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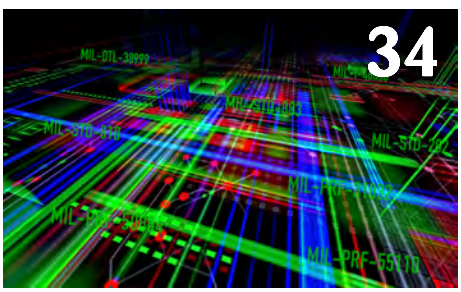
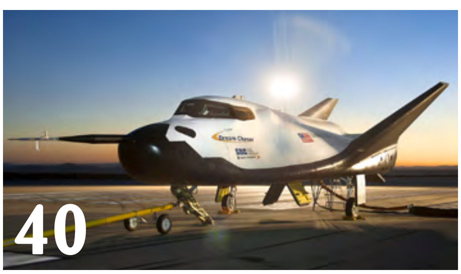
Military/Aerospace

Participating in the military and aerospace industries is not for the faint of heart, nor for those lacking persistence or looking for the quick project or sale. Our feature contributors this month, which include several of our regular columnists, provide valuable insight on the mil/aero market and what is required to be in the game.





FEATURE:

FEATURE COLUMNS:

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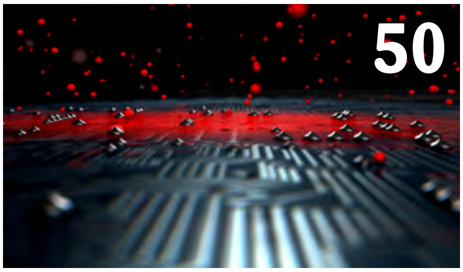

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Are We Flying Yet?

by Patty Goldman
I-CONNECT007

Walt Custer is on a photo safari in Africa and suggested I take a look at some of his slides regarding the military/aerospace market and then give a little report on it. Well, I am no Walt Custer, so while I can tell you a bit about where things are, far be it from me to make predictions.

In 2015, the military market represented 8.4% of the world market for electronic equipment production. As a comparison, the communication and automotive markets were 22.2% and 8.6%, respectively. Monthly defense equipment orders have been between \$3–3.5B for 2015, rising slightly in 2016, while inventories have remained stable at around \$6 billion. For 2015, worldwide production of military and aerospace PCBs was 5.1% of the total \$59.2 billion market. Note that all of these numbers and percentages are in dollars, which no doubt means the total percent of square footage produced for the mil/aero industry was considerably lower. See the charts on the next page.

Aircraft deliveries have seen a steady rise; predictions are for a slow, steady rise from approximately 1430 units in 2016 to approximately 1750 by 2032. In the aircraft end of things, non-military represents roughly two-thirds of the shipments (including parts).

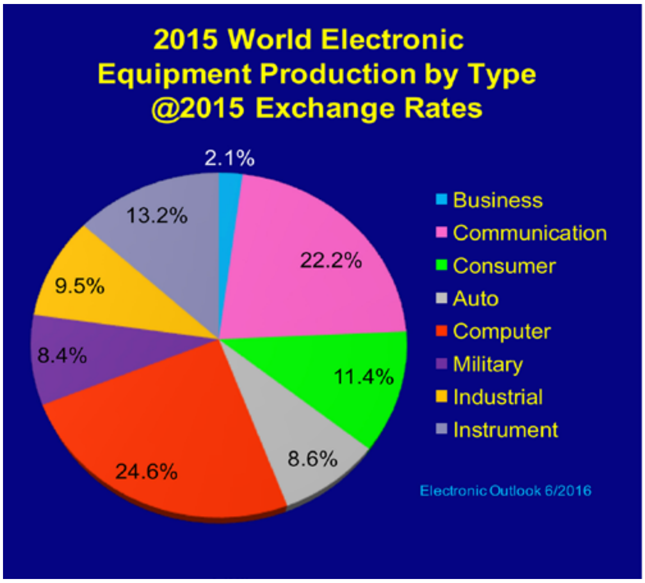
According to Walt (and others, of course) the best opportunities for North American and European PCB manufacturers are military, security and medical electronics; PCBs with intellectual property/sensitive content issues; quick-turn, prototype and novel PCBs; and those requiring close collaboration and local support. Most everyone has figured out the need for a high mix/low volume operation and often look to global (read Asia) partnerships for high-volume work.

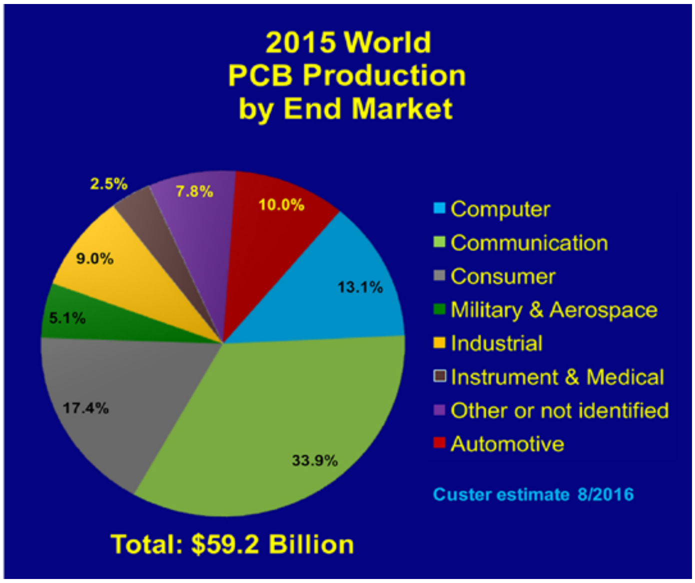
We all know that building for the military and aerospace industries is not for the faint of heart, nor for those lacking persistence and/or looking for the quick project or sale. We hope that our authors and columnists below provide some additional insight on this important market and what is required to participate.

First up, John Vaughan (Zentech Manufacturing) fills us in on recent market developments that should be of particular interest to both PCB and EMS manufacturers. He covers the F-35 and F-16 programs in detail, then discusses foreign military sales (FMS) and efforts to speed up the approval process.

Next, Dan Feinberg (Feinline Associates) explores disruptive technologies, in particular virtual and augmented reality. While we often think of VR/AR as sophisticated toys, in reality many applications are already in use involving the mil/aero industry, including training, treatment and more—a lot more.

Regular columnist Dave Becker (All Flex Flexible Circuits) discusses mil/aero specifications from the flex circuit manufacturer's point of view. He first gives us a little history on flex specs including Mil-P-50884, Mil-PRF-31032 and IPC 6013, explaining the differences along the way. Omni PCB's Tara Dunn, in her column, complements this nicely with a discussion on troubleshooting some mil/aero flex projects.





Keith Sellers (NTS-Baltimore) gives a very nicely detailed description of the pertinent MIL standards that you may come across when building military product. While he doesn't cover every single specification, as Keith says, "…the list is a good representation of common documents…associated with a PCB's or PCA's place in the military market."

Todd Kolmodin (Gardien Services) is our electrical test expert and true to form, he explores the military and aerospace aspects of electrical testing for the most common MIL-specs, covering both rigid and flexible circuits. As you can guess (or perhaps already realize), it's not all that simple.

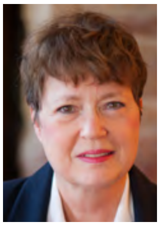
Steve Williams (The Right Approach Consulting) tells us about an aspect of the aerospace specification AS9100, namely, FOD. Originally a requirement to prevent damage to aircraft engines from forgotten repair tools and similar foreign object debris/damage, it now encompasses everything down to the bare PCB. Steve explains all parts of a good FOD program.

Taking a little break from the military side of things, Barry Lee Cohen (Launch Communications) tells us in his usual light way to "take social media seriously." He's not talking so much about the social aspect as he is the media aspect—using social media to spread the word about your company, your products, and especially your expertise. It's getting to be necessary, so we might as well bite the bullet on this one.

Last, but of course never least, we have a fine article by Happy Holden. In this segment of his Essential Skills series, Happy takes on Lean manufacturing. This one is chock full of the practical and useful information we expect from Happy.

So there you have it—a look at the industry we all love and love to complain about. Is it for you? Are you already there? Regardless, I do believe you will find much useful info in here, so keep turning the pages.

Be sure to tune in next month and learn all about leadership—what it takes to be a great leader, the changing roles of leaders, leadership training, tips on leading and more. You know you can have it delivered right to your inbox along with our daily newsletter just by subscribing here. **PCB**



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

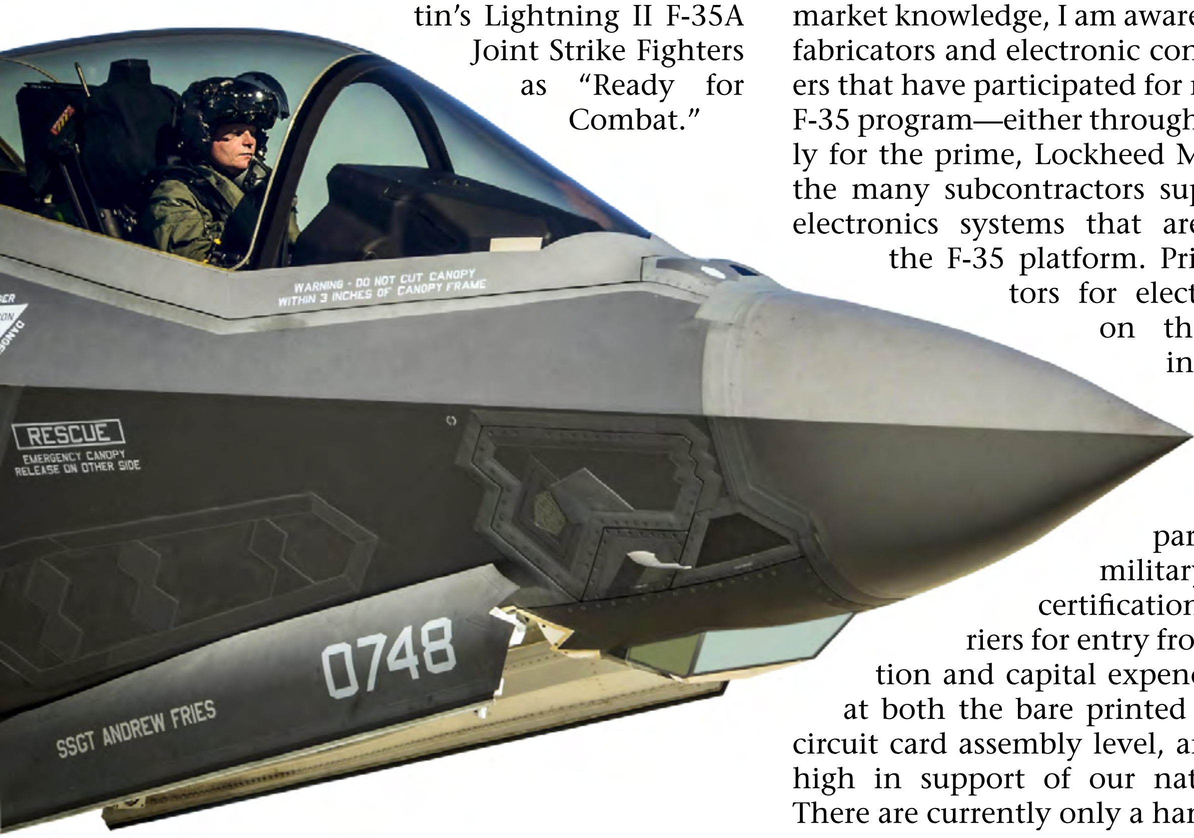
F-35 Declared Combat-Ready

John Vaughan
ZENTECH MANUFACTURING

Electronic subsystems are an integral part of all modern military fighter jets, with a substantial portion of the electronics supporting intelligence, surveillance and reconnaissance (ISR) systems, electro-optical/infrared (EO/IR), avionics, munitions and radar related subassemblies. This equates to a very high content of PCBs and SMT assembly requirements.

