reasons why people used them. Certainly, if you're building a satellite that's going to cost a billion dollars, you don't care if you have to spend another $100,000 to make it work.

But here's what we did and how we addressed those issues. First, we did address cost tradeoff issues, in terms of providing spreadsheet programs with the goal of selecting a single layer. The single layer is the lowest possible cost adder; if you have to use two layers, say one for the terminating resistors and one for the pull-up and pull-downs, you just doubled that cost-adder. So our goal was to provide a single layer. We would have customers give us the bill of materials, we'd go through the resistors and say these are the ones you leave on the surface, these are the ones you can embed using the terminating resistors. For the applications, if we had a BGA we could do something with a BGA that you couldn't do with a surface resistor, mainly terminate every lead onto the footprint of the BGA and free up a lot of space on the surface. All these were ways to reduce cost.

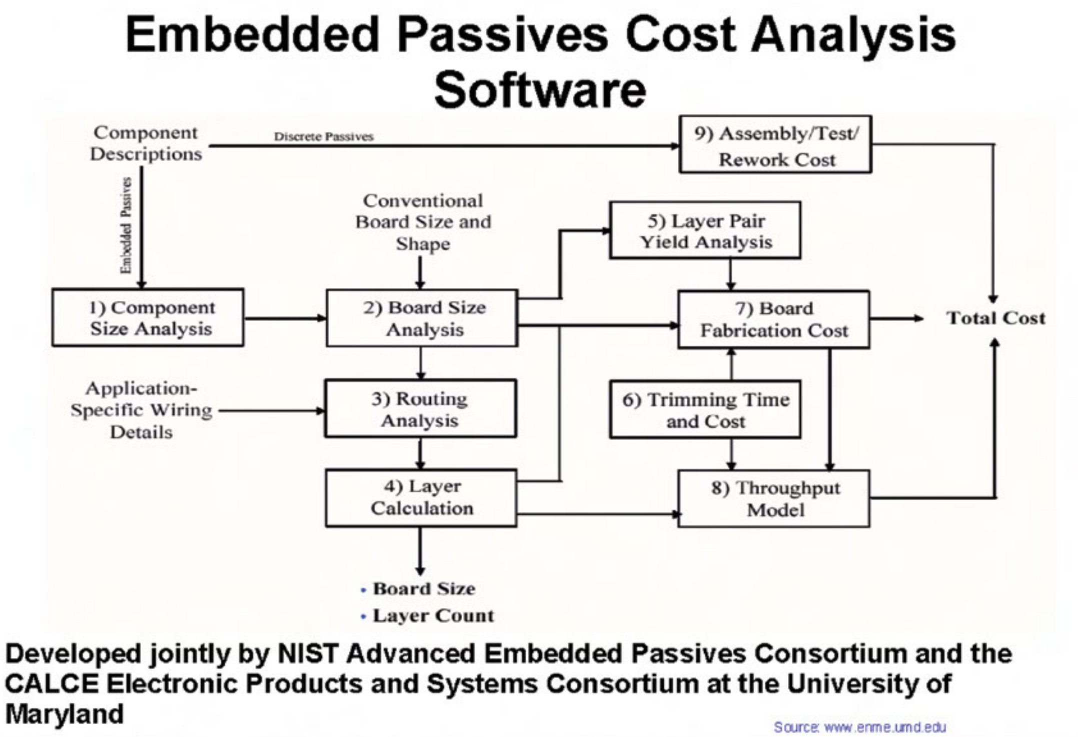


Figure 1: Cost analysis software developed by NIST and CALCE.

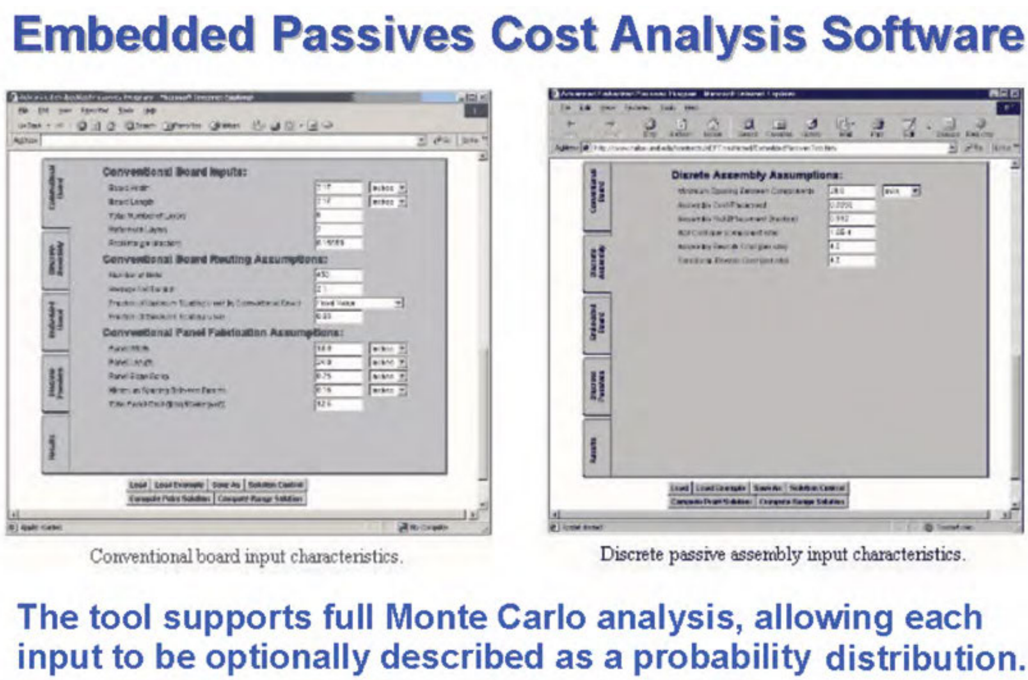


Figure 2: Sample input for embedded passives cost analysis software.

The cost wasn't the main thing; the main thing was you had to terminate every lead.

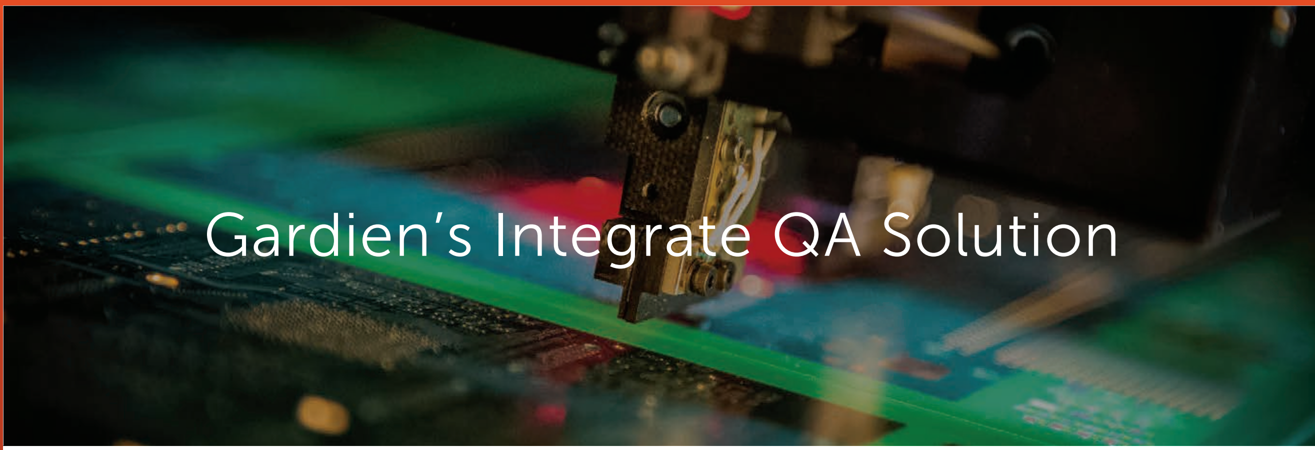
The other thing we did was, when some CAD designer ran out of room, the only way they're going to get more parts or more leads was to add layers, and adding layers was the fastest way to increase cost. Using embedded layers was an alternative to adding layers so you wouldn't have to route back to the surface or go down the multiple layers to escape the array. I think, Happy, you did some of this work when you talked about resistor density limits and things like that and crossing that density level, how many IOs per square centimeter or whatever. On one hand was conventional surface mount and the other was embedded. We did that too; we developed those same kinds of models.

The other thing that took place was miniaturization, for example in cellphones. These costs that you're talking about are basically area pricing. As the resistors got smaller and smaller, the amount of material that's in a cellphone is minuscule. They're so very small that a ten-inch by ten-inch material would be enough for thousands of cellphones. Miniaturization also made this economically feasible. Believe me, the cellphone manufacturers have very tight production cost schedules. The combination of miniaturization and the use of resistive layers is to avoid adding more layers or to go to more complex-type printed circuit, like HDI. If you could postpone going to HDI by embedding a layer, then there is a savings. It's not a surface mount versus resistor layer model. You're looking at the total system cost of reducing that and cost tradeoff.

In terms of design tools and fabrication, one of the things we do is provide excellent tech support all over the world. We have very good distribution representation in Asia. We can go in and provide all kinds of tech support both in the initial phase in the design, working with the CAD guys and the CAM guys. There are all kinds of unique applications. There are resistors you wouldn't recognize as resistors. Also, my job here is to `give away the process technology and to provide help with processing. Fortunately, most of that is standard and they don't really need a lot of new equipment. If they can do controlled impedance they can make resistors.

But that's an area we're doing really well on—maybe I'm biased, of course. But we do provide design support and tech support, and

Gardien



Gardien's Integrate QA Solution

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Integrate is a new approach to bare board PCB quality assurance. We address and are responsible for 100% of your tail end QA needs, whether it's AOI, testing, final inspection, or a combination of all three. We can provide the service in one of our service centers or fully integrate within your facility.

WHAT MAKES IT DIFFERENT?

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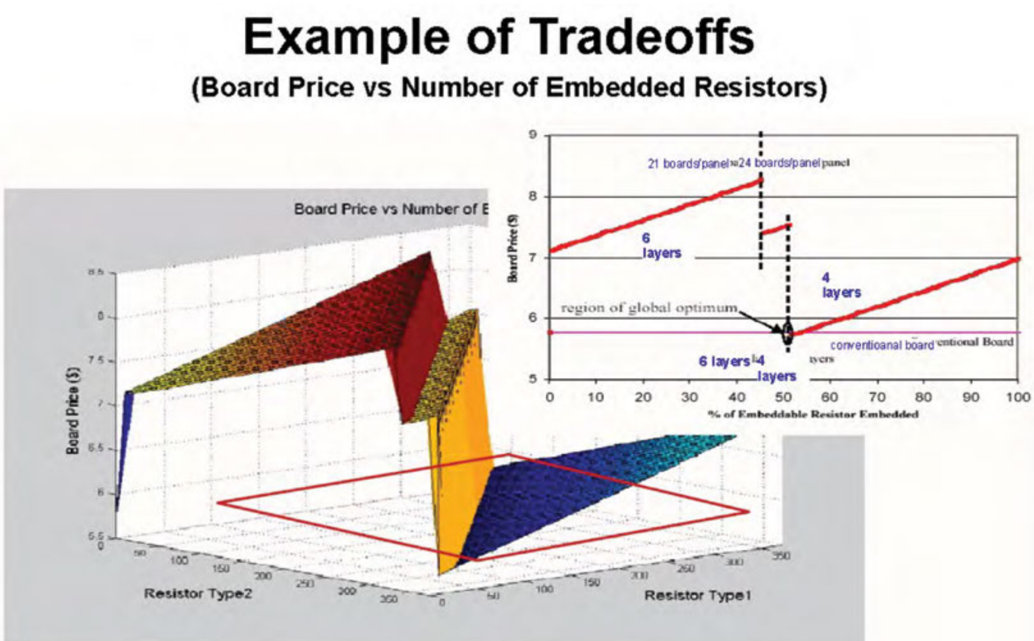

Figure 3: Showing the effects of embedding resistors on the board price for a 5.1 x 15.24 cm board with 500 discrete resistors of type 1 and 400 discrete resistors of type 2. The optimal board price is realized at ~52% of embedded resistors.

we provide it all over the world. Now is the cost of the materials, the laminate, going to go up? You bet it is. But the tradeoff in how the design changes at the end of the line, and I agree that's very difficult to model, but an old break-even chart with how many resistors per square inch, I don't consider that relevant anymore. We're in an area now where we're being used because there's no other way to do it. That's what is driving this whole thing and there are tradeoffs and costs.