Let's explore recent market developments that bode well for ITAR-certified, domestic PCB and electronics contract manufacturers, particularly for those subcontractors participating on the F-35 and F-16 platforms.

In early August, after 15 years on contract—and amid considerable scrutiny and consternation over the seemingly never-ending technological development issues and cost overruns—the United States Air Force declared its first squadron of Lockheed Martin's Lightning II F-35A Joint Strike Fighters as "Ready for Combat."



"Ready for Combat" status is officially known as Initial Operational Capability (IOC) confirmation.

Previously, on July 31, 2015, the United States Marines also advised of IOC status for their F35B variant Joint Strike Fighter.

The Air Force F-35A variant IOC proclamation[1] is especially noteworthy as the Air Force is the single largest customer of the Joint Strike Fighter and plans to procure 1,763 of the F-35A fighter jets.

There are three variants of the F35 platform: the F-35A conventional takeoff and landing (CTOL) Air Force variant; the F-35B short takeoff/vertical landing (STOVL) Marine Corps variant; and the F-35C Navy carrier variant (CV). The variants are primarily distinguished by their take-off and landing capabilities.

Through my business activities and general market knowledge, I am aware of at least 20 PCB fabricators and electronic contract manufacturers that have participated for many years on the F-35 program—either through their work directly for the prime, Lockheed Martin, or through the many subcontractors supporting different electronics systems that are integrated into the F-35 platform. Primary subcontractors for electronic subsystems on the F-35 platform include Northrop Grumman and BAE Systems.

It is important to note that participation in the military sector is very certification-driven. The barriers for entry from both a certification and capital expenditure standpoint, at both the bare printed circuit board and circuit card assembly level, are understandably high in support of our nation's warfighters. There are currently only a handful of PCB fabri-

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Appropriately, the level of commitment by those that currently support F-35 through advanced certifications such as IPC Class 3 Trusted Source, IPC J-STD 001 with Space, and AS9100—and that have also made the required CAPEX and process development investments—are well-poised to enjoy near term dividends as the U.S. Air Force moves the F-35 program from its current LRIP (low rate initial production) build rate to more of a matured production status.

While a 15-year commitment to a program is certainly long, the potential reward is commensurate. The F-35 Joint Strike Fighter is full of electronics suites, has a cost per aircraft of over $100 million each, and the program is both the largest airplane and the largest weapons system procurement in Pentagon history, with a projected service life of sixty years. To those that made a sustained commitment to support the F35 program, well played!

In a March 2014 column, Foreign Military Sales: Back to the Future for Sales Opportunities, I detailed what I felt to be the tremendous upside opportunities to support legacy electronics manufacturing as the prime contractors, in a sequestered U.S./DOD budget environment, repositioned their businesses to support foreign military sales (FMS) initiatives. The column closely examined Lockheed Martin's F-16 fighter jet, the potential for increased sales of the F-16 to our allies, and identified the prime contractors that had significant electronics content position for the upgrade packages. As the F-35 consortia countries recognize that their ability to actually procure and field the 5th generation fighter (F-35) could take up to a decade, their primary near-term initiative is to purchase the 4th generation alternative F-16 fighter with upgraded electronics suites.

The demand for USA technology is so high in the FMS market, that there are now ongoing government initiatives to streamline the approval process by all the stakeholders: DoD, Commerce and State. American competitiveness in the global market is highly dependent upon the ability to expedite the FMS process, as it is a highly competitive landscape. Our current turn-time on the approval process is one to two years, with other countries offering platform alternatives to the F-16 and turning deals in months. Despite the approval delays, and highlighting the tremendous growth in FMS spending, the Defense Security Cooperation Agency (DSCA)[4] announced 2014 FMS FY spending of $34.2 billion and 2015 FY FMS spending of over $47 billion.

The upward trend continues in 2016, with Defense News[5] highlighting a Guggenheim Securities report that shows FMS spending through the first half of FY 2016 is on track to meet or surpass last year's totals. There are several pending FMS cases that could increase this substantially; one example, according to Defense News, is a pending $40–50 billion FMS military funding plan for Israel which could include F-35s, Boeing F-15s (Israeli version) and the Textron-Boeing MV-22s.

The FMS spending environment warrants a deeper dive as many munitions programs are now processing through the DSCA process in support of United Arab Emirates (UAE) initiatives to combat ISIS.

I will explore that in detail in the next column.

Lastly, for those of you attending SMTAI in Chicago in late September, I am honored to be named the Chair for Roadmaps in their Spotlight[6] session and invite you to attend. This will be a particularly informative Spotlight as we have both Mack Miller from Naval Surface Warfare Center–Crane and Chuck Richardson from iNEMI slated to present. Plan to join us for a forward technology look and to identify your technology gaps to best prepare your business for future success.

Naval Surface Warfare Center (NSWC) Crane Division[7] is chartered by the DoD as the Executive Agent for Printed Circuit Board and Interconnect Technology to ensure access to trusted technologies for critical national defense and Warfighter superiority. The NSWC-Crane Roadmap will look closely at PCB fabrication and technology, supply chain and counterfeit issues, PCB assembly, constrained materials and lead-free issues. A preview of iNEMI's Q2 2017 release of the 2017 Technology Roadmap will be presented by Chuck Richardson with particular emphasis on IoT/Wearables, Board Assembly and Optoelectronic Technologies.

I look forward to your comments, seeing you in Chicago at SMTAI to explore future technology roadmaps, and continuing to explore the expanding FMS opportunities in my next column. **PCB**

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1. www.F35.com
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3. IPC Validation Services
4. Defense Security Cooperation Agency (DSCA)
5. Defense News
6. SMTAI Spotlight sessions
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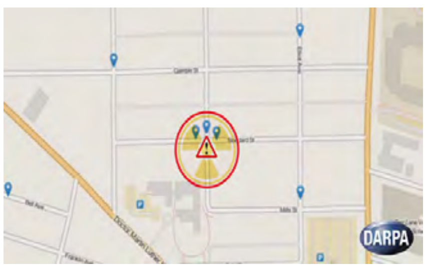
John Vaughan is vice president of Zentech Manufacturing. To contact the author, or to read past columns, click here.

Ushering in a New Generation of Low-Cost, Networked, Nuclear-Radiation Detectors

A DARPA program to prevent attacks involving radiological "dirty bombs" and other nuclear threats has developed and demonstrated a network of smartphone-sized mobile devices that can detect the tiniest traces of radioactive materials. Combined with larger detectors along major roadways, bridges, etc., and in vehicles, the new networked devices promise significantly enhanced awareness of radiation sources and greater advance warning of possible threats.



The demonstration of efficacy earlier this year was part of DARPA's SIGMA program, launched in 2014 with the goal of creating a cost-effective, continuous radiation-monitoring network able to cover a large city or region. Although radiation detectors have in recent years been installed in a number of key locations in the United States and around the world, the SIGMA program has sought to increase capabilities while lowering their costs, in order to network an unprecedented number of advanced detectors and provide a comprehensive, dynamic, and automated overview of the radiological environment.

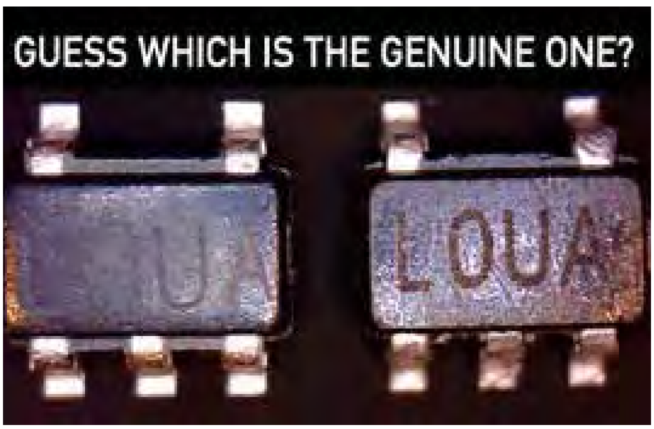
The demonstration was conducted at one of the Port Authority of New York and New Jersey's major transportation hubs where DARPA tested more than 100 networked SIGMA sensors. During the month-long test, the system provided more than a 100-fold increase in ability to locate and identify sources of radiation as compared to currently installed systems. All sources of radiation that SIGMA sensors identified were non-threatening, but the system proved how it could pinpoint the location and intensity of a source and specify, in each case, the type of radiation to which it was alerting authorities.

Disruptive Technologies—VR, AR and Star Trek

by Dan Feinberg
FEINLEIN ASSOCIATES, INC.

This article and subsequent follow-ups will cover various disruptive technologies. During the planning stage for this month's issue of *The PCB Magazine,* I was asked to consider a number of potential topics; two of them are areas that I am very interested in—augmented reality (AR) and virtual reality (VR), and 3D printing and security. Another is a topic that I do not believe gets enough coverage—counterfeit components. Faced with a difficult choice I decided to cover not one, but all, and in order to cover them in some detail they each deserve their own research and commentary. Therefore, this will be the first of at least three articles.