Matties: So the physical parameters have forced them into this model, not the cost.

Brandler: Partly physical parameters and partly really high-speed, eliminating parasitics. There are no inductive reactants like you have with a surface mount device. The technology is what's driving this and the cost is sort of following it. Nobody wants to add costs, I agree. There's no designer in the world that wants to come up with a new design that adds cost to the substrate; that's the worst place to add cost. But the reality is, when they see the alternatives that they have to do to accomplish the design, then it looks more attractive. That's basically the issue, but I think mostly that's a 20-year old issue. Now we're well beyond the realm of surface mount versus resistor tradeoff.

Holden: I agree with all that. Miniaturizations and various kinds of modules that become BGAs that get attached is an area, but that is not a predominantly North American circuit area. That's limited to those things that demand that miniaturization, like mobile phones but most of the industry doesn't demand that much miniaturization. And I haven't really seen an article that I can recall that talks about the performance and the miniaturization aspects of embedded components. There just haven't been any articles that talk about this.

Brandler: We can send you some. We're going to these trade shows and exhibitions and publishing these things all the time. But the one thing I also want to say is on the whole issue of North American versus Far East. The North American market for us is primarily aerospace defense. Our competitors are in the same market too, it's not just us, and what is driving that are things like power dividers and other similar

RF electronics designs that allow them to make all these networks and such. Really, you could do it with strip resistors and things like that, but this has been around for a long time and the new microwave horns and things that are using absorbers to improve the signal integrity by absorbing all the stray signals and shielding and these are applications where normally you want to get heat out of the chip, but if you talk about space sometimes you want to put it in.

All these kinds of applications are military aerospace that are using this for entirely different reasons. They're not very cost sensitive because compared to the cost of what they're doing this is negligible. Again, reliability, performance and such are the main things that they're looking at and the fact that it costs a little more than a surface mount board or something isn't a big deal for them.

Matties: What sort of challenges does this place on designers?

Herrera: Well, I think a lot of the questions that I get are what tools can we use to design this in? And I know Altium and some of the Mentor Graphics tools have embedded functionality built in that designers can use if they want these resistors to be embedded; the tool will help them embed them. Then there's the method that I'm more familiar with, which is the manual method, where you're sizing resistors based on the geometries and the power requirements or tolerance requirements, and then manually putting them in the artwork that way. But I think for designers, if they have the idea that they want to embed, it's reaching out to the tool provider that they're using and getting resources there or coming to us to get resources to figure out how to do it, and in addition to that we will also work with the board shops.

If it's a board shop that's not familiar with processing our material, we'll get involved and help there, but for the most part we have a pretty big catalogue of board shops that are processing our material, that are familiar with it, and the support there is also great for the designer. For example, the board shop will adjust the artwork to compensate for processing factors. This is commonly done to hit controlled impedance targets and usually happens behind the scenes. The experienced board shops also understand how changes in geometries affect the finished resistor values. This becomes more critical as geometries become less than 0.010" (0.254 mm).

Andy Shaughnessy: It does seem like the tools have gotten better, though, because I remember there used to be no embedded design functionality in any of the EDA tools for PCB.

Herrera: Screen prints or even embedding the surface mount components themselves, and active components too.

Brandler: I was at the last IPC conference on this and they moved on from passive to active. [See Figures 4, 5, 6 and 7.] That's the next big thing: embedding active components. And all the issues we had to deal with passives, like what happened with the lamination destroying some components? Well, it'll destroy the active component too or possibly the interconnects. There's a whole new world with actives, but we're still there. The passives are already established as being embedded. Then there's the introduction of highly precise printing and etching using direct imaging, where you could do compensation and you don't have to laser trim to hold tolerances. As you eliminate tolerance as an issue then, what Manuel said becomes true, power starts becoming an issue when you get extreme miniaturization.

Even though we normally don't think of any power being required, for things like terminating resistance down to a few milliwatts or whatever, it starts to add up. And then they get smaller and smaller and we have to deal with a temperature rise. This then becomes another constraint that is part of it. The other constraint we have to deal with is ESD. ESD was a big deal particularly in the cellphone business when you're talking about human body model; can it pass 8,000 volts? Remember I said it was getting increasingly thinner because of the high frequency? Well, then ESD endurance becomes less and less. Now we have to design for ESD. At what voltage can you test these at and expect them to pass? And so that's been incorporated in our latest software.

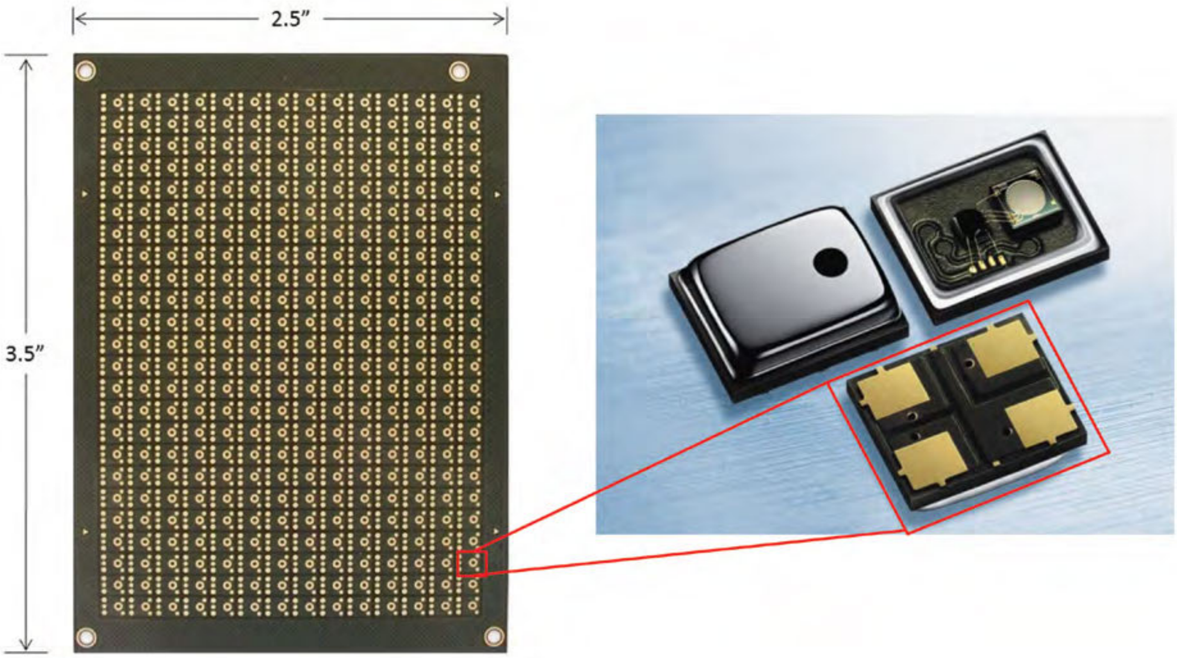

Figure 4: MEMS microphone sub-panel with projection to module shown.

Our latest spreadsheet model now includes, besides power and tolerance normative value for the minimum size, we're also saying what's the minimum size for the voltage you're going to be testing on ESD. When we talk about direct, that means directly applying the ESD to the module. These are new challenges that we didn't really have a big problem with before, and because of this, it also changes the sheet resistivity, because the lower the sheet resistivity the thicker it gets. Maybe it doesn't pass 8,000 volts at 50 ohms per square, but it does pass 8,000 volts at 40 ohms per square.

What this has done for us is created a whole new range of products we have to add and we offer different ohmic values. In terms of copper, most of the time half-ounce copper dominates the whole world, but now we're supplying a significant amount of 12-micron copper. Why? Because for fine-line etching they want thinner copper. We're seeing some 5-micron but that requires a carrier we don't like. It's very expensive. If you think the costs are high now, that's really expensive. Also, it's not available in the United States so we have to get it from Japan or Taiwan, whereas 12-micron copper is made here in the U.S. Because not only do you want conductors for high frequency, you also want it for fine line etching.

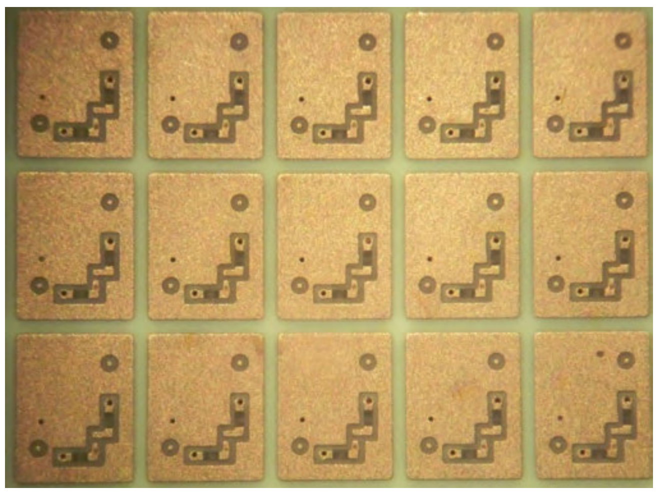

Figure 5: MEMS microphone PCB array with exposed planar resistors.

We're seeing smoother surfaces and thinner coppers. All this of course is still half-ounce so what that means is when we add six or eight products now we have 20 products, and since we basically ship from stock, rather than manufacture to order because the lead time would be too long, it requires us to now inventory a

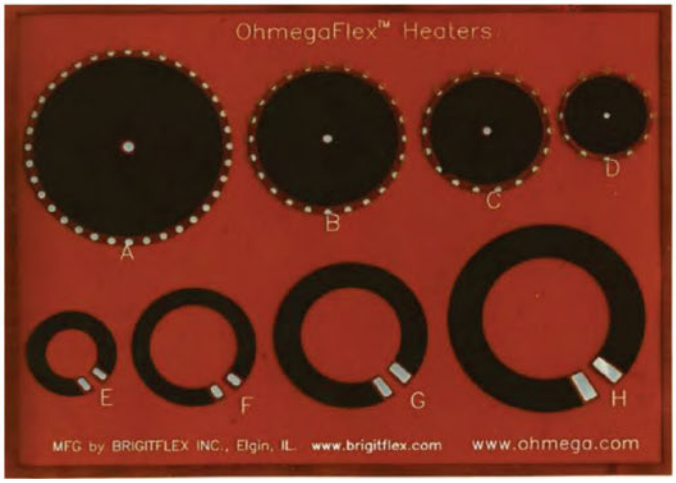

Figure 6: OhmegaFlex rectangular and circular heaters.

whole wide range of products that we didn't have before. That's something else that we're dealing with. Fortunately, we're in very large facility here so we're able to do it.

Matties: This is really interesting, especially when you mention embedding actives. Happy, do you have any thoughts around that side of this?

Holden: Well, we had to spend an awful lot of money to make embedded actives work because the little secret that they don't tell you until after you sign the licensing is that you have to have a yield of 99.7% on very complex HDI, otherwise you throw away more money in the ICs than you save. We had to switch to a third facility in Northern China, which is basically employees made up of North Koreans. And there we found the discipline it takes. You can do this in Japan, but outside of Japan nobody else can really make this thing work except for these Korean workers and we got to 99.85%. Now we're shipping 10,000,000 modules a month that use both embedded capacitors and resistors and ICs because they're so small. The surface is taken up with an active device either with the MEMS microphone, the optical sensor for the camera, or the antennas for the Wi-Fi, and things like that. But this is all mostly dedicated to the mobile phone market.

Matties: Aren't those also in applications like hearing aids and other medical devices?

Herrera: We have seen them in applications where they're calling them micro-fluidics or micro-fluids, where they need to heat up a liquid and move it through these small channels on a MEMS sensor. That's an application in the medical field and that's the one that comes to mind. Others had medicine delivery applications; the heater would heat up the medicine and help push it through a patch.

Brandler: Since resistors are heaters, we see a greater demand for, usually, flex heaters in which the dielectrics are extremely thin because you want the heat to go right through it. I'm sure it applies to our competitors as well, because it's very thin; the advantage of using these as heaters is that it takes very little power to get a very fast temperature rise because there's so little thermal mass—you can get a fast temperature rise even though there's not a lot of heat. There are applications for that and it's not really big, even though Manuel is involved with designing this. I would say in terms of percentage of our business it's very low compared to the other things we were speaking about.

Herrera: Maybe the reason it's gaining a little traction is due to the way these devices are being built. They're more modular. Imagine a motherboard for a computer—this has actually been done—with embedded resistors, say 700 embedded resistors on the whole motherboard. Now, our process is a subtractive process, so all the area that's not being used as resistors is basically etched off; essentially 95% of that layer is gone and only 5% is left for the resistors.

Since they're all termination resistors, we decided to make a small interposer board and put all the termination resistors on it. Now instead of getting four motherboards on a panel, we'll get hundreds of these small interposer boards and that will be used to attach the IC; then that'll go on to the motherboards. What this does is essentially use a lot more of the resistive material. And the same idea is what we're seeing in the MEMS microphone market—the concept of making it a module. You have tens of thousands of these little PCBs on a panel and each one of those PCBs has two resistors; you're basically using 30% of the resistive material now. I'm just throwing those numbers out as an example but you're using a lot more of resistive material in that kind of design, a modular design. But you have these smaller PCBs and essentially you use more material and that's what you want to do.

Holden: And that's clearly what Sandborn's software showed. The more you shrink things down and use the embedded capacitor resistive devices in the sensor or module, the more cost effective it is unless you're using an additive process. But since most of the materials are subtracted and not additive, the software allows you to choose both additive and subtractive or allow both to be plotted to see the difference. But I agree, the challenge is to take the applications that you've all talked about and step back and show the partitioning or the change in thinking that allows performance to go up and cost to go down by doing things differently than we've always done it.

I haven't seen any articles that talk about the way we did it 20 or 30 years ago, where it's going to be like this, but if we partition it like you said and put the interposer in there, not only do we save costs but maybe now we don't have to buy fine pitch devices because the interposer can be 0.5 mm pitch, but the top of the interposer can be 1 mm. Now you're no longer forced to use very exotic HDI technologies on a whole board when the HDI is only used

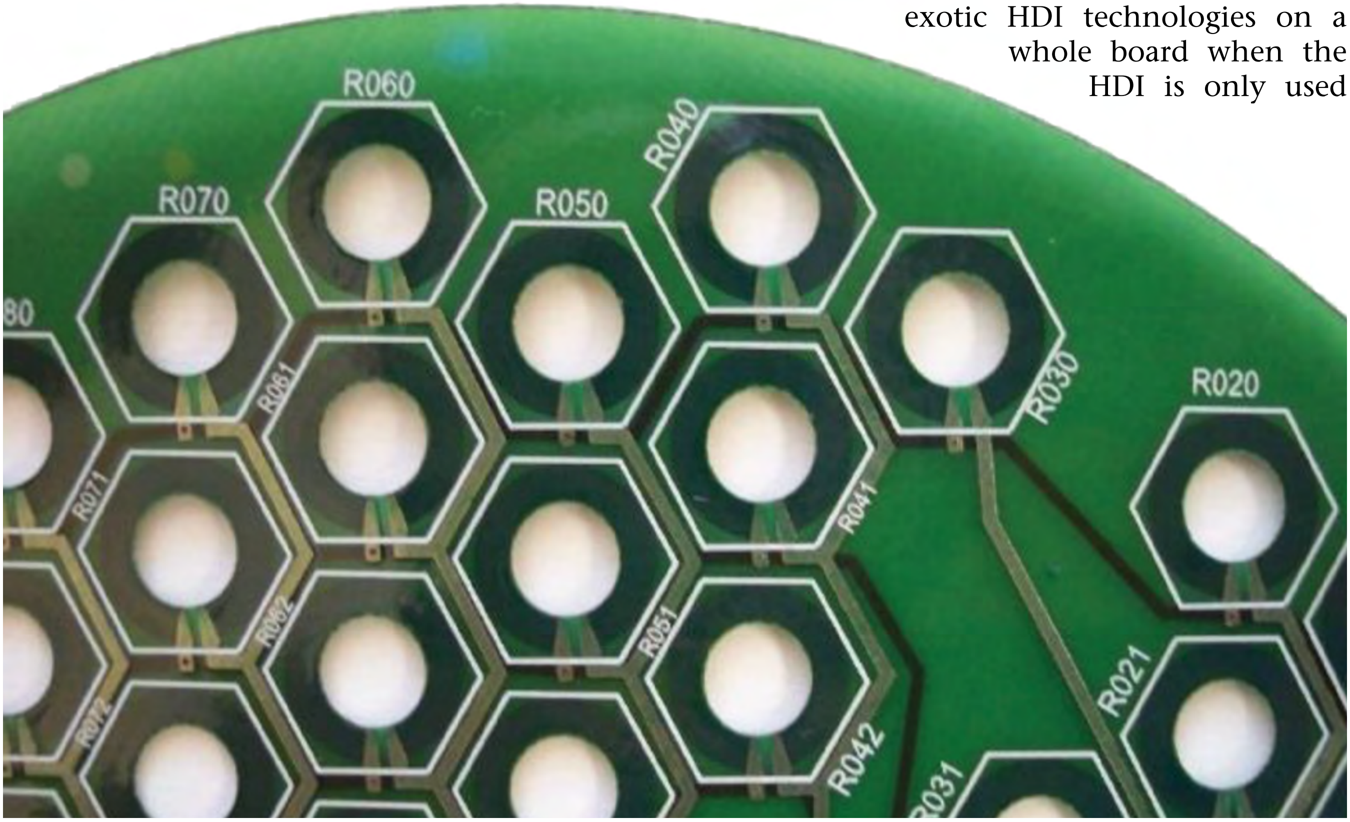

Figure 7: BioMed heater application—soft tissue expansion.

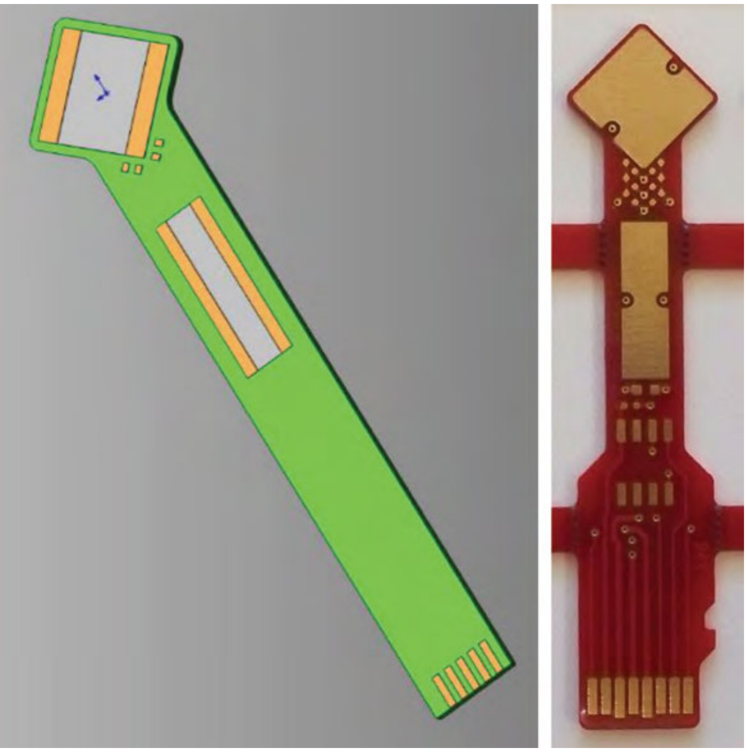

Figure 8: BioMed heater application—fluid delivery.

on the interposers—a big advantage in performance and cost. Nobody has written an article that says this doesn't just apply to mobile phones or to earphones, but let's step back and see how miniaturization can improve things in general or take away problems that are plaguing you now.

Matties: You mentioned the North American market is not really tied to the mobile phone; what impact or advantage or opportunity exists for North Americans with this technology? Are we missing something, or is there a story to tell here as well?

Herrera: I think a lot of the designs are created in America. Now, the actual fabrication and such may be going overseas, but a lot of the design work is still happening here, by OEMs such as Qualcomm and others, and then it's being sent out to be mass produced elsewhere.

Matties: Are there other applications that might be a competitive advantage? Perhaps for someone that says, if I use this in my automobile circuits, for example, I'm going to need functionality, space, etc.

Herrera: That's interesting you bring up the automotive market. In my opinion, the millimeter wave, the radar stuff, the sensors that are going to be going into the cars, again those are modular designs. I think that's a great opportunity there, and the opportunity is performance related. Like Dan was mentioning, you remove the chip component and you're reducing the parasitic inductance involved with the surface mount chip package and the PCB footprint. There are less physical transitions for the signal to propagate through. And when you're going out to these 66 gigahertz, 70 gigahertz frequencies, a small improvement can make a big difference.

Matties: Is the reliability improved as well?

Herrera: Yes, especially in operating environments exposed to wide spectrum vibration and extreme temperatures that may occur under the hood. Replacing a surface mount component with one embedded in the PCB adds an extra layer of protection. In automobiles, as in aerospace, there will be a lot of redundancy, so that can be an opportunity there, but then who's to say that, as these things are being designed, the manufacturing and the processing won't be sent overseas because it can be done

Goldman: What types of components are embeddable? Is it just capacitors and resistors, or are there more?

Brandler: The one other thing is inductors. There are just three kinds of passives that we usually talk about. We don't call diodes passives, but there are resistors, capacitors and inductors. Inductors are basically little spiral designs, fine-lined things. There may be other chip-type things embedded in the cavities and so forth, but basically when you're talking embedded passives 99.9% of them are going to be either resistors or capacitors. I don't know how many people are making inductors because they don't have to buy anything from us to do that. But the rest of it is some form of active component.

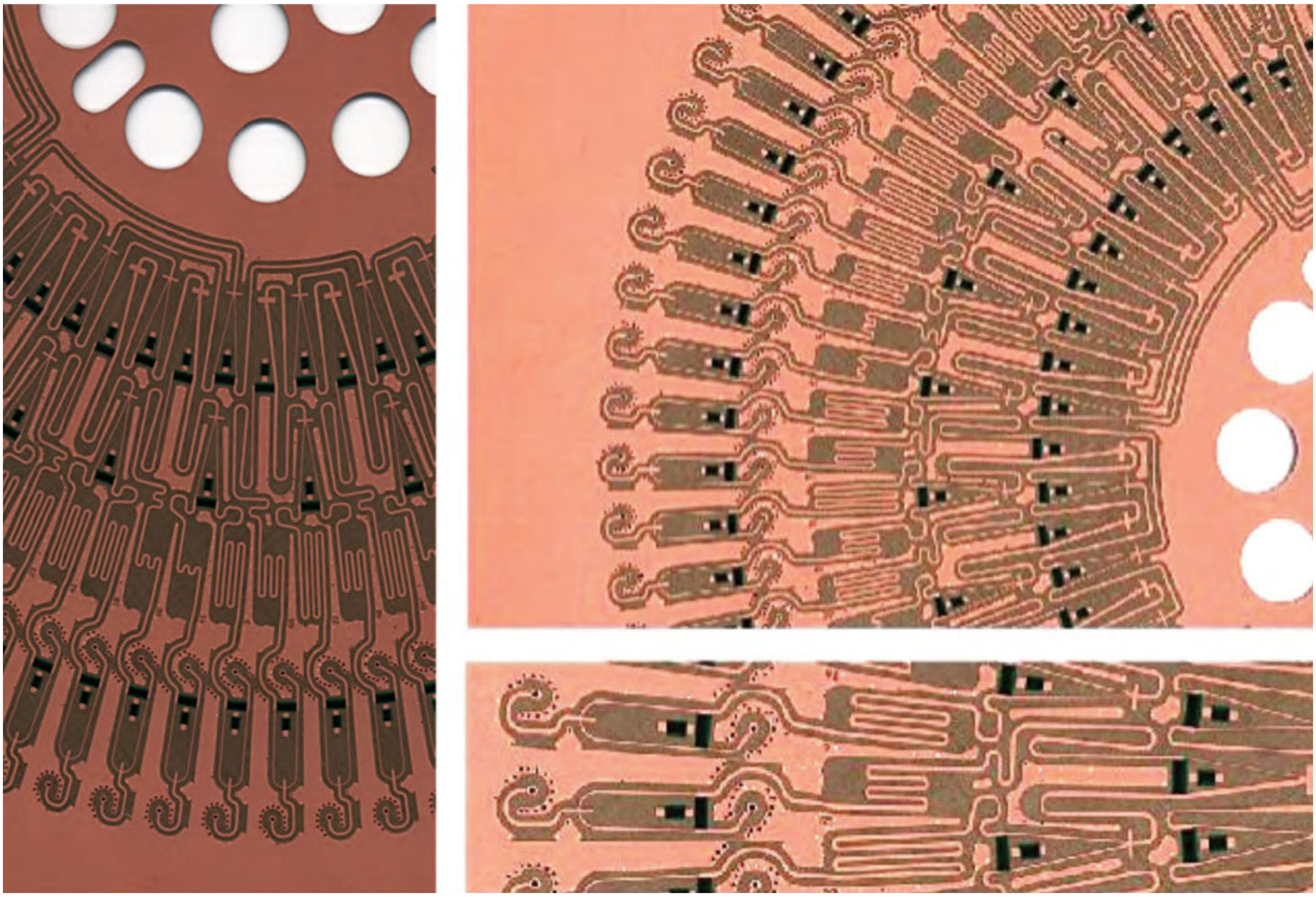

Figure 9: RF power divider application in Globalstar satellite antenna.