The topic I chose for this month is disruptive technologies, focusing on AR, VR, and mixed reality (MR). In future articles, I will cover security issues such as phishing, hacking, malicious code insertion, etc. Then, I'll cover new techniques and progress in 3D manufacturing (no longer limited to printing) as well as the growing problem of counterfeit components and assemblies.



As I look at these topics and their impact on the overall industry we cover, I realize that any of these are deserving of their own, more detailed and continuing coverage. After all, things are moving very fast and accelerating. They will be revisited at a later date.

So here we go with the game changing world of VR and AR, as well as mixed reality and how they differ. From there, I'll address what to expect in the next year and how VR/AR are far more than a gaming technology (in some cases they are perhaps better than real life), and finally, how they are changing our military and aviation industries.

Virtual Reality

VR is really not that new. Think about it—the black-and-white silent movie of the late 1800s was really the beginning of VR. If you consider 100 years ago, imagine how someone who had never seen a moving picture would feel when entering the embryonic world of VR. In the next 100 years or so, we went from jerky stuttering B&W silent moving pictures to sound and color, to higher definition and faster frame rates and 3D, all more and more immersive. In the mid-1990s *Star Trek TNG* introduced us to the HoloDeck, a vision of what very advanced VR might become. In fact, it probably will, and do so at least 100 years before it was prophesied to. In the last 20 years, and especially in the last few years, we have taken great strides, and thanks to ever-increasing computer and graphics abilities, we are about to truly enter this brave new world.

The main difference between *virtual* and *augmented* reality is that in VR you become immersed in a totally virtual world; you are transported to some place where you are not, you can interact with it to some degree, and it becomes difficult to tell the difference between what is real and what is not, at least from a sight and sound standpoint. The visuals and sound make it seem as if you were there and think about images of people with whom you are conversing, except you cannot touch, feel or smell anything (yet). With *augmented* reality a virtual world is brought into your real world. It is the blending of virtual reality and real life. Think about seeing 3D images of people to whom you are speaking while sitting in your living room as you converse. The living room is real, but the people visiting are virtual—doing and saying things while they are perhaps halfway around the world.

Both VR and AR are similar as they immerse you, but in different ways. With AR, users continue to be in touch with the real world while interacting with virtual objects around them. With VR, the user is isolated from the real world while immersed in a world that is completely fabricated or transported to you (such as the surface of an alien planet or the bottom of the ocean, or a simulated battle—whether as a game or a rehearsal for the real thing).

We stand at the dawn of this new age with this technology just being made available to the general public. It is expensive and it has significant limitations but the progress over the last few years has been amazing. Already we can see very real-looking 360-degree 3D images in high definition, we can move around in a virtual environment and we can to some extent interact with it. What will the future hold in the next quarter-century or probably sooner: Touch

Virtual reality demo playing with a whale under the sea

and feel? Smell? Taste? Anything that we can imagine may be possible and most will happen.

Right now, as of the last few months we have the following commercially available:

The VR Oculus Rift is the unit that perhaps did most to kick start and commercialize this technology. This unit requires a relatively high-power PC and the cost for just the headset is in the $600 range. The experience while using one is amazing and, as each eye gets its own HD screen, the experience is very real—extremely so. So real that some get ill or become frightened when using it.

A second unit, the HTC Vive, has added some AR features to its VR capabilities in that you can walk around within the limits of a space that you set and when you try to walk past this "safe space" you approach a transparent wall that warns you that you are exceeding the space limitations you have set. Microsoft has set up an HTC Vive demo at many of its stores. You can walk the ocean bottom and greet very real sea creatures, you can fight space aliens and you can paint and sculpture in 3D. The Vive is also just available and it seems to be modestly more capable than the Oculus Rift, but its cost is a few hundred dollars more and it also requires a beast of a PC. If you have access to a Microsoft store go and do the demo, you will be amazed. It is so real that you will have to sign an agreement stating that you accept full responsibility—I guess that is just in case the whale you encounter at the bottom of the ocean eats you.

At the other end of the spectrum is the very low-priced but interesting and actually useful Google Cardboard, a cardboard box shaped like a headset that you assemble and insert your smart phone into (with limitations as to type and size) and experience games as well as a number of other apps with more on the way. You can use Google Earth with it and fly anywhere, you can view videos on your phone in a virtual huge screen and more. While the Google cardboard costs under $30 (about $60 if you want to get a sturdier plastic version) you will need a relatively expensive smartphone.

Similar, but more capable, is the slightly higher but still very reasonably priced Samsung Galaxy Gear VR. This unit is a very capable VR viewer that holds one of the newer Galaxy smartphones. It is really fun to use but neither the Galaxy VR nor the Google cardboard come anywhere near the experience you would have with more expensive and far more capable HTC Vive or Oculus Rift units. Still, inexpensive and easy to use, a good start for those interested.

So what does the near future hold, not 10 to 20 years out, but just a few years away? We are on the verge of being able to use a full step up in the VR/AR universe. In my opinion we are about to go from B&W silent films to widescreen color stereo, from the early 1900s to the turn of the last century when comparing VR to movies. Microsoft has announced the availability of the first developers' version of the HoloLens. This potential beast is the first commercially available mixed reality unit. Mixed reality combines the

ability to roam and interact in a fully computer-generated world and overlay computer-generated information on the real world. Imagine looking out your window and seeing a new Lamborghini (wish) or having a virtual criminal break into your house so you can test your mettle with your virtual Glock. How about your favorite rock band playing in your living room or dancing with the movie star or anyone else of your choice. All that and more is coming—and soon.

The HoloLens is in development but those who want to become part of the development effort can now get one; the cost is a mere $3000 and you have to wait in line.

OK, so besides taking a virtual roller coaster ride, dancing with your idol, fighting very real looking aliens, touring very realistic underwater seascapes or mountain tops, or being immersed in and perhaps part of the next Harry Potter movie, or being on field at the 2020 Super Bowl, what else will this all lead to and how does it change the military and aeronautical world? As you might expect, a great deal.

Some of the applications already in use and growing rapidly include military training programs; the military are supporters of VR technology and development. Training programs can and will increasingly include things from vehicle simulations to ground and in-the-air combat. One would expect that VR/AR systems are much safer and are considered actually less expensive than traditional training. I have read that soldiers who have gone through extensive VR training have proven to be as effective as those who trained under traditional conditions. And now add in AR where they can practice an assault on a known target as if they were really there and they can do it with much less risk.

Additional military uses for VR and perhaps soon AR, in addition to battlefield simulation include:

- **Flight simulation.** This is in fact an area where VR has been in use for quite some time. Flight simulators have been widely used by both the military and commercial aviation for many years to learn to handle emergency issues as well as flight skills. VR is used to train combat pilots, for example helicopter pilots who have to navigate in difficult conditions, such as night flying, bad weather and under fire. They use a flight simulator and wear a head mounted display (HMD) which enables them to experience a change in perception as they move their head.
- **Teamwork.** Learning to work together as a unit, using VR weapons together which feel, look and act as real weapons.
- **Battle field medical training.** VR is now used to train medics in battlefield situations. Medical personnel have to be able to deal with a wide range of injuries caused by exposure to gunfire, unexploded devices, mines etc. Using VR enables realistic training covering a wide range of injuries—far more than could be duplicated in a lab or training operating room. Using a VR multi-platform system—which is extremely immersive—lets trainee medics engage in complex medical situations and do so over and over again with no additional expenditure of valuable or scarce resources.
- **PTSD treatment.** Per the Virtual Reality Society, "Soldiers suffering from battlefield trauma and other psychological conditions can learn how to deal with their symptoms in a "safe" environment. The idea is for them to be exposed to the triggers for their condition which they gradually adjust to. This has the effect of decreasing their symptoms and enabling them to cope with new or unexpected situations."[1]

• **Mapping out a real war.** Recently Joe Wileman, a researcher at the National Geospatial-Intelligence Agency (NGA), has reportedly said that discussions "have just started" between the NGA's immersion researchers and mobile app developers. The plan is to use a drone or even a handheld smartphone to reconstruct a war zone. At HQ, officials wearing an Oculus Rift or HTC Vive could see the field before them. On-the-ground details could be given a panoramic view for experts thousands of miles away. Perhaps soon, using MR a solder could train by being placed in a virtual battleground that he would soon visit in real life.

The uses of VR in the military are numerous and seemingly growing exponentially. The closest application to, and advanced by the PC gaming industry, is the use of VR to prepare soldiers for a real, live combat situation. Just as a gamer would learn the intricacies of battle and the environment in which they will be fighting in order to win his/her game, the soldier has to learn to deal with unexpected events, such as a failed weapon, an unexpected attack, or a situation where a comrade becomes injured and a response is needed. It is vitally important that they become as comfortable as possible reacting to dangerous settings and unexpected situations where the wrong decision or a non-practiced flinch action could mean the difference between life and death for the individual as well as their comrades.

A new innovation for the navy is the virtual torpedo. A fleet of submarines is equipped with an on-board simulator which is connected to synthetic targets. The software enables the trainee crew to fire a virtual torpedo at a synthetic target as part of a training exercise. The resulting data is then analyzed and used as part of feedback during the training process. Again, the ability to do it over and over again in order to get it right with low expenditure of resources.

Yes, setting up a VR/AR training center is expensive for the military, as is updating training software on a regular basis, but just as with commercial aviation where the use of MR has been a "can't do without" technology the value to the military for combat training, battle preparation and rehearsal, medical care and weapon use training and weapon effectiveness the payback on that investment will pay huge dividends in mission effectiveness and lifesaving techniques.

It is already in use and proving its worth, and that is just with older technology. Can you imagine what will happen with the use of technology that is right around the corner? **PCB**

Reference

1. Virtual Reality Society

Dan Feinberg is owner and president of FeinLine Associates, Inc. In addition, Dan is a technology editor for I-Connect007. To visit his columnist page or to contact him, click here.

Supply Lines
Highlights

Mentor Graphics Launches New Xpedition Enterprise Platform
Mentor Graphics Corporation today announced the first phase of the new Xpedition printed circuit design flow to address the increasing complexity of today's advanced systems designs.

Isola Names Ken Rizvi CFO
Isola announced that it has appointed Ken Rizvi as chief financial officer, effective immediately. Rizvi succeeds Interim CFO Donald Colvin, who will continue to serve on Isola's board of directors, a position he has held since 2010.

Ruwel and tw-elektric Horst Müller GmbH & Co. KG Jump Ahead of the Direct Imaging Game with Ucamco's Ledia
PCB manufacturers Ruwel and tw-elektric Horst Müller GmbH & Co. KG have integrated their industry-leading Ledia direct imaging machines from Ucamco with autoloading solutions from ASS Luippold, their specialist automation supplier of choice. The resulting systems combine robust reliability and ease of use with intelligent data management, speed, versatility and flexibility.

Rogers to Relocate Global Headquarters to Arizona
Rogers Corporation will relocate its global headquarters from Rogers, Connecticut to Chandler, Arizona. The move will build upon Rogers' presence in Arizona, where it already has major business and manufacturing operations.

UVA Teaches PCB Design with NI AWR Tools
The University of Virginia (UVA) Engineering School, the third oldest public university engineering school in the United States, is dedicated to providing significant hands-on experiences in RF and microwave circuit design to its students.

Technic Releases Techni IM Gold AT6100
Technic has announced the release of Techni IM Gold AT6100, representing a paradigm shift in immersion gold plating. In the typical ENIG process, immersion gold is a replacement reaction, whereby Ni is removed or corroded from a substrate and replaced with gold.

EMA Acquires Accelerated Designs for its Extensive Part Library and Expertise
EMA Design Automation has acquired Accelerated Designs, a company known for its dominance in EDA part library content and solutions including a 7.2-million-part database and its specialist library tool Ultra Librarian.

Heraeus and Intego Show a New Optical Inspection Method for Patterned Touch Sensors
Heraeus launches a new touch panel process to pattern Clevios conductive polymer films by DFR (dry-film resist) photolithography.

Mentor Video: Impact of Power Integrity on Temperature
One of the most common outputs from a DC Drop simulation is a current density plot. But how much is too much current density? The answer depends on temperature rise, and requires a PI-thermal co-simulation to properly characterize.

Uyemura's George Milad Addresses IPC Designers Council
George Milad, Uyemura National Accounts Manager for Technology, will conduct an important workshop on HASL Alternative Finishes, at PCB West. The workshop will be held Wednesday September 14 at the Santa Clara Convention Center.

Flex Circuit Specifications for Commercial and Military Applications

by Dave Becker
All Flex Flexible Circuits LLC

Applications across the various markets for printed circuit boards can have significantly different specifications and performance requirements. Circuits for toys and games logically have lower performance requirements than those used in medical devices. IPC 6013 is an industry-driven specification that defines the performance requirements and acceptance features for flexible printed circuit boards. This specification was drafted to recognize the differences in performance requirements for different applications. Three classes of performance and acceptance requirements have been created in it: Class 1, Class 2 and Class 3. Class 3 specifies the most stringent set of requirements and is used to specify quality requirements for products requiring the highest level of reliability. Class 3 requirements are often specified in applications for the Department of Defense (DOD), aerospace, and medical devices.

While IPC 6013 Class 3 is often used to specify flex circuits for military applications, MIL-P-50884 and MIL-PRF-31032 are two military documents also being used. These three different specifications define performance requirements for essentially the same applications and, in fact, there is significant redundancy and often confusion regarding how to properly specify product for military applications. To understand how things got to where they are today requires a review of some history.

Background

The evolution of flexible circuit military specifications can be associated with the legendary story about the $600 toilet seat. In the 1980s during Reagan's presidency, the U.S. was embarking on a major expansion in the size and capabilities of the U.S. forces. Defense spending increased dramatically, which had

some political ramifications. In the mid-1980s, the Project on Government Oversight reported the Pentagon was dramatically overpaying for commercially available items. Notable examples used were a $435 hammer and a $600 toilet seat.

In response, President Reagan created a commission, headed by David Packard, to study the procurement practices of the U.S. Department of Defense. The basic findings of the commission were that there was no rational system for specifying and procuring products. Extremely high costs were due to overly rigid specifications created by overly complicated organizations (Source). The results of these findings drove a number of efforts to simplify government procurement processes. One of these efforts was to specify commercial off-the-shelf products (COTS) when possible. Specifically, the military started to look at specifications used for commercial product as at least a guide in developing procurement specifications.

Specifications for flexible printed circuits

Previous to the 1990s, MIL-P-50884, “Printed Wiring Board, Flexible or Rigid-Flex, General Specification For” was used to define sampling plans and quality requirements for the procurement and specification of flexible circuits for DOD applications. Among other things, circuit fabricators were required to periodically submit coupons from fabricated panels for testing at a certified independent laboratory. A supplier also had to be certified as capable to build to this specification. This was accomplished by periodically producing test coupons and submitting them for examination and test for specific quality metrics. As with many specifications created before the 1990s, MIL-P-50884 was rigid and complex. The DOD decided to look at the commercial world for developing a more practical specification.

During the 1990s, IPC developed a pair of specifications intended to set universal standards for circuitry performance in known applications. Those documents were IPC-6013, “Qualification and Performance Specification For Flexible Printed Boards” and IPC-6012, “Qualification and Performance Specification For Rigid Printed Boards.” The IPC is a trade association of material suppliers, circuit fabricators and OEMs. The military worked closely with this consortium in creating requirements that could be used for military applications. They did this with the knowledge that the existing MIL-P-50884 was going to be discontinued. These IPC documents specified requirements for the three classes of circuit application as defined in IPC-6011:

- Class 1: General Electronic Products
- Class 2: Dedicated Service Electronic Products
- Class 3: High-Reliability Electronic Products

IPC 6013 Class 3 describes the most stringent quality requirements and it was the intention of the military to use this document to procure flexible circuits for military applications. This specification was also intended to replace MIL-P-50884. Unfortunately, an additional specification evolved as the DOD decided to create its own replacement specification for MIL-P-50884 (the new specification is MIL-PRF-31032) that incorporated the principles of commercial products. Further adding some confusion, there was no documentation or guidance given on what should happen to drawings specifying the discontinued MIL-P-50884 specification. In effect, the industry was left in limbo regarding what documentation should be used when drawings called out MIL-P-50884. This has generally resulted in a default to continue using MIL-P-50884 as the quality specification for legacy parts.

Flexible circuit fabricators continue building product to and are certified to MIL-P-50884. This only applies to programs designed and specified before 1999. MIL-P-50884 can no longer be used for designs specified after February 1999. Most large OEMS are procuring military and aerospace products to IPC-6013 and specifying Class 3 quality requirements but some new military documentation specifies MIL-PRF-31032. Consequently, it is possible that a circuit fabricator may be required to produce similar products/applications for three different specification requirements.

What are the differences between IPC 6013 Class 3 and MIL-PRF-31032?

IPC 6013

IPC 6013 specifies performance and qualification requirements for a flexible printed circuit board. The document specifies:

- Physical and electrical characteristics
- Performance requirements
- Raw material requirements
- Inspection methods
- Acceptance criteria
- Sampling plans
- Tests methods

IPC 6013 specifies requirements for three classes of products. Class 1 and Class 2 would normally be applicable for most commercial products; Class 3 is often required for military/aerospace products and other high reliability applications such as medical. When a supplier and customer adopt IPC 6013, they agree the characteristics and performance of the given part numbers in their contract will meet that standard. A flexible circuit supplier can produce products in accordance with IPC 6013 requirements, but there is no "certification process" required to produce parts per IPC 6013.

MIL-PRF-31032

MIL-PRF-31032 also specifies the features and performance requirements for flexible circuits. The requirements are generally similar to IPC 6013 Class 3, with some minor differences. With very few exceptions, a flexible circuit that meets the performance requirements of IPC 6013 Class 3 would also meet the performance requirements of MIL-PRF-31032. But MIL-PRF-31032 goes further and details requirements for a supplier's quality management system. This requirement is similar to the quality management aystem as defined by ISO 9000. To become certified a suppler one is required to implement a quality management plan, establish a self-assessment system, have an on-site audit performed and perform periodic self-audits.

A summary of the difference might be IPC 6013 applies to products; MIL-PRF-31032 applies to the quality management system and the products. A company does not become certified or qualified to IPC 6013 as the quality of the end product governs compliance with the specification. But a fabricator does need to be certified to MIL-PRF-31032, by the Department of Defense DLA (Defense Logistics Agency). Approval of a supplier's documentation and an on-site audit approval are required to build product that meets the requirements of MIL-PRF-31032 or MIL-PRF-50884. The OEM generally defines the specification determining whether a supplier must be certified to MIL-PRF-31032, however for some military programs, the DOD may require an OEM only use a supplier that is MIL- PRF-31032 certified.

Differences in performance and features in IPC 6013 Class 1, 2, and 3 are often slight and in general there is little reliability sacrifice among the three classes. The following categories include cases where Class 3 differs from Class 1 or Class 2.

- **Design features/characteristics:** There are a number of instances where a Class 3 circuit has more stringent design requirements, either directly stated or implied, based on manufacturing tolerance specs or performance in testing. Some examples include: Gold-plated fingers must be plated thicker for Class 3, or larger annular rings must be designed around vias.
- **Manufacturing tolerances:** Class 3 circuits have tighter tolerance requirements for a number of features such as conductor width and spacing reduction, copper thickness, solder wicking, soldermask adhesion and stiffener registration are examples. At least 30% of the specific features and criteria documented in IPC 6013 have tighter manufacturing tolerances for Class 3 than for Class 1.
- **Testing or Stress performance:** Most of the performance testing criteria are the same between Class 2 and Class 3 with a couple of exceptions:
  - Dielectric withstand voltage
  - Insulation resistance after exposure to moisture
- **Materials:** IPC 6013 has specific requirements for all materials for a flexible circuit, but there are no materials uniquely specified for a given class. In most cases material sets that

meet Class 1 requirements would meet Class 2 and Class 3.

• **Quality Conformance:** Class 3 products have more rigorous requirements for quality conformance measures. In general, Class 3 products are required to use a more discriminating sampling plan and many of the conformance tests need to be performed at a higher frequency than Class 2 or Class 1.

It was mentioned that MIL-PRF-31032 specifications are very close to IPC 6013 Class 3. While this is largely true, there are some differences worth noting. The following are a few examples:

• MIL-PRF-31032 specifically states that tin plating is not allowed; IPC 6013 class 3 allows tin plating

• MIL-PRF-31032 sets a different conductor thickness reduction allowance for electrodeposited copper (ED) versus rolled annealed copper (RA). IPC 6013 does not distinguish between the two copper types for thickness requirements

• MIL-PRF-31032 sets the requirements for minimum conductor space and width reductions as “As Specified” whereas IPC 6013 states a specific percentage (20%)

Many believe that, from a true performance standpoint, there is little or no difference between products built to IPC 6013 Class 3 versus MIL-PRF-31032. Much of the criteria and wording is the same and in fact MIL-PRF-31032 will refer to IPC 6013 for many of its feature requirements. Most of the differences that do exist are inconsequential to product performance. **PCB**

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

I-Connect007 Survey: A Look at the Mil/Aero Industry

In a recent I-Connect007 survey on the military/defense and aerospace markets, respondents were asked about their greatest challenges regarding PCB design, fabrication, and assembly; their customers' demands; whether lead-free components are still an issue; and compliance challenges.