The big challenge with active components is getting reliable interconnects, and they're doing it. I think that's the next big thing to get devices off the surface of the board. I would also like to add that, while we're talking embedded, sometimes we use the word buried meaning within a multilayer structure, an HDI. For these cellphone MEMs modules, a lot of them use surface resistors where the only thing over them is solder mask. Basically, it's like solder mask on bare copper except they're over the resistor element. One of the challenges for the board shops that also drives up the cost is when you're doing a surface resistor or an embedded resistor on a board that has buried vias. Then you panel plate because you have to metalize the holes, then pattern plate and etch through more copper for the second etch to define the resistor elements. Not only is it difficult, but it adds cost.

Before, we thought surface mount resistors were inexpensive and all we were doing is putting solder mask over them; in terms of fine-line etching they can be just as much a challenge as anything else. But that's old news. The new news is the buried vias and sequential-build type PCB constructions where the resistors are in the subassembly of the sequential build and are essentially buried surface resistors; so there isn't solder mask over them, but prepreg or whatever they're using to build it up with.

The challenge, again, is using direct imaging to etch through not only the copper cladding or the OhmegaPly copper, but etch through the plating as well. There may be a 25-micron minimum on the hole wall that turns out to be what you're adding to the traces and then etching becomes more difficult. People do it all the time, but you're adding cost to it.

Holden: The Japanese are still working on this. What are the Japanese doing on embedded components? I firmly believe their big focus is miniaturization of everything; they certainly have more examples of miniaturization than we do. Their mobile phones are smaller than ours are, and they always try to make the lightest ones they can get by with or the thinnest ones they can get by with.

Brandler: I agree with you on that 100%. We're working with some Japanese companies who are doing their manufacturing in Malaysia with their automatic lines and so we have to supply rolls instead of sheets, which is our preference—laminated sheets. We also supply rolls for the Japanese companies. There is something going on but they have their own technology and they do exquisite work. There's no question about it. They're top notch.

Stephen Las Marias: I've been hearing the challenges are in the design and the fabrication of the boards with these embedded components, but do you see any relevant challenges when it comes to the PCB assembly side?

Brandler: Normally our thinking is that, by embedding all components, we make assembly easier by limiting the number of solder joints. The only thing I've really heard that seems to be bothering them is in-circuit testing. Because if you're starting to embed actives, now you're doing in-circuit tests on essentially a bare board, and since the board is not fully populated, you often cannot do a complete in-circuit test and so maybe you're just testing for continuity and that all the connections are right. Normally with embedded passive resistors you're not only testing for shorts and opens at the bare board level, you're testing for the value of the resistors. But now with actives, the testing at the bare board level becomes a lot more complicated, because as Happy said, you don't want to get to the point where you've populated the board with all these expensive semiconductors and then find out that some of the embedded ones are no good. That's the only assembly issue that I've heard that they seem to be concerned about.

Herrera: I just want to make one other comment about opportunities for North America. Going back to this whole modular design thing and the idea of deploying sensors, whether they be for industrial applications or even in homes, these low-power energy-harvesting communicating sensors I believe are a great opportunity for North America. I think we'll see that here more so than in other parts of the world, at least I'm hoping. Like the idea of deploying these sensors everywhere and again it goes back to the modular design. I think that's an opportunity that people here in the States should be looking at if they're not already.

Brandler: Yes, sensors. When we talk about autonomous cars, all these autonomous cars are driven by sensors and loaded with sensors. The question is how many ports are they going to have and how vulnerable they'll be to hacking, and so forth. But tons of sensors, and who's going to build them, I don't know but they're going to require them. You're going to have tires that take control in a skid or something. You know there'll be all kinds of things going on.

Matties: It's definitely a world of sensors and measurements now, isn't it?

Holden: My son's an electrician and I encouraged him to go back to school and become specialized in electronics and other forms of energy because I told him that in a few years, homes and businesses won't use electricians anymore because every switch and every bulb will have a sensor in it. You just mount it and plug it into a local area network and it doesn't require a licensed electrician anymore because it will all be done in the module in terms of what turns on and what turns off, etc. So because of this cost of labor and the cost of an electrician versus the cost of an untrained, unskilled person putting together house wiring, he needs to bolster up and move up in the terms of technology of electricians and to control wiring and specialized things.

Since I came from the automotive electronics in my last job, the cars just have a local area network and every light bulb and turn signal and brake pedal has a sensor on it. There's no longer point-to-point wiring, which is why you can't troubleshoot your cars anymore. Because it's all a redundant pulse signal that makes that left or right turn signal turn on. It's no longer closing a contact on the steering column that makes it turn on; those modules only cost a nickel because they're purchased by the hundreds of millions. The interesting thing is we didn't have part of it when it was a wiring harness and now somebody has to make all of those modules and assemble them on these big panels, usually done in the Far East. But nonetheless, they've reduced the cost and allow the cars to be a lot smarter. That form of application will slowly pervade everything.

Matties: That will also contribute to, as we continue to see this advance, a lot of different design opportunities for the automobiles as well, because you don't have the standard constraints that you may have had otherwise.

Holden: Yes. GenTech just shipped their first set of rearview mirrors for Cadillac in which the rearview mirror is 100% LCD, because the camera is on the outside, on the top of the car. The challenge was that for safety and automotive sources, if the electrical fails it has to revert to a reflective mirror, and that took a lot of work on glass technology and thin films to make an LCD also revert to being simply reflective. I asked somebody why would you do that and they said the car guys don't like that rear window, and if they can take the rear window away where you don't have to look at it through a mirror then they have the opportunity for a lot more styling and other types of benefits. So two cars now have 100% LCD rearview mirrors; it's no longer reflective.

Matties: That's a great example, and when we do this for the cockpit of airplanes then the nose of an airplane might look a lot different if we don't have to worry about the windows for a pilot to see out of.

Holden: By watching what is being pioneered in the mobile phone and automotive industries, new innovators will apply these sensors as solutions to their problems. Just like I said, we're going to have wearable electronics, but we're not likely to have four-inch by four-inch circuit boards or something like that. They're likely to be very tiny modules in wearables just simply to make them more convenient and to get through a washing machine—although I still believe in printed electronics where they're all disposable, where you only use them for one to five days and throw them away.

Matties: Good, well thank you gentlemen. This has been extremely interesting.

Brandler: Okay, thank you. We appreciate the opportunity. **PCB**

Sustainability, Business Transformation and the Circular Economy

Forward-thinking businesses are abandoning the traditional linear economy, in which inputs and manufacturing processes move in one direction and end products find landfills and oceans. With each passing day, more are gravitating toward the circular economy—a model based on the recovery, reuse, and regeneration of materials, to ensure they are at their highest utility and value at all times. Released by The Conference Board, "Business Transformation and the Circular Economy" lays out risks and rewards of undertaking this shift, offering real-world case studies and recommendations, from companies that are leading this transition. More details here.

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American Standard Circuits Completes Asset Acquisition of Camtech Technologies

The acquisition brings increased offshore capabilities to American Standard Circuits and demonstrates American Standard's continued commitment to helping clients with their most pressing business challenges, from prototype to high-volume production.

If It's My Data, I Can Do What I Want, Right?

In the light of the new IoT philosophies that are rapidly becoming the expectation, the problem of flexibility versus risk is resolved on the lower level, as IoT establishes the transfer and availability of data everywhere without the need for "hacking" into internal system database structures.

Global Smart Manufacturing Market: Players Need to Explore New Markets

The global market for smart manufacturing is characterized by the presence of numerous companies, making the landscape fragmented and highly competitive. The competition is being dictated by the demand for huge investments in infrastructure and development of technologies.

Blackfox Program Trains Vets for Manufacturing Jobs

It's harder than ever for managers in the PCB manufacturing industry to find qualified staff, with some reporting that positions are remaining open for months at a time. On the other hand, there are thousands of soldiers, sailors, airmen and marines transitioning out of the service each year and seeking good jobs.

Europe Ramps up Defense Spending as Budgets Rise on Heightened Threats

Defense budgets across Europe will grow by 1.6% on average annually for the next five years, to reach $245 billion in total by 2021, according to new analysis released today by IHS Markit.

Mentor FloTHERM XT Release Simulates Complex Geometries Quickly, Accurately

Mentor, a Siemens business, has launched the newest release of the FloTHERM® XT electronics cooling software product with advanced thermal management capabilities. The award-winning FloTHERM XT product is the industry's first integrated mechanical design automation (MDA) and electronic design automation (EDA) electronics cooling solution.

Bruce Mahler Discusses Ohmega's Resistive Material Technology

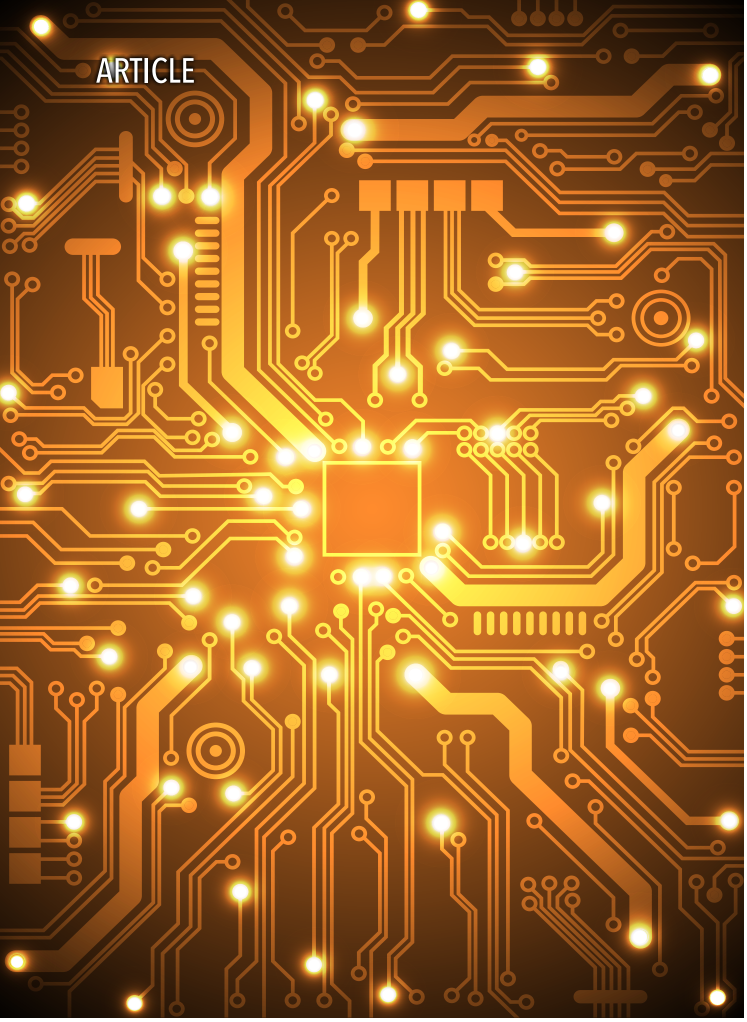
Bruce Mahler, vice president of Ohmega Technologies, sat down for an interview at DesignCon 2017. He discussed the company's latest embedded resistive materials, as well as some of the drivers and challenges in that segment of the materials industry.

Executive Agent for PCB and Electronic Interconnect Technology PrCB Trust Accreditation

The DoD mandate for trust in the PrCB supply chain is mirrored in DoDI 5200.44, which states: "Employ protections that manage risk in the supply chain for components or subcomponent products and services (e.g., integrated circuits, FPGAs, PrCBs) when they are identifiable (to the supplier) as having a DoD end-use."

Developments in the Defense and Protection Markets

Markets and Markets reports the active protection system market is projected to grow from $2.84 billion in 2016 to $4.15 billion by 2022, at a CAGR of 6.50% during the forecast period. Several influencing factors are expected to drive this market during the forecast period.



Megasonic Acoustic Surface Treatment Process for Enhanced Copper Electrodeposition in Via Interconnects

By Thomas Jones, Dr. David Flynn, Marc P.Y. Desmulliez and Dennis Price

Introduction

A printed circuit board is populated with a multitude of electro-mechanical components plus various active and passive devices such as transistors, capacitors, inductors and resistors, which enable the functionality and assembly of the PCB. Increasing the density of the components on the surface of a board enables greater functionality and use. A high-density (HD) design is desirable for technology high end applications, which include automotive, aerospace, space, defense, mobile phones, medical, networking, communications, and computer storage[1].

The current trend in PCB markets is low-technology, high-volume demand and is typically supplied by low-cost, large-scale facilities in Southeast Asia, such as China, India and Thailand. High-value, low-volume PCB markets are typically supplied by smaller-sized facilities in western regions such as North America and Europe, but also economically developed eastern locations such as Japan, South Korea and Taiwan[2]. The UK PCB demand typically focuses on this latter market. Manufacturing developments bringing increased capability and cost savings to a factory in the UK would be highly desirable and enable increased market competitiveness.

For more than four years, Merlin Circuit Technology Ltd (MCT), in Deeside, North Wales, has been working in collaboration with Heriot-Watt University (HWU) in Edinburgh, Scotland, on a UK government project funded by the Engineering and Physical Sciences Research Council (EPSRC), looking to improve HD PCB manufacturing capability through enhancements to the electrodeposition of copper using high frequency acoustic, applied within a copper plating bath [3,4,5]. This article outlines some of the key findings from this project.

High-Frequency Acoustics Applied within Manufacture

The introduction of high frequency acoustics—greater than the human hearing range which is typically over 20 kHz—has been used

as a manufacturing tool to assist the etchant abilities of wet chemical processes. Examples include enhancement to the surface treatment of chemically inert materials by applying 40 kHz ultrasound waves within the permanganate desmear process used in the electroless copper plating[6] and for the cleaning of silicon wafers for the adhesion of photoresist dryfilm[7]. Another application is the enhancement to the streaming of fluidic currents within copper plating baths, which has a use in electrodeposition processes as an assistance to the circulation of electrolyte plating solution in difficult-to-plate regions on the PCB. The resulting use of ultrasonic (US) and megasonic (MS) assisted agitation, leads to increases in the throwing power of the electrolyte bath—its ability to plate into low current density areas with the same thickness as higher current density areas.

The introduction of MS agitations within a copper suphate plating bath has been demonstrated in laboratory trials at HWU to increase the throwing power of the bath[8]. The advantages outlined in those laboratory-scale trials indicate that the microfeatures present in PCB interconnects, such as a through-hole via (THV)—a drilled feature which provides electrical connection between a board's two outer surfaces and inner layers—can be uniformly filled with copper with a feature size of 0.2 mm diameter and diameter-to-depth aspect ratio (ar) 8:1. Also, the uniform filling of a blind via (BV)—a drilled feature smaller than a THV connecting an outer layer with the underlying one, two or three innerlayers—observed on features of diameter 0.1 mm and ar 3:1[3].

The increased throwing power of the bath due to the MS-assisted agitation has demonstrated a potential to manufacture via interconnects with a uniform fill of copper, which is desirable for enhancing thermal transport on a PCB whilst enabling HD interconnection[9]. Increasing the throwing power enables an increased plating performance and via ar, as shown by the 3:1 ar BV which is typically manufactured with a maximum ar of 1.2:1. The outcome of this increased connectivity is illustrated in Figure 1. The figure shows a PCB schematic of a 26-layer

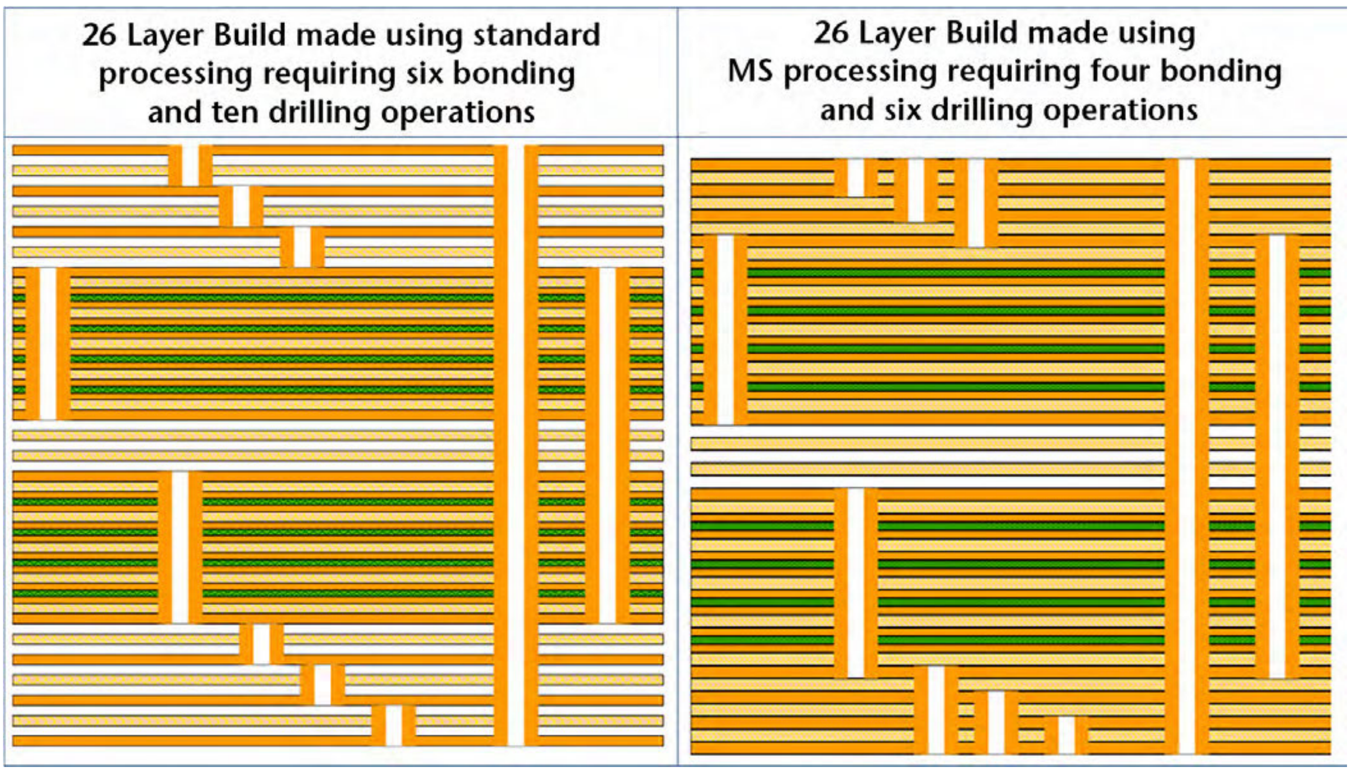


Figure 1: PCB build comparison of current technology and megasonic processing.

multilayer board fabricated with standard processing on the left, and MS-assisted agitation on the right, with the THVs and BVs indicated by the orange vertical features.

A multilayer PCB is constructed by the bonding together of its individual layers by thermally degrading processes. With MS-assisted processing the number of bonding operations is reduced from six to four and the drilling operations reduced from ten to six, which together reduce fabrication costs and overall manufacturing time, and increase the lifetime of the board due to the reduction in high thermal stresses induced during its fabrication. Increasing the lifetime of a PCB is a highly desirable trait for the PCB assembler, who may perform multiple high temperature operations up to 260°C, in the reflow soldering of components onto the PCB surface[10].

Manufacturing a PCB with the material processing and cost savings outlined here would enhance the capability of a PCB fabricator, so a series of investigations were performed looking to scale-up the process from a small-scale laboratory setting—processing in 40 litre tanks at HWU—into a medium scale setting with 500 litre processing tanks at MCT.

Plating Setup and Experimental Investigations at Merlin

The experimental setup reproduced at MCT was comprised of a 500W Sonosys MS acoustic transducer device, submersed within a copper sulphate electroplating bath with a solution provided by Schloetter Ltd., which was SLOTOCOUP CU110 set up for soluble anodes. Before MS-plating, the PCBs were processed through a MacDermid M-System Omega electroless copper plating line at MCT, depositing 1–2 µm of copper.

When in operation, the acoustic transducer was oriented with its active face towards the surface of the PCB, where the features to be plated—THV and BV—were exposed to the oncoming waves. A 2-D schematic of the arrangement is indicated in Figure 2. In the setup, one soluble anode was used to the left of the PCB and one transducer was used to the right of the PCB. This setup was applied for the plating trials discussed below.

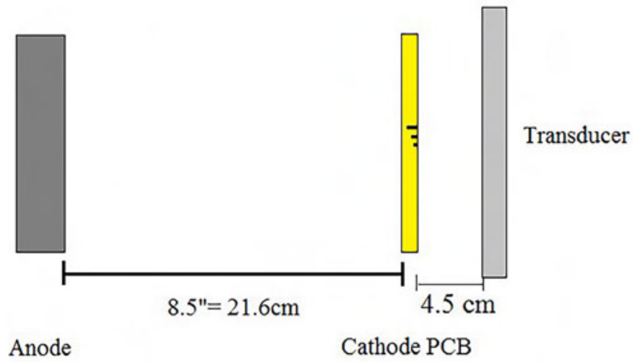


Figure 2: Schematic of experimental setup: acoustic transducer (right); PCB (middle); and soluble anode (left). Acoustic agitation applied from right to left onto the PCB surface facing the transducer and into the via interconnects.

A series of investigations were performed aimed at the following:

- The influence of the MS agitation on the surface finish of the plated copper, from observations using optical microscopes and scanning electron microscopes (SEM), at MCT and HWU, respectively
- The ability for the MS acoustic streaming to transport solution down microfeatures, specifically small, 0.15 mm diameter THVs
- The ability for the MS acoustic streaming to enhance the amount of copper deposited down small BV interconnects compared to industry standard solution agitation techniques, which include panel movement and bubble agitation

Megasound Acoustic Effects Observed on the PCB Surface

The application of high-frequency acoustic agitation during copper electroplating was seen to form periodic features within copper deposited onto substrate surfaces. The periodic features were characterised by regular lines which decreased in distance with increasing frequency[11]. This behaviour was also witnessed in the MS investigations performed at MCT within the deposited copper[4]. A 1.6-mm FR-4 PCB was DC-