Their biggest issues include reliability, outdated drawing/specifications, component obsolescence, complicated paperwork and documentation, counterfeit components, quality, and compliance to standards.

According to our survey, most companies no longer have any issues on lead-free components, which was the case as the industry transitioned to RoHS compliance. While the supply chain consists of lead-free components now, companies have figured out what to do to work with them. However, the only problem still is cost.

Some issues, on the other hand, include controlling phosphate levels in lead plating, reflow temperature compatibility, and connection reliability.

The International Traffic in Arms Regulations (ITAR) is a set of United States Government regulations on the export and import of defense-related articles, related technical data and defense services. EMS providers creating electronics subassemblies for military/defense applications are required to register with the Directorate of Defense Trade Controls (DDTC) in order to be ITAR compliant.

Respondents indicated that ongoing compliance is the biggest issue when it comes to ITAR, especially with global enterprises.

According to the respondents, the classifications are not based on an understanding of the technology, but rather, they are political, and as such subject to intense lobbying efforts. They are also changing frequently, which leaves companies scrambling to reclassify parts of their designs on the fly.

Troubleshooting Flex Circuit Applications for Mil/Aero Projects

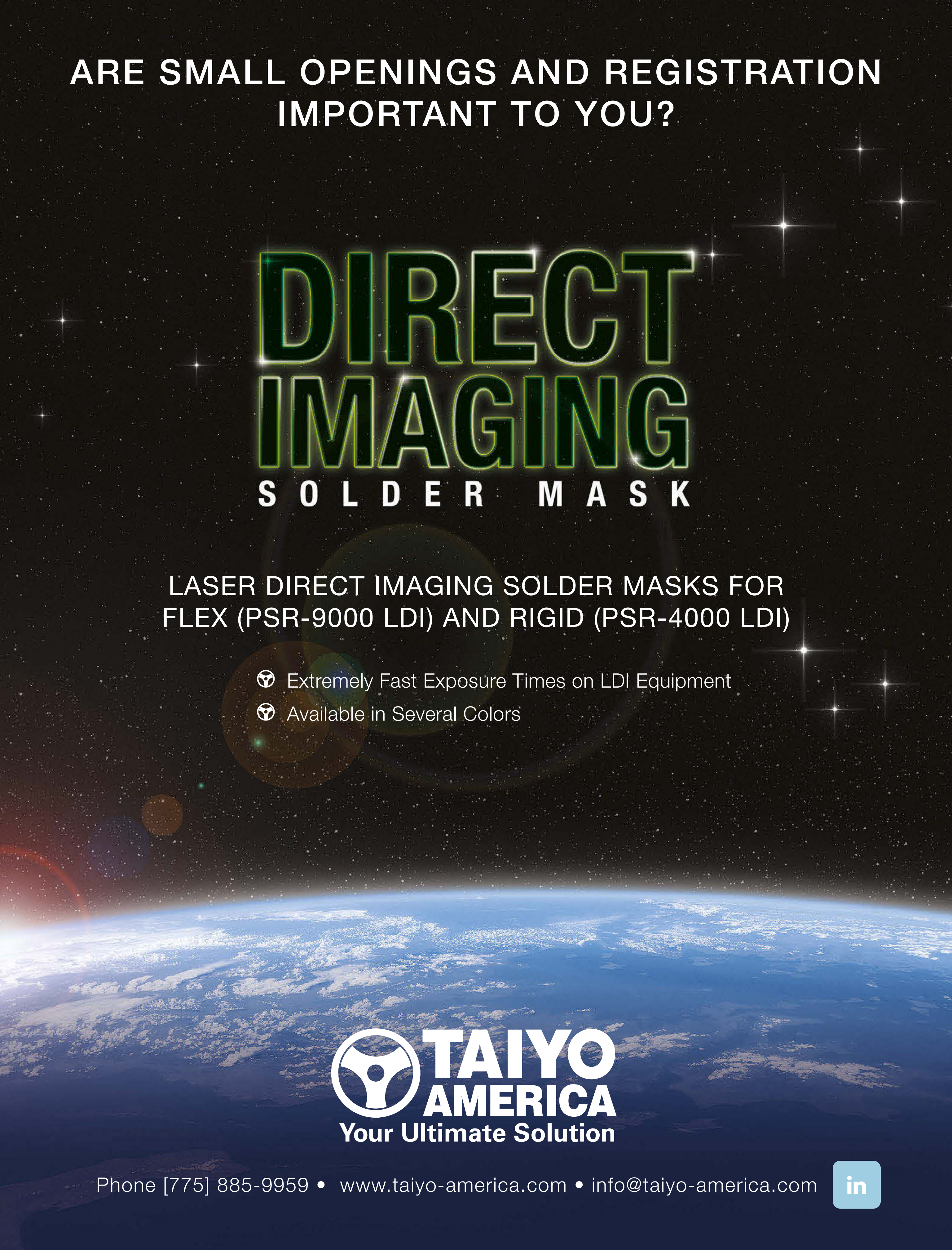
by Tara Dunn
0MNI PCB

I imagine that everyone has been in this position at one time or another: Despite everyone's best attempt at creating the perfect design, PCB fabrication and assembly, something goes wrong and the troubleshooting begins.

I had the opportunity to sit down with Ed Knutson, the president and founder of Dimation, to swap some of our best war stories. Ed specializes in quick-turn assembly and design. Our banter, to which I brought the fabrication piece of the puzzle, was primarily focused on flexible circuit applications for mil/aero projects. I am not sure if that is because of the more stringent requirements for those applications or because we both work regularly in that industry segment. At the end of our discussion, we concluded that most of our war stories could be traced back to a breakdown in communication and often simply not fully understanding how each piece of the design-fabrication-assembly puzzle fits together. Here are a few of our stories and lessons learned.

UL Materials

Aircraft applications typically require materials rated to UL94V-0. The assembly is complete and the burn test fails. What happened? The perfect storm. When the design files were created for fabrication and assembly, the UL requirements were noted in the assembly files only and called out by test requirements, not UL 94V-0. This was an ITAR application, so the PCB fab files were separated from the assembly files and forwarded to the flex manufacturer. Because there were no UL requirements listed on the fabrication notes, the supplier defaulted to their standard materials and the flex was not built with flame-retardant materials. That ex-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plains why the final assembly failed the burn test. Lesson Learned: Always clearly communicate UL requirements and include the requirement in both the PCB fabrication notes and the assembly notes.

Coverlay

There were many stories along this line, but this one is classic; we have both seen this more than once. A particular application on a tiny flex circuit requires a very tight pad pattern. Standard, adhesive-based coverlay, was called out in the stack up. As the flex manufacturer was setting up the tooling, they asked if that area could be "gang opened" because the tight features would cause fabrication issues when aligning the drilled coverlay. That is a very common question that I have seen asked and approved hundreds of times. The designer agreed that this would be fine and that pad location was left free of coverlay. But once the parts arrived at the assembler and they went to screen print the paste, the area shorted out. The problem was ultimately solved by using photoimageable coverlay to accommodate the tight feature pattern. Lesson Learned: Review even the standard requests with a critical eye for the next processing steps the flex will see after fabrication. The size of this particular flex combined with the tight features was the perfect combination to cause an issue with something that is routinely done.

Bend Radius

By definition, flexible circuits are designed to bend, fold, and flex during installation and/or use. That doesn't mean that the copper will not crack or break when it is overly stressed. There are two very important things to be aware of. First, let's look at rolled annealed (RA) copper versus electrodeposited (ED) copper. There really is a significant difference in ductility. With a tight bend radius, or for a dynamically flexing application, specify RA copper. Second, involve your fabricator. The flex manufacturer is only going to see the design in a two-dimensional view. They will not know exactly how this is going to be used in your final assembly. If you are concerned about bend radius or otherwise stressing the copper, ask for their advice. There are many different tricks of the trade that a flex fabricator can recommend to ease the stress on the copper and improve performance. Use their knowledge!

Array Configuration for Assembly

It is common knowledge that assembling flex can create challenges. A lot of trial and error is done to find the best way to handle it. Flex circuit size, array configuration, component placement and stiffener requirements all play into the decision, which just may be equal parts art and science. The first decision is whether the assembly will be done by hand or machine. If the assembly is not done by hand, whether to use a stiffened array or machined pallet needs to be determined. Here are a few examples:

1. For a small flex, with a few components on just one side and no stiffener requirements, consider creating an FR-4 stiffener pallet with adhesive on the outside perimeter only (Figure 1). After assembly, the flex can easily be peeled away from the stiffener pallet. Caution: a stiffener pallet with adhesive in selected areas only can easily be misunderstood during fabrication. Make the objective very clear in the fabrication files.

2. For a long flex with stiffeners, we suggest cross-hatching the copper, or adding in a copper pattern to maintain as much of the copper

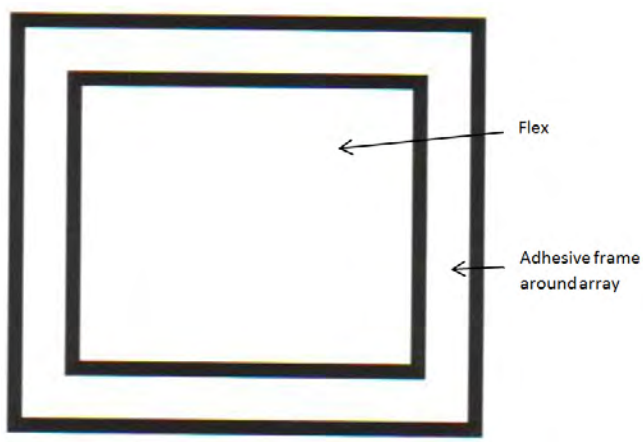


Figure 1: Array option with adhesive frame bonding the flex array to FR-4 for assembly.