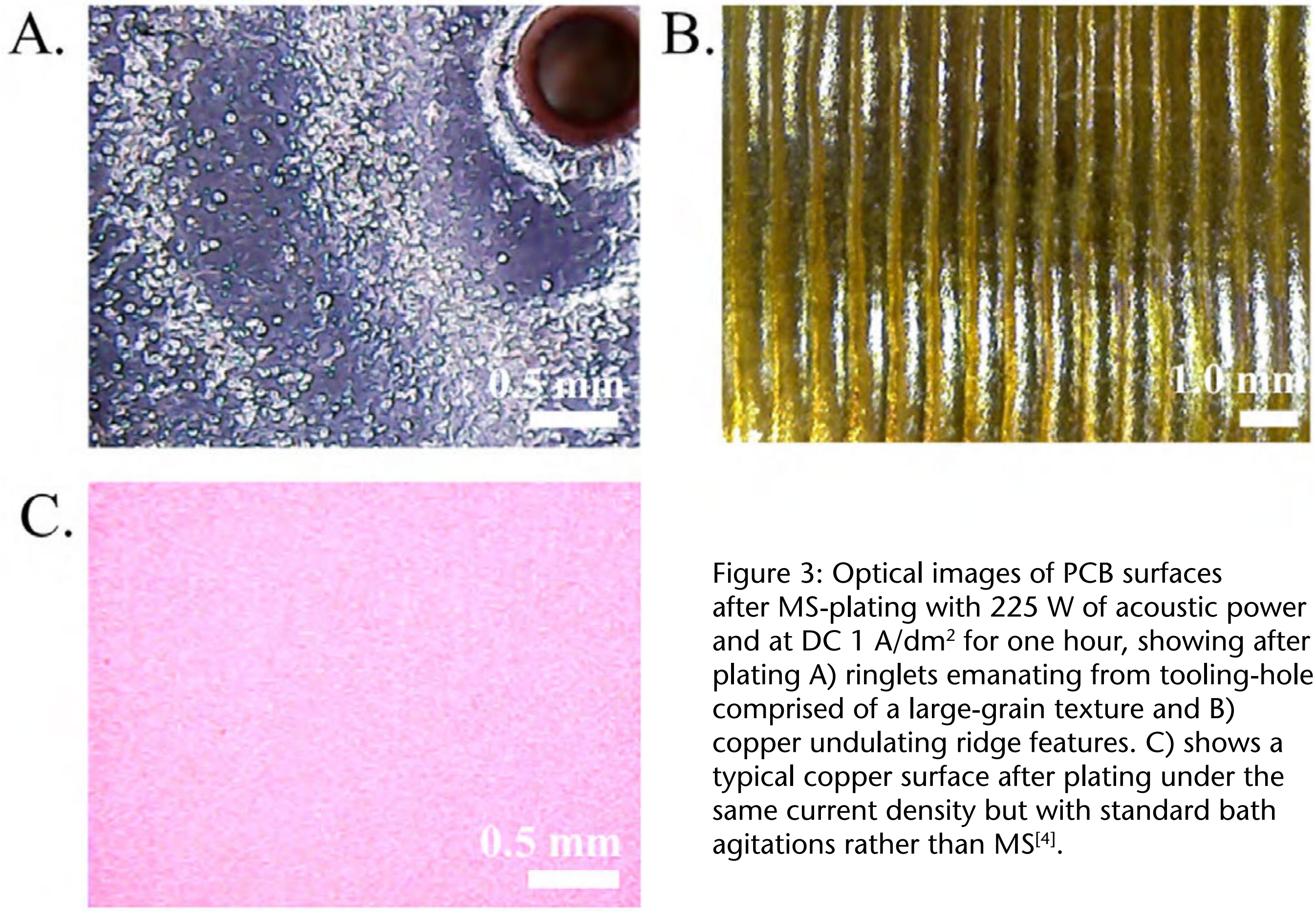


Figure 3: Optical images of PCB surfaces after MS-plating with 225 W of acoustic power and at DC 1 A/dm^2 for one hour, showing after plating A) ringlets emanating from tooling-hole comprised of a large-grain texture and B) copper undulating ridge features. C) shows a typical copper surface after plating under the same current density but with standard bath agitations rather than MS[4].

plated at 1 A/dm^2 for one hour with an acoustic power output of 225 W.

After plating, the sample was rinsed in D.I. water and dried. A variety of ridge-like features were observed on the plated copper. Shown in Figure 3A is a top-down image of the copper surface surrounding a tooling hole shown on the top right of the image. Emanating from the hole were concentric ringlets, observed as a dull finish on the PCB. The distance between the ringlets was approximately 0.7 mm, which corresponds to half the acoustic wavelength (λ) in the electrolyte solution. The appearance of the periodic ringlets suggested the presence of Rayleigh-type surface acoustic wave (SAW), which have scattered off the PCB and become confined within its surface at fixed locations[12]. The ringlets were characterised by a deposition of large grains with a fine grain region in between. Large grain formation was due possibly to low concentrations of additives at the SAW pressure maxima—these are periodic regions in a SAW where particles or organic molecules attached loosely to a surface will be maximally displaced[13]. The additives might concentrate in the pressure nodal regions, where minimum displacement occurs, increasing in concentration and encouraging a shiny, fine grain finish, shown inbetween the matte ringlets.

A matte finish characterised by a large grain structure is more structurally unstable than a fine-grain finish, as it demonstrates a greater brittleness and greater susceptibility to fracturing. A PCB has to pass thermal shock testing requirements, for example IPC-6012 standard, where the board is exposed to temperatures up to 288°C. Under these tests a brittle or large grain structuring will be more likely to degrade and cause electrical opens, effectively scrapping the circuit.

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Variations in the thickness of the surface finish were also observed within the SAW features. Shown in Figure 3B are copper ridges formed on top of the MS-plated PCB surface. The ridges are again separated by around 0.7 mm and are characterised by peaks and valleys. Ridges occurred on both sides of the board, although during some trials they would appear greater on one side of a panel rather than the other. This was possibly because of the interplay between the absorption and transmission of the wave through the PCB. The ridge orientation was typically vertical to the orientation of the board in the bath, and changes to the angle of incidence of the acoustic waves altered accordingly their positions and orientation across the surface. The ridges induced a variation of 20 µm in plating uniformity as measured from cross-sections. This variation is large and could produce a manufacturing difficulty when attempting to keep within a customer's specification for copper thickness. A typical copper surface is indicated in Figure 2C, highlighting more ideal copper plating behaviour, which is characterised by high uniformity in height and grain structure.

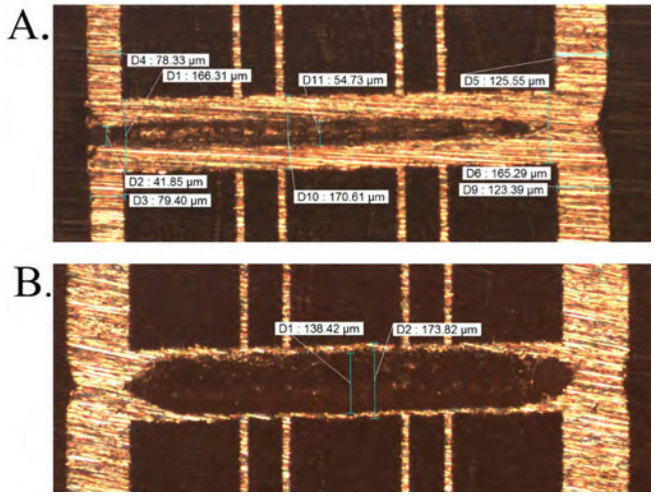

Figure 4: Plating performance witnessed down through-hole vias of diameter approximately 0.15 mm, ar = 5.7 :1, DC-plated at 0.5 A/dm^2 for a duration of 16 hours showing A) with 450 W of MS and B) without any agitation[5].

Through-Hole Via (THV) Plating Outcome

Plating within a 500-litre tank displays different acoustic reflections and characteristics than plating within a smaller 40-litre tank, due to the standing waves and acoustic streaming currents setup within the bath[14]. An experiment was performed to observe if the changes in acoustic conditions in the new bath, due to bath size and fluid flow in the tank at MCT, would still enable electrolyte replenishment down small via interconnects[5]. Plating was performed on a 1 mm thick, FR-4 PCB which contained drilled THVs of diameter approximately 0.15 mm and ar 5.7:1. 450 W of MS agitation was applied to the board with the transducer setup as in Figure 2. The board was DC-plated at 0.5 A/dm^2 for a duration of 16 hours.

Displayed in Figure 4 are the plating results for with MS agitation during the plating and without any agitation whatsoever, shown in A) and B) respectively. A thicker deposit is clearly highlighted down the MS-plated THV, which show that the changes in acoustic conditions due to operating within the new plating tank—such as convective fluid motions and the acoustic reflections off the walls of the tank—did not interfere with the MS plating performance and that fluid transport down the THV was possible, enabling a higher throwing power.

This investigation provided evidence that microfluidic motions induced by the MS acoustic streaming were sufficient to enable electrolyte to be replenished and copper deposited. A plating investigation was then performed to look at how the replenishment of electrolyte by MS compared to the standard processing techniques used in plating. This investigation is discussed next.

Blind-Via (BV) Plating Enhancement

The standard agitations applied in PCB manufacture are the movement of the PCB in solution at a rate of 3 cm/s and the application of bubbles into the solution by a sparge pipe. The action of these two agitations serves as a method of replenishing depleted electrolyte within the microvia features on a board and enables the bath to display a high throwing power suitable for the electrodeposition of copper.

A plating experiment was performed on a 1.6 mm thick FR-4 PCB drilled with 0.15 mm diameter ar 1:1 BVs, looking to observe the

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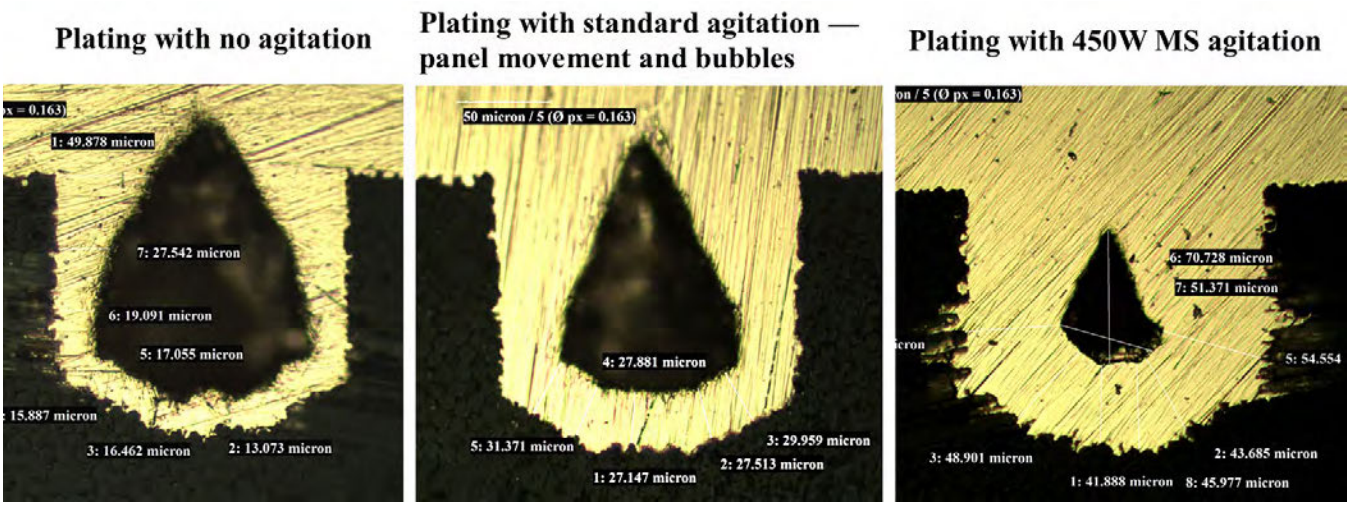

Figure 5: Microsections of blind vias of size 0.15 mm diameter ar 1:1, plated with reverse-pulse at 1:3 A/dm^2 for 12 hours, showing results for processing with different electrolyte solution agitation conditions.

copper plating outcome in response to applying different bath agitations alongside the MS. The acoustic transducer was set up as indicated in Figure 1, and the PCBs were plated with the SLOTOCOUP-CU110 plating solution. The plating solution was not configured for via filling and so it was not expected from the plating trials that a uniform filling of Cu would be observed.

Figure 5 shows PCBs plated for 12 hours under pulse-reverse—with a forwards/reverse current density of 1:3 A/dm^2—and with differing bath agitations showing A) no agitation whatsoever; B) panel movement and bubbles; and C) 450 W MS agitation. The results show clearly that with MS-assisted plating the copper thickness was the greatest. As expected, a void was formed in the middle of the via due to the non-filling copper plating properties of the used solution. Regardless, the plated result shows that, with MS agitation, greater volumes of electrolyte can be transported and the concentration replenished within the BV over the plated duration, increasing the throwing power of the bath.

Conclusions

A range of plating investigations were performed characterising the plating performance when applying high-frequency 1 MHz acoustic agitation to improve the throwing power of a copper sulphate electroplating bath.