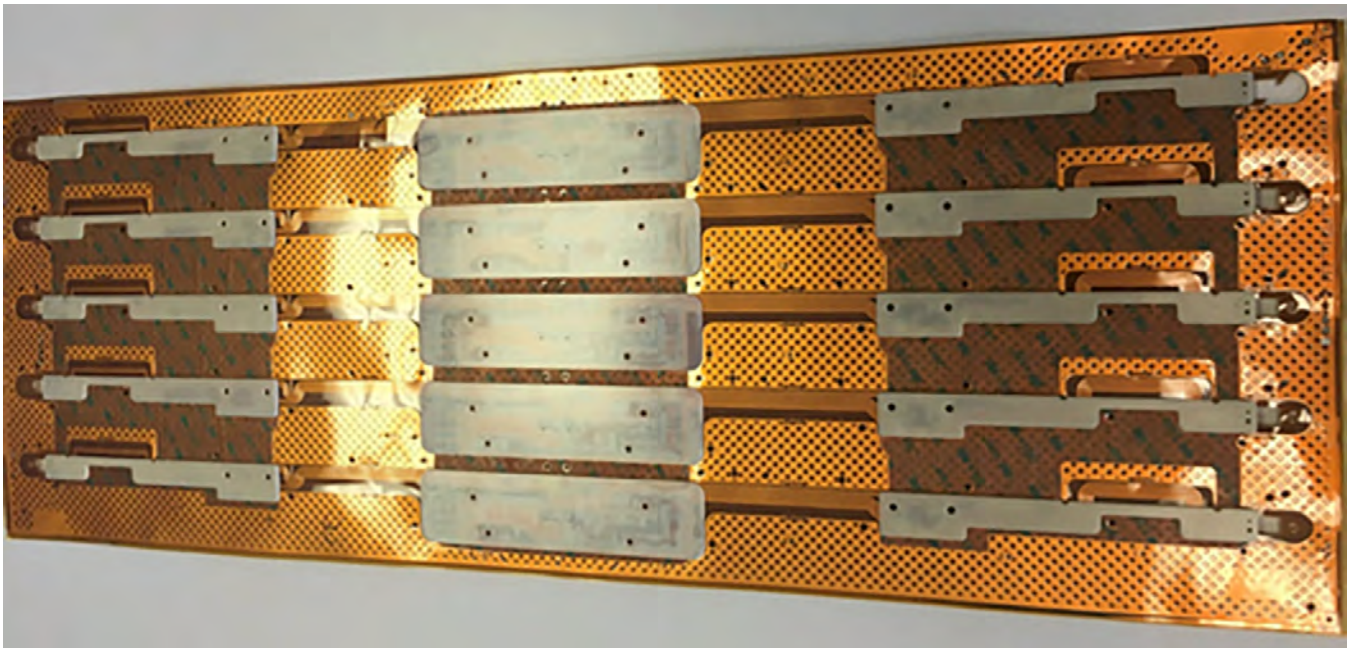


Figure 2: Full panel array with cross-hatched copper and stiffeners.

in the array as possible to add stability. The flex can be pre-routed with tabs left to hold this into the array during assembly. Once parts have been assembled, simply cut the tabs to release the flex from the array. Caution: stencil tolerance over this long length is an issue to be aware of.

3. A custom pallet is another common choice for assembly, especially when you are running more than a few panels. Most often this is designed with FR-4 material. The benefit to this is stability and flatness during assembly and also the ability to nest the flexible circuits in the tightest configuration possible to reduce the cost of the fabrication. There is no need to add in extra copper area in the array for stability.

These are just a few of the lessons learned that we have accumulated over time. I hope that they provide insight and information that will help with your future flex designs, or at the very least, let you commiserate and know that you are not the only one challenged with these types of issues. Feel free to get in touch and share your stories with us! **PCB**

Tara Dunn is president of Omni PCB. To contact Dunn, or read past columns, click here.

Wanted: Ideas for Protecting Against Small Unmanned Air Systems

The evolution of small unmanned air systems (sUAS) technologies is fueling the exponential growth of the commercial drone sector, creating new asymmetric threats for warfighters. sUASs' size and low cost enable novel concepts of employment that present challenges to current defense systems. These emerging irregular systems in diverse environments require technology advancements to quickly detect, identify, track, and neutralize sUASs while mitigating collateral damage and providing flexibility to operations.

Does your Product have a Military Application?

by Keith M. Sellers
NTS-BALTIMORE

Just like any other industry segment within the circuit board world, the military sector has its own share of documents…and likely many more than most! These documents have been developed over the years to guide, shape, and test anything and everything that might go into a jet fighter, a radar system, a warship, a weapons system, etc. Even though military technology and equipment has certainly become more dependent on electronics over the more recent years, this industry has always been at the forefront of technological breakthroughs and thus their testing protocols have been around for decades. Believe it or not, for example, MIL-I-46058, mentioned in more detail later, has been around for more than 50 years!

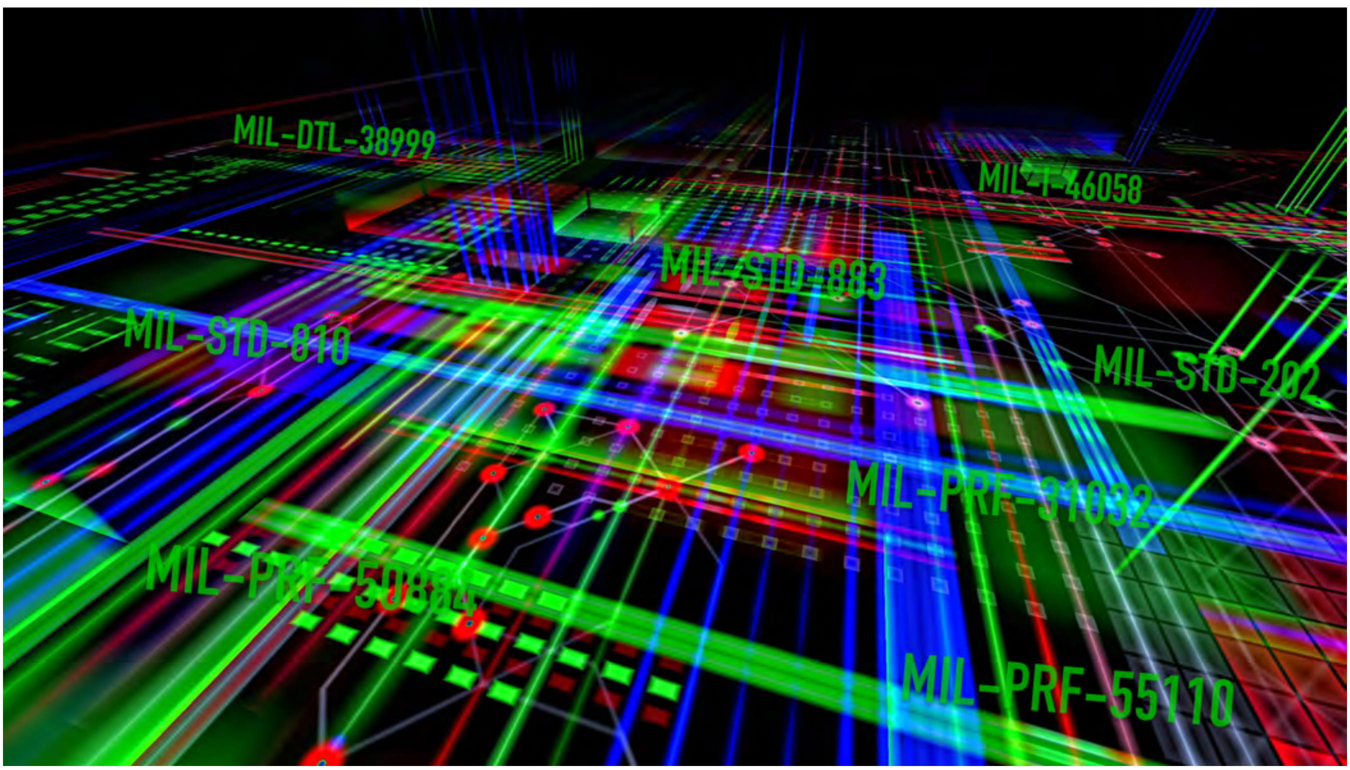
In this column, a brief taste is supplied of the common military testing documents that guide PCBs, printed circuit assemblies, and some electrical components in this most complicated of industries. The summaries below give you a short description of these common documents in respect to their focus and structure.

MIL-DTL-38999

This military detail specification covers four series of electrical connectors that are capable of operation from -65°C to +200°C. The series includes connectors containing pin & socket contacts with the document providing information pertaining to orientation guides, hermetical sealing, and EMI shielding. Additionally, guidance is presented with respect to the various mechanical, environmental, and electrical tests that are required, including specific test requirements for different classification ratings.

MIL-I-46058

This military specification was established for the qualification of electrically insulative compounds used for coating printed circuit assemblies. These compounds are commonly re-



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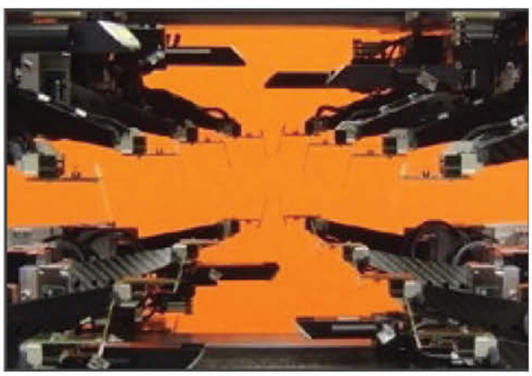

Test area:	610 mm x 620 mm (24.0" x 24.4")
Number of test heads:	16 (8 top + 8 bottom side)
Smallest pad / pitch :	35 µm (1.4 mil) / 80 µm (3.2mil)
Test voltage:	Up to 1000V
Max. measurements / minute:	Up to 15000 measurements /min. *
Loading capacity:	390 mm , max. 80 kg weight
Max board weight:	20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

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ferred to as conformal coatings within the circuit board industry. The document, although officially inactive since 1998, is still widely used throughout the printed circuit board/assembly industry to this day and contains various visual, electrical, and environmental test methods, pertaining to the analysis of the coating material itself.

MIL-PRF-31032

This military performance specification was established to test printed circuit boards and printed wiring boards in a manner that would certify they meet the necessary requirements for military use. Successful completion of the certification/qualification process results in a company being listed on the qualified manufacturer's list (QML)—a resource that others can use for various other aspects of the marketplace. As for the document itself, requirements for obtaining the QML listing are obviously included, along with appendices that address various requirements/methods grouped by technology and specific end use.

MIL-PRF-50884 and MIL-PRF-55110

These military performance specifications were established to test flexible and rigid-flex printed wiring boards (MIL-PRF-50884) and rigid single-sided, double-sided, and multilayer printed wiring boards (MIL-PRF-55110), as they pertain to military use. The main document contains general information about the qualification process, with various appendices dedicated to topics such as: the qualified products list (QPL), the QML (as mentioned in the MIL-PRF-31032 section above), testing products to superseded design standards, as well as requirements for this qualification specifically.