Observations were made of a surface artifact unique to MS plating which was characterised by an increase in the copper grain size and reduction in plated uniformity. These effects were detrimental to PCB fabrication. Further studies into MS plating using an acoustic transducer, which varies the phase of the outputting wave, may be able to reduce the appearance of these features whilst maintaining the desired acoustic streaming properties[15].

When electroplating within a 500-litre tank in a manufacturing setting, the acoustic streaming currents produced by the 1 MHz acoustic wave were shown to transport electrolyte down microscale features in a THV. This confirmed the throwing power of the MS agitations and led to further investigations, which showed that throwing power was higher than the standard bath agitations when plating down BVs. The results obtained show however that considerable development steps are still required to bring MS-assisted plating up to a working standard procedure for implementation into PCB manufacture.

A particular issue in achieving high ar plating down BVs (ar larger than 1.2:1) is the lack of a sufficient copper seed layer provided by an electroless copper process. This is because of the difficulty in introducing fresh electrolyte solution into the microsized regions, due to the effective viscous forces of the fluid medium preventing electrolyte flow. It is the opinion of the

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author that, using the increased agitation ability of the MS streaming currents, it may be possible to enhance deposition during electroless copper plating, paving the way to further processing developments in the formation of high ar BVs.

Acknowledgements

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Is Exceptional Service Worth a 40% Cost Increase?

by Steve Williams
THE RIGHT APPROACH CONSULTING LLC.

Introduction

"When did this happen?" I asked myself during a recent visit to my men's only barbershop as I noticed that my $10 haircut was now $14. While I vaguely remember the price going up a little every couple of years, I really hadn't been paying attention. This caused me to revisit an article I wrote 10 years ago and research whether this 40% cost increase was reasonable.

Background

Ten years ago, I wrote my first series of columns on Lean, and one issue focused on the topic of delighting the customer. The theme of the piece was on the benefits portion of the customer delight equation and highlighted one company that truly gets it: a small neighborhood business called The Barbershop (www.thebarbershops.com). The customer delight aspect is well worth revisiting given today's business environment and ever-increasing customer expectations. First, I will take you through a typical experience at The Barbershop from a guy's point of view, which is important in this case because the customers are exclusively guys. Second, we will answer the question of the 40% cost increase over the course of the last 10 years.

Figure 1: The waiting room at The Barbershop.

The Barbershop

The company advertises themselves as "A hair salon for men," and from the minute you walk through the door it is pleasantly apparent that they are serious about living up to that motto. The waiting room is a spacious, uncluttered area that surrounds you in rich earth-tone colors and hardwood floors. There is a big-screen plasma HDTV on the wall (usually tuned into ESPN), a barrel of peanuts for your munching pleasure, and cold bottled water and fresh coffee to occupy you during your short wait for service. And the best part? Large, overstuffed leather chairs and guy magazines everywhere you look; not a Cosmo in sight! Most of us guys go to The Barbershop early just so we can relax in these surroundings (Figures 1 and 2).

The Service

When it is time for your service, your stylist leads you back to their station, where you are immediately handed a remote to operate your very own personal TV for your viewing pleasure as you get your hair cut. Another point most men appreciate is that once you sit down, you don't have to get back up again until you are done. There is no "let's go over to this station to wash your hair, then we will come back here to cut your hair" stuff,

Figure 2: Big-screen TV in the waiting room.

Figure 3: Stylist's station at The Barbershop.

everything is done at the stylist's station while you enjoy the cable program of your choice (Figure 3).

The haircut itself is unhurried and thorough, the opposite end of the spectrum from the low-cost salons that process you through with assembly line efficiency and a perfunctory regard for quality. Every minute detail is addressed, with the standard service including a beard/mustache, eyebrow, ear and neck trim.

After your haircut is complete, the stylist next washes your hair while you relax with a steaming hot towel over your face (keeping your eyes clear of course for uninterrupted TV viewing). This is followed with your choice of a blow dry and/or hair product style, and for good measure your stylist will wipe you down with a lint brush to avoid those embarrassing little hairs that always seem to pop up all over your clothes during your afternoon meetings. The final touch of guy heaven comes when your stylist straps on an industrial size vibrating massager and gives you a good old-fashioned barber neck and shoulder massage! And just like when you get your oil changed, the service includes follow-up neck and ear touch-ups between cuts.

Now for the very best part: All these services will cost you a grand total of $10 (2007 dollars)! Every time I use my wife's hair stylist, I can expect to pay conservatively triple that and the bargain speed-cut shops can't touch that price either, even after factoring in a sizable tip for your favorite The Barbershop stylist.

The Concept

I had the opportunity to speak with the owner of one of The Barbershop franchises about the origin of the concept. He told me the idea

Historical US Pricing 2007-2017				
Consumer Products	**Unit**	**2007**	**2017**	**% Change**
Newspaper	Ea.	$ 0.35	$ 1.00	186%
Movie Ticket	Ea.	$ 6.88	$ 13.69	99%
iPhone	Ea.	$ 399.00	$ 749.00	88%
Automobile	Midsize	$ 18,995.00	$ 33,560.00	77%
Air Jordan Sneaker	Pr.	$ 125.00	$ 190.00	52%
Data Plan	Mo.	$ 59.99	$ 90.00	50%
The Barbershop	***Ea.***	***$ 10.00***	***$ 14.00***	***40%***
House	Median	$ 254,400.00	$ 308,000.00	21%
PCB Related	**Unit**	**2007**	**2017**	**% Change**
Gold	Oz.	$ 636.00	$ 1,150.00	81%
Reinforced Fiberglass	Baseline	$ 113.70	$ 168.30	48%
Silver	Oz.	$ 12.85	$ 16.12	25%
Oil	Gal.	$ 2.37	$ 2.48	5%
Copper	Lb.	$ 3.10	$ 2.55	-18%

Figure 4: Price index 2007-2017. Source: US Bureau of Labor Statistics 2017.

originated out of the dissatisfaction with getting his hair cut at the traditional women-centric hair salon, and began thinking about all the things he would change about the experience if it were up to him. He began asking anyone who would listen: "Imagine getting your hair cut at a place with hardwood floors, TVs, and men's magazines; a place that offered an extended line of salon services with a personal touch, all for $10." After the initial laughter stopped, friends and family helped fine tune the idea, and the rest, as they say, is history.

The Barbershop is validation to all the Lean preaching I have done over the past 20 years; and that attitude, vision, and execution are the cornerstones of delighting the customer. The Barbershop is proving, daily, that exceeding customer expectations is ultimately more profitable when you factor in customer satisfaction, loyalty, and reputation.

The 40% Cost Increase

So, this research exercise was extremely interesting as I looked at the prices of things from 2007 and compared them to the current price. The US Bureau of Labor Statistics tracks more than you ever wanted to know about almost any product, service or commodity you can imagine, and was a wealth of information. I tried to look at big-ticket consumer items as well as some of the critical raw materials used in the PCB industry.

Figure 4 shows the cost comparison of the items selected to study, and the percent cost change between 2007 and 2017.

Conclusion

So, is the 40% cost increase for exceptional customer service justified? Well, in the case of The Barbershop, ABSOLUTELY! Compared to most comparative items in Figure 1, they have done a great job of managing costs over the past decade with no drop-off in their service level. There's a lesson there for all of us.

And besides… it's only $14. **PCB**

Steve Williams is the president of The Right Approach Consulting LLC. To read past columns, or to contact Williams, click here.

Having an Impact from the Shop Floor to the Halls of Government

by John Mitchell
IPC—ASSOCIATION CONNECTING ELECTRONICS INDUSTRIES

When you have concerns about government regulations and policies that impact your business, what can you do? Among several options, a direct approach is one of the best: Reach out to your elected officials and share your concerns. The odds are good that they will be responsive and look into ways of helping out a hometown business.

Enter IPC's "Meet the Policymakers" program, which is designed to put IPC members directly in front of the people who can make a difference. Under this program, IPC's government relations staff help arrange opportunities for those in our industry, including suppliers, PCB fabricators, EMS companies and OEMs to host their elected officials at company locations.

Site visits are one of the most effective ways to educate and influence members of Congress on the issues affecting our industry. Many officials have proven to be receptive to opportunities to meet with their constituents at IPC member companies and hear opinions about the key issues affecting their businesses.

It is also a chance for IPC members to build long-term relationships with policymakers that can be useful down the road. One recent site visit brought a representative from the office of Senator Tammy Baldwin (D-WI) to VirTex MTI in Menomonee Falls, Wisconsin. During a tour of the facility and a group discussion, VirTex MTI personnel were able to ask questions and share their concerns about the local economy and growth opportunities for their facility. The discussion focused in particular on the growing skills gap and how VirTex MTI can engage with local schools and colleges, veterans, and other stakeholders to help boost the local skilled workforce.

Based on that success, IPC coordinated a second site visit a few weeks later at its Austin, Texas facility with Congressman Michael McCaul (R-TX).

Other IPC member companies that have hosted congressional site visits in recent years have included Bay Area Circuits, Creation Technologies, Hunter Technology, Juki Automation Systems, MC Assembly, Suntronic, TTM Technologies and Viscom.

Members of Congress find the visits valuable as well. After touring TTM Technologies' facility in San Jose, California, Rep. Zoe Lofgren (D-CA) said, "The advanced manufacturing industry has contributed greatly to our economy here in California and across the globe. I was very interested to see the work taking place at TTM Technologies, and I'm glad we had an opportunity to discuss the policies that impact the industry today."

Having coordinated nearly 60 of these site visits in the United States and more than a dozen in China, the program continues to grow. IPC is now seeking to arrange "Meet the Policymaker" events in Europe, as well.

All in all, these site visits provide a unique opportunity for you to have your voice heard as a business leader, and for IPC to advance the interests of the entire industry.

For more information on the Meet the Policymakers program, contact IPC Government Relations Coordinator Julie Desisto. **PCB**

John Mitchell is president and CEO of IPC—Association Connecting Electronics Industries. To read past columns or to contact Mitchell, click here.

IMPACT 2017: Electronics Industry Leaders Meet on Capitol Hill

IPC places a high priority on making our presence known in the halls of government, to educate our government officials on the policies that will strengthen the advanced manufacturing industry. Senior executives from leading electronics manufacturing companies—all members of IPC—gathered in Washington, D.C. recently for IMPACT Washington, D.C. 2017 to advocate for a pro-growth, pro-advanced-manufacturing policy agenda.

The gathering was especially timely considering President Trump's recent moves to strengthen U.S. manufacturing, including establishing a new White House Office of Trade and Manufacturing Policy, and launching a wave of policy initiatives in the areas of taxes, trade, workforce skills, and regulations.

During the two-and-a-half day event, nearly 30 executives met with members of Congress and leaders of the Trump Administration to share

their views on issues including tax reform; federal funding for manufacturing-related research and development programs; environmental policy and conflict minerals regulations.

The electronics executives met with leaders of the Trump Administration including:

- U.S. Environmental Protection Agency Administrator Scott Pruitt
- Earl Comstock, Director of the Office of Policy and Strategic Planning at the U.S. Department of Commerce
- Kim Ford, Deputy Assistant Secretary for Education for Career, Technical, and Adult Education
- Dr. Robert Irie of the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics
- Alexander Gray, Special Assistant to the President and Deputy Director for Defense Industrial Base, White House Office of Trade and Manufacturing Policy;
- Daris Meeks, Deputy Assistant to the President and Director of Domestic Policy for Vice President Mike Pence

Participants also met with key members of Congress. To read the full article, click here.

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Position: CheckSum is seeking a senior salesperson to help us add new automotive electronics customers. We will shortly launch a new technology solution to further our throughput advantage and open doors with new customers.

Requirements:

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- Five years of experience selling CapEx electronic equipment required
- Experience selling automated board test equipment preferred
- General technical knowledge of electronics required
- Demonstrated ability to network to develop leads and multiple relationships at target accounts
- Salesforce fluency
- Strong communication skills
- Self-starter with a sense of urgency and an ability to work independently

Compensation: Negotiable depending on experience

Contact: Please send resume and cover letter. To apply, click below.

Click here to apply

MacDermid PERFORMANCE SOLUTIONS

Do you have what it takes?

MacDermid Performance Solutions, a Platform Specialty Products Company, and daughter companies manufacture a broad range of specialty chemicals and materials which are used in multi-step technological processes that enhance the products people use every day. Our innovative materials and processes are creating more opportunities and efficiencies for companies across key industries – including electronics, graphic arts, metal & plastic plating, and offshore oil production. Driving sustainable success for companies around the world, and at every step of the supply chain, takes talent. Strategic thinking. Collaboration. Execution.

The people of MacDermid Performance Solutions stand united by a guiding principle: That if it doesn't add value, don't do it. This belief inspires a unique culture where each team member has opportunities to imagine, create, hone and optimize. Do you have what it takes? Join our growing team of over 4,000 professionals across more than 50 countries with openings in research, finance, customer service, production and more.

MacDermid Performance Solutions and its affiliates are Equal Opportunity/Affirmative Action Employers.

Apply now!

CANDOR

Experienced Sales Reps Needed

Candor is an advanced printed circuit board manufacturer with a unique manufacturing process. We can genuinely stand out among conventional board shops due to our unique Simplified Process.

Join the Candor team, targeting rapid high quality prototype PCB manufacturing.

We are looking for industry experienced sales reps to manage current customers and find new leads in the USA. Candor is in a unique position to hire onto our team using a very generous sliding commission rate. Contact Sunny Patel for details.

Click here to apply

NCAB GROUP
Integrated PCB Production

Outside Sales/ Key Account Managers

Job DescriptionNCAB Group USA is looking to add to our existing outside sales team in various U.S. locations; Ontario, California and Itasca, Illinois. We are looking for sales professionals with at least 5 years of printed circuit board experience and/or Semiconductor experience and knowledge. This is a sales position that requires the ability to convert those cold calls into high-value customer meetings.

What are we looking for?

- A "hunter" mentality
- The ability to create solid customer relationships
- A desire to excel and not settle for mediocrity
- 5+ years of experience in the Printed Circuit Board or Semiconductor industry
- An excellent ability to present your product and do the "deep dive" during your customer visit by asking the open-ended questions and identifying your customer's pain points
- The energy to sell—from prospecting to cold calls to getting the "wins"
- Knowledge of "SPIN" selling
- A college degree
- An enjoyment to travel both domestically and globally
- Must be a U.S. citizen with a valid U.S. Passport

What's next? Interested?
Then send your resume to:

Click here to apply

Visit us at www.NCABGroup.com

MicroCraft

Looking for an energetic
OUTSIDE SALES REPRESENTATIVE.
Entry levels are welcomed.

Job Description: Grow business by setting up meetings with customers and handling presentations, selling products, and meeting customer needs. Required to meet customers face to face on weekly basis.

Territory: All states including parts of Canada.

Skills/Qualifications: Great communication skills; customer hospitality; meeting sales goals; closing skills; territory/account management; prospecting skills; negotiation; travel scheduling; computer and network skills (intermediate level); self-confidence; presentation skills; client relationships; motivation for sales; motivation to learn; loyalty to company; respect to customer and team member; patience; due obligation.

Plus Aspects:

- Bachelor or higher degree
- Experience in outside sales
- Knowledge of print circuit boards

MicroCraft offers:

- Domestic travel allowance
- International travel allowance
- 401(k) with company match
- 90% coverage on health insurance and dental insurance for the employee
- Life, AD&D, short term and long term Disability for the employee
- PTO and holidays
- Work environment/helpful coworkers
- The opportunities to expand your knowledge

Salary: $40,000 to $75,000 or more. Your salary depends on your sales performance. This figure includes sales commission.

Click here to apply

Contact: Kohei Maekawa

ARLON

Arlon EMD located in Rancho Cucamonga, California is currently interviewing candidates for **manufacturing** and **management positions.** All interested candidates should contact Arlon's HR department at 909-987-9533 or fax resumes to 866-812-5847.

Arlon is a major manufacturer of specialty high performance laminate and prepreg materials for use in a wide variety of PCB (printed circuit board) applications. Arlon specializes in thermoset resin technology including polyimide, high Tg multifunctional epoxy, and low loss thermoset laminate and prepreg systems. These resin systems are available on a variety of substrates, including woven glass and non-woven aramid. Typical applications for these materials include advanced commercial and military electronics such as avionics, semiconductor testing, heat sink bonding, high density interconnect (HDI) and microvia PCBs (i.e., in mobile communication products).

Our facility employs state of the art production equipment engineered to provide cost-effective and flexible manufacturing capacity allowing us to respond quickly to customer requirements while meeting the most stringent quality and tolerance demands. Our manufacturing site is ISO 9001: 2008 registered, and through rigorous quality control practices and commitment to continual improvement, we are dedicated to meeting and exceeding our customer's requirements.

Click here for more details

COAST to COAST CIRCUITS

Advanced technology manufacturer of printed circuit boards in Huntington Beach, CA is looking for manufacturer's representatives in Southern California. Please forward inquiries to Crystal Barrett. (585) 254-2989 ext. 225

Click here to apply

all flex

Flexible Circuits • Heaters • Assemblies

HELP WANTED

In order to support its continued growth and leadership position, All Flex Flexible Circuits and Heaters is seeking a TECHNICAL APPLICATION SALES ENGINEER for our inside sales team. Candidates are to have 5+ years in the PCB industry including a minimum of 2 years with flexible circuitry and/or flexible heaters. Experience in component assembly and flexible heater design is a plus.

The position involves providing extremely high responsiveness and follow-up to assigned accounts and new prospect inquiries. Although primarily an inside sales service provider, the individual must also be able to travel several times per year to support tradeshows and in-person customer support. The positon provides technical application knowledge to assist customers in the design and use of flexible circuits, heaters, and assemblies, a key service that All Flex provides.

Background to include:

- Success in a team environment
- Managing large customers – ideally in medical, military, aerospace, and industrial markets
- Proficiency in Microsoft Office Suite with good typing/keyboard skills
- Attention to detail
- Good organization skills in handling multiple activities at the same time
- Professional telephone and e-mail communication skills
- Experience working trade shows
- Good listening and customer management abilities

This position is located in Northfield, MN.

Click here to apply

ZENTECH

Zentech Manufacturing is Hiring!

Looking to excel in your career and grow professionally in a thriving business? Zentech, with locations in Baltimore, MD and Fredericksburg, VA is rapidly growing and is seeking experienced professionals in all areas: engineering, manufacturing engineering, program management, testing, QA and SMT operations. Zentech offers an excellent benefit package including health/dental insurance and an employer matched 401(k) program.

Established in 1998, Zentech holds an ultimate set of certifications relating to the manufacture of mission-critical printed circuit card assemblies, including ISO:9001, AS9100, DD2345, ISO 13485, maintains an IPC 610 Trusted Source QML status, J-STD 001 with Space Certification and is ITAR registered.

Click here to apply

Click for drone video tour of Zentech Facility

EAGLE electronics Inc.

PCB Front End CAM Engineer

Associates degree or better is required. Must have a minimum of 3 years of experience working for a printed circuit board manufacturer. Must have Valor Genesis software experience. Scripting knowledge is beneficial but not required. This is a full time salaried position on 1st shift. Pay commensurate with experience.

Click here to apply

eptac

TRAIN. WORK SMARTER. SUCCEED.

Become a Certified IPC Master Instructor

We are growing! EPTAC, a leading provider in the Electronics Training Industry is looking for some great people to join our team. If you love teaching and working with great companies in your travels, contact us.

Click here to apply

MivaTek Global

Application/SalesEngineer

Positions available Eastern, Midwestern and Western United States. Position will focus on supporting sales and applications development for Miva Technologies DLP direct imaging system with the PCB and micro-electronics markets. Experience with photoresist and imaging preferred but not required.

Service Technician

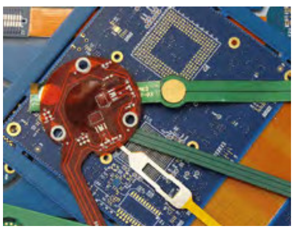
Positions available for Eastern and Western United States. Service Technicans will support our rapidly expanding installed base of Miva Technologies DLP imaging systems as well as other systems sold by the company.

Send resume and contact information for both positions to Brendan Hogan.

Click here to apply

Recent Highlights from PCB007

1 Standard of Excellence: The Advantages of Flex and Rigid-Flex Circuits



Since their introduction, flexible and rigid-flex circuits have been steadily moving from the fringe of electronic interconnection towards its center. Today, flex and rigid-flex circuits are found in countless products from the very simple to the highly complex.

2 TTM Shines a Light on Optical Interconnect

Are embedded optics on PCBs set to make a breakthrough in the upcoming years? According to Dr. Craig Davidson, VP of Corporate Technology at TTM, it might be closer than you'd expect. In a recent interview with the I-Connect007 team, Craig outlines TTM's current pursuit of high-volume manufacturing lines able to deliver embedded optical interconnect and other insights.

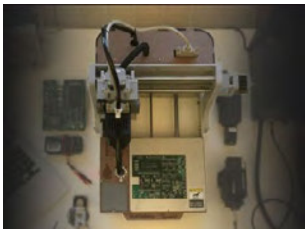
3 Punching Out! Selling a Company—Seeing it as a Triumph, Not a Defeat

Somehow, there is a still a stigma that selling a company is a negative for the owner. Many people think that there must be something wrong, otherwise, they would not be selling. However, exiting a business should be looked at as a triumph for the owner, not a defeat.

4 Material Choices for High-Speed Flexible Circuits

High-speed flexible circuits materials are now available from many suppliers. In deciding which materials to test or use, remember the tradeoffs the suppliers made in categories we discussed: electrical properties, mechanical/flex properties, and ease of processing. A choice should only be made after considering these options.

5 Flex Talk: Squink—Integrating Fabrication and Assembly in One Package



When walking through trade show expos, I tend to be drawn into product demonstrations on the show floor. Recently, at IPC APEX EXPO, I stopped in front of a piece of desktop printing equipment that was demonstrating with a flexible circuit.

6 All About Flex: FAQs for Extended-Length Flexible Circuits

Extended-length flexible circuits are larger than typically offered sizes in the interconnect industry. The length of these oversized circuits can be anywhere from two to 10 feet or longer. A long, continuous flexible circuit can offer design advantages over using normal sized circuits.

7 Ding Cheng of BYD Electronic: Embracing the FPC Factory Model of the Future

The topic of the third issue of PCB007 China Magazine is "The Wide World of Flex." Around this theme, we asked one of the leaders of China's FPC industry, Ding Cheng, general manager of the FPC Division of Shenzhen BYD Electronic Parts Company, to share his perspective about trends in flex.

8 Weiner's World—April 2017

China's economy accelerated for a second-straight quarter as investment picked up, retail sales rebounded, and factory output accelerated in March. Gross domestic product increased 6.9% in the first quarter from a year earlier, compared with a 6.8% median estimate in a Bloomberg survey.

9 All About Flex: Origami Interconnection

Origami is the art of folding paper; it was believed to have originated in Japan, but historical evidence suggests it existed in several parts of the world during the same period. Origami artistry starts with a flat sheet of paper and by making a series of folds and creases, the result is a three-dimensional figure.

10 The Right Approach: Finding the Next Generation of 'Board Rats'

Owners of printed circuit board shops across the country are united in their top concern for their businesses: finding new talent. While this problem crosses all industries, what is unique is the complexity and learning curve of our business.

For the latest PCB news and information, visit: PCB007.com

Events

For 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.

EIPC 2017 Summer Conference
June 1–2, 2017
Birmingham, Solihull, UK

IMS 2017 International Microwave Symposium
June 6–8, 2017
Honolulu, Hawaii, USA

JPCA Show 2017
June 7–9, 2017
Tokyo, Japan

FLEX 2017
June 19–22, 2017
Monterey, California, USA

IPC Reliability Forum: Emerging Technologies
June 27–28, 2017
Düsseldorf, Germany

24th FED Conference
September 15–16, 2017
Bonn, Germany

SMTA International 2017 Conference and Exhibition
September 17–21, 2017
Rosemont, Illinois, USA

electronicAsia
October 13–16, 2017
Hong Kong

IPC Flexible Circuits: HDI Forum
October 17–19, 2017
Minneapolis, Minnesota, USA

TPCA Show 2017
October 25–27, 2017
Taipei, Taiwan

productronica 2017
November 14–17, 2017
Munich, Germany

HKPCA/IPC International Printed Circuit & South China Fair
December 6–8, 2017
Shenzhen, China

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Update on the military industry

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Process Engineering
A comprehensive look at process engineering