MIL-STD-202

This military test method standard was established for the testing of electronic and electrical component parts. The methods contained within the document set guidelines for environmental, physical, and electrical tests, in line with conditions expected for military operation. The test methods are grouped in the following way: environmental tests (100 class), physical characteristics tests (200 class), and electrical characteristics tests (300 class).

MIL-STD-810

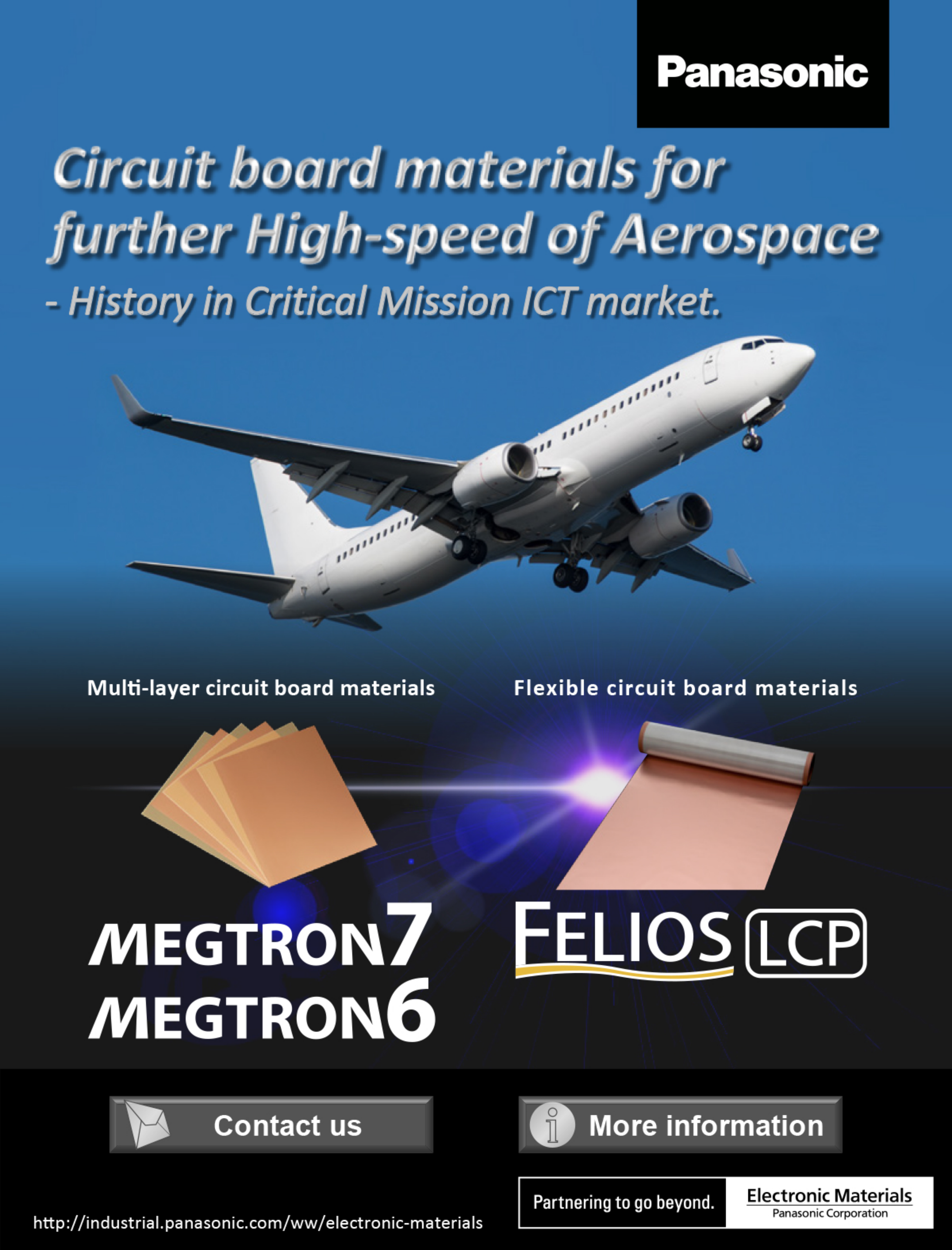
This military test method standard is not so much a collection of test methods, although it does have some, but more so a document to help engineers, analysts, and managers with material selection. Specifically, the direction of the document is to marry an environmental test screening process with expected design and end use environment.

MIL-STD-883

This military test method standard was established for the testing of microelectronic devices that are destined for use within military and aerospace systems. The document as a whole is comprised of environmental, mechanical and electrical tests, as well as workmanship and training procedures that have been shown to ensure a specific level of quality and reliability. The test methods are grouped in the following way: environmental tests (1000 series), mechanical tests (2000 series), electrical tests—digital (3000 series), electrical tests—linear (4000 series), and test procedures (5000 series).

The above descriptions are general in nature and by no means cover all of the documents that govern the military electronics world. That being said, the list is a good representation of common documents that are typically associated with a PCB or a printed circuit assembly's place in the military market. At the same time, it is not uncommon for those desiring high levels of quality and reliability to test to these same documents even if the end use of the specific product is not military in nature. After all, the military realm is one sector of the market always looking for the best products and the most dependable equipment. **PCB**

Keith M. Sellers is operations manager with NTS in Baltimore, Maryland.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Panasonic Corporation
http://industrial.panasonic.com/ww/electronic-materials

MilAero007 Highlights

DoD Announces Groundbreaking Policy to Stop Counterfeits

The Department of Defense (DoD) yesterday issued a new regulation that will greatly reduce the risks of counterfeit microelectronics entering the military supply chain.

Congressman Bill Johnson Visits TTM Technologies Manufacturing Facility in Ohio

Congressman Bill Johnson (R-OH-6) met with executives and employees of IPC-member company TTM Technologies, Inc. at their manufacturing facility in North Jackson, Ohio. Coordinated by IPC, this visit is part of an ongoing effort to help policymakers learn first-hand about legislative and regulatory issues that impact the industry.

Multiple Markets Merge for PCBs at H&T Global

While at the SMTA-Ohio expo I met Rob DiGiovanni, VP of sales and marketing with H&T Global, a printed circuit manufacturer based in Florida. I was attracted to the H&T booth by a large photo of an Army jeep. I wanted to learn what this particular photo had to do with PCBs, and Rob had a ready answer.

Event Review: 7th Electronic Materials and Processes for Space Workshop

This year's Electronic Materials and Processes for Space Workshop discussed a wide range of technology issues and developments when it comes to PCB fabrication and assembly for space applications. From addressing reliability issues to dealing with cracks that may form during thermal cycling, to REACH regulations and their impact on space hardware, and tin whisker growths.

Space Launch System Rocket Gets Updated Adapter for Journey to Mars

NASA's Space Launch System (SLS) rocket is designed to be flexible and evolvable to meet a variety of crew and cargo mission needs, and with an exploration upper stage (EUS) planned for future configurations, the rocket will require a new adapter to connect it to the Orion spacecraft.

American Standard Circuits Now Provides DFM Software

Anaya Vardya, CEO at American Standard Circuits, announces that ASC is now providing free Design for Manufacture (DFM) software on their website. Customers can simply upload their Gerber files to ASC's server and within approximately 60 minutes they will be emailed a detailed summary in PDF format.

LPKF Equips German Armed Forces with Circuit Board Plotters

LPKF ProtoMats machine conductive patterns out of fully coated substrates by contour milling. Contact and mounting holes are then drilled. The vision system integrated in the ProtoMat E44 helps reliably detect the substrate position on the working surface to ensure that the same area is covered on the front and back sides.

Flex is Where it's at

At the recent SMTA-Ohio Expo event, Jack Baculik of Circuits LLC speaks with I-Connect007's Patty Goldman about the latest developments driving demand for flex and rigid-flex circuits.

Smart Weapons Market Worth $15.64 billion by 2021

The report "Smart Weapons Market by Product (Missiles, Munitions, Guided Projectile, Guided Rocket, Guided Firearms), platform (Air, Land, Naval), Technology (Laser, Infrared, Radar, GPS, Others) & Region—Global Forecast to 2021," published by MarketsandMarkets, the market is estimated to reach USD 15.64 billion by 2021, at a CAGR of 6.3% between 2016 and 2021.

Military Satellites Market to Reach $14.37B in 2016

The military satellites market is set to be worth $14.37 billion in 2016, resulting from several major contracts in the United States, Israel and Russia and continuing satellite fleet modernization in China and India, according to a new report by visiongain.

Testing Military/Aerospace–Houston, We Have a Solution

by Todd Kolmodin
GARDIEN SERVICES USA

This month we will dive into the testing of aerospace and military product. These designs require special processing in many cases above and beyond the IPC standards. The main specifications used when testing military product are MIL-PRF-55110, MIL-PRF-50884 and MIL-PRF-31032. All of these specifications have gone through revision changes over the years so for the sake of our discussion today I will only be referencing the current revisions as of today.

From a testing perspective in today's electrical test theatre, the question of whether flying probes can be used to test this type of product is quite common. Historically, fixture testers were used for testing military and aerospace product. With the complexity of designs today and the cost of manufacturing fixtures, the requirement for testing on fixtures is not always the case.

As of September 2015, IPC released revision "D" of the IPC-6012 Specification for the Qualification and Performance Specification for Printed Wiring Boards. Historically there was an appendix in the specification for Aerospace and Military Avionics. For electrical test this was important as it stated requirements above and beyond the IPC-Class 3/C standard. With the release of revision "D" of the specification there was also a separate release of IPC-6012DS. This supplemental document titled Space and Military Avionics Applications Addendum to IPC-6012D moves the historic appendix to this new document. This should be reviewed for changes from the previous revisions.

The main document reference for standard testing still remains IPC-9252A w/Amendment 1. This document still outlines the methodology

and requirements for electrical testing of unpopulated printed wiring boards. (Spoiler alert: There is a revision B forthcoming.) Both the IPC 6012 and military specifications tag this document as reference.

With that said, let's now explore the military and aerospace aspects of electrical testing. From the aforementioned military specifications, we will first look at MIL-PRF-55110. This specification rests at revision "H" w/Amendment 1. Although this specification is still called out in today's manufacturing, it actually was retired in December 1997. Although the specification is still maintained for historic builds the notation on the cover states that post December 1997 MIL-PRF-31032 should be used. The main question here is whether I can flying probe my product under this specification or do I have to build fixtures to test? The simple answer is yes. The use of flying probes for testing under this specification is allowed. Requirements are specified in section A.3.7.5 and A.4.8.5[1]. Industry standard adjacency window value is used however unless otherwise specified vertical adjacency must also be used. The used of indirect testing by signature comparison is also allowed. See section A.3.7.5.1 of the specification for reference on this attribute.

MIL-PRF-50884 is the specification around flex and rigid-flex circuits. The specification rests as MIL-PRF-50884 "F" w/Amendment 1. Again, the question regarding fixtures or flying probes? Again, the answer is yes. These requirements are listed beginning in section A.3.7.5[2]. The use of indirect testing by signature comparison is also allowed for production screening. See section A.3.7.5.1 of the same specification.

Now the big one, **MIL-PRF-31032.** This is the new specification "Printed Circuit Board/ Printed Wiring Board, General Specification For." This specification currently rests at revision "B" w/Amendment 1. The caveat here is that though this is the general specification there are list of build classifications with different performance requirements. These are referred to as the "Slash Sheets." This is where it can get tricky. One requirement from the Defense Logistics Agency Land and Maritime is that when a test is performed and the Certificate of Compliance is generated they require not only the specification used but the specific class and amendment level. There are six class levels under the MIL-PRF-31032. They are: /1C w/Amendment 2, 2B w/Amendment 1, 3B w/Amendment 1, 4B w/ Amendment 2, 5A and 6A. Each of these address a specific build class. A proper Certificate of Compliance for testing product under this specification would have on it for example: MIL-PRF-31032B w/Amendment 1 /2B w/Amendment 1. This could be shortened to MIL-PRF-31032B-1 /2B-1 if your system reconciled the notation to the specific revisions of the specification and slash sheet. The requirement is to have the specific revision and amendment levels noted on the Certificate of Compliance. This is important as a yearly report is required by the DLA for all product tested under the Military Specifications. Suitability labs are required to provide this. For an independent or captured test facility knowing just that it is MIL-31032 is NOT enough. The specific revisions and sub class are also required information. If not provided it should be researched prior to performing and certifying the product electrically.

Slash Sheet	Table 1: MIL-PRF-31032B w/Amendment 1	Fixture	Flying Probe	Indirect
1C w/Amendment 2	Printed Wiring Board, Rigid Multilayered, Thermosetting Resin Base Material, with or without Blind and Buried Plated Through Holes	X	X	X*
2B w/Amendment 1	Printed Wiring Board, Rigid, Single and Double Layer, Woven E-Glass Reinforced Thermosetting Resin Bas Material, With or Without Plated Holes	X	X	X*
3B w/Amendment 1	Printed Wiring Board, Flexible, Single and Double Layer, With or Without Plated Holes, With or Without	X	X	X*
4B w/Amendment 2	Printed Wiring Board, Rigid -Flex or Flexible, Multilayer, with Plated Holes, With or Without Stiffeners	X	X	X*
5A	Printed Wiring Board, Rigid, Multilayered, Thermoplastic, Thermosetting, or Thermoplastic and Thermosetting Resin Based Material with Plated Through Holes. High Frequency.	X	X	X*
6A	Printed Wiring Board, Rigid, Single and Double Sided, Thermoplastic Resin Base Material, with or Without Plated Through Holes. High Frequency.	X	X	NO
	* Production Screening			

Table 1: MIL-PRF-31032B w/Amendment 1.

Okay, the question again regarding fixture vs. flying probe? With this large specification I have created Table 1 outlining the specific “Slash Sheets”[3] and allowances therein.

Also remember that when testing military/aero product the specifications require monitoring of atmospheric conditions at the time of test. These traceability records must be retained for a minimum of three years[4]. AS9100 and medical retention carry longer requirements.

Overall the testing of military/aerospace product has become less of a challenge in recent years than historically. The relaxation of the fixture only requirements has made it much more cost-efficient and expedient. Historically minor changes in net design required new fixture tooling which is expensive and time consuming. Changes to flying probe programs are fast and only require time from the front end. Take the time to review the specifications. There are some minor differences outlined in the specifications that differ from the default requirements of IPC-9252A. The performance specifications for military can be found on the Defense Logistics Agency’s website[5].

Remember that customer procurement documents and master drawings may override the general requirements of any specification. Many specifications call out the minimum requirements that meet the specification. Customers may require stronger parameters and simultaneous (fixture) tests when the specifications allow flying probe. All procurement documents and master drawings should be consulted prior to developing the test solution for any given product. This will guarantee the correct solution and prevent costly delays with time to market. **PCB**

References

1. MIL-PRF-55110H w/Amendment 1.
2. MIL-PRF-50884F w/Amendment 1.
3. MIL-PRF-31032 /1C, 2B, 3B, 4B, 5A, 6A.
4. MIL-PRF-31032B w/Amendment 1 Section 3.9.
5. List of military performance specs

Todd Kolmodin is the vice president of quality for Gardien Services USA, and an expert on electrical test and reliability issues. To read past columns, or to contact Kolmodin, click here.

NASA Space Robotics Challenge Prepares Robots for the Journey to Mars

NASA, with Space Center Houston, the Official Visitor Center of NASA Johnson Space Center, and NineSigma, a global innovation consultant organization, has opened registration for the Space Robotics Challenge. This event seeks to develop the capabilities of humanoid robots to help astronauts on the journey to Mars.

The Space Robotics Challenge is a $1 million prize competition designed to push the boundaries of robotic dexterity. Teams must program a virtual robot, modeled after NASA’s Robonaut 5 (R5) robot, to complete a series of tasks in a simulation that includes periods of latency to represent communications delay from Earth to Mars.

Though some dexterity has been developed for Earth-based robotics systems using hydraulics, such robots cannot be used in space because of the below-freezing temperatures and the harsh environment of planetary surfaces. The R5 uses elastics technology instead of hydraulics—an innovative way of addressing the problems of operating in space.

“Precise and dexterous robotics, able to work with a communications delay, could be used in spaceflight and ground missions to Mars and elsewhere for hazardous and complicated tasks, which will be crucial to support our astronauts,” said Monsi Roman, program manager of NASA’s Centennial Challenges.

In the virtual competition environment, each team’s R5 will be challenged with resolving the aftermath of a dust storm that has damaged a Martian habitat. This involves three objectives: aligning a communications dish, repairing a solar array, and fixing a habitat leak.

FOD and the Aerospace Industry

by Steve Williams
THE RIGHT APPROACH CONSULTING LLC

Introduction

Unless you are currently building aerospace product to AS9100[1] you are probably saying, "What the heck is FOD?" What started out as a requirement to prevent damage to aircraft parts such as engines has been flowed down to any component or assembly including PCBs.

What is FOD?

Foreign object debris/foreign object damage (FOD) is defined by Boeing[2] as, "A substance, debris or article alien to an aircraft or system, which would potentially cause damage." Foreign object debris can lead to foreign object damage. The classic examples of FOD are things like a wrench or other hand tool left in a jet engine after maintenance has been performed. From a printed circuit board perspective, it means things that can become a permanent part of the product like dirt, dust or other debris that can be entrapped under soldermask or during lamination. It also means surface contamination that could be cleaned off but hasn't been.

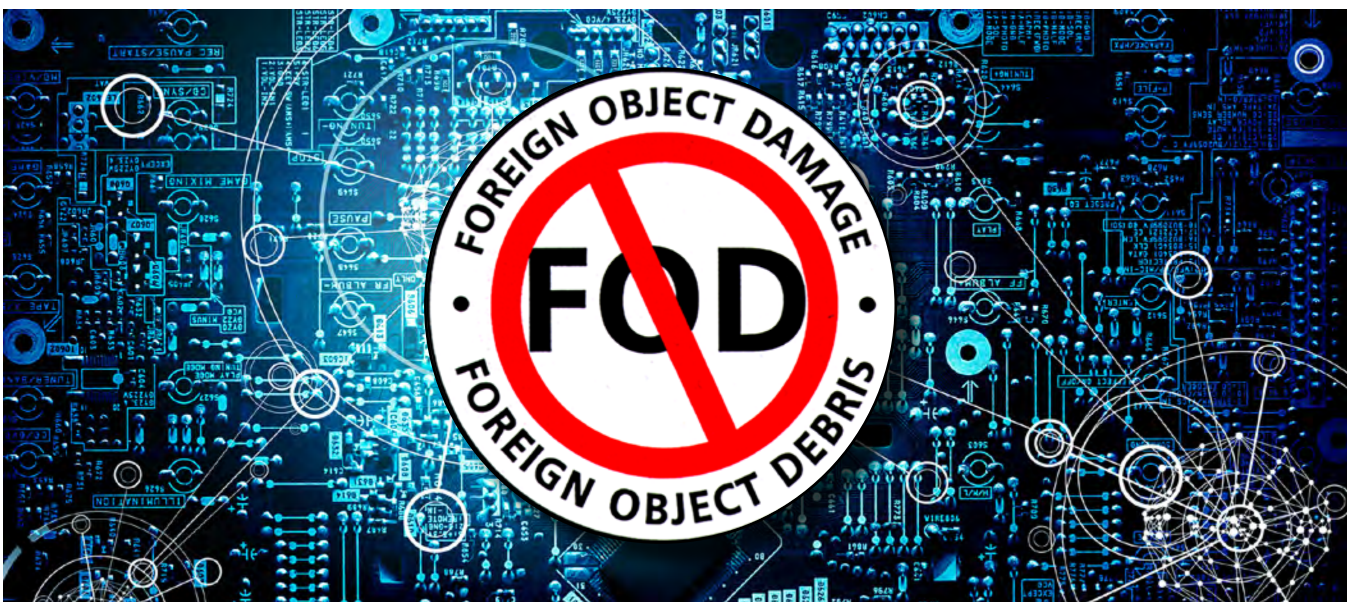
Why is FOD Important?

In an industrial environment, when a part doesn't work the machine may go down. When something malfunctions in an automobile, the occupants have a high chance of survival. When something malfunctions in a plane, the plane goes down and people die. Aside from the human cost, an airplane is probably one of the most expensive pieces of equipment your product can go into. For example, it can cost more than $1 million to overhaul a McDonnell Douglas MD-80 engine after FOD, $10 million to replace it, with the cost of the entire airplane at around $50 million. A Boeing 747-8 costs in excess of $357 million!

FOD Area Levels

FOD programs typically use a three-tier system of controls for activities with different titles in work areas. The system described in this document uses:

1. FOD Awareness Area
2. FOD Sensitive Area
3. FOD Critical Area



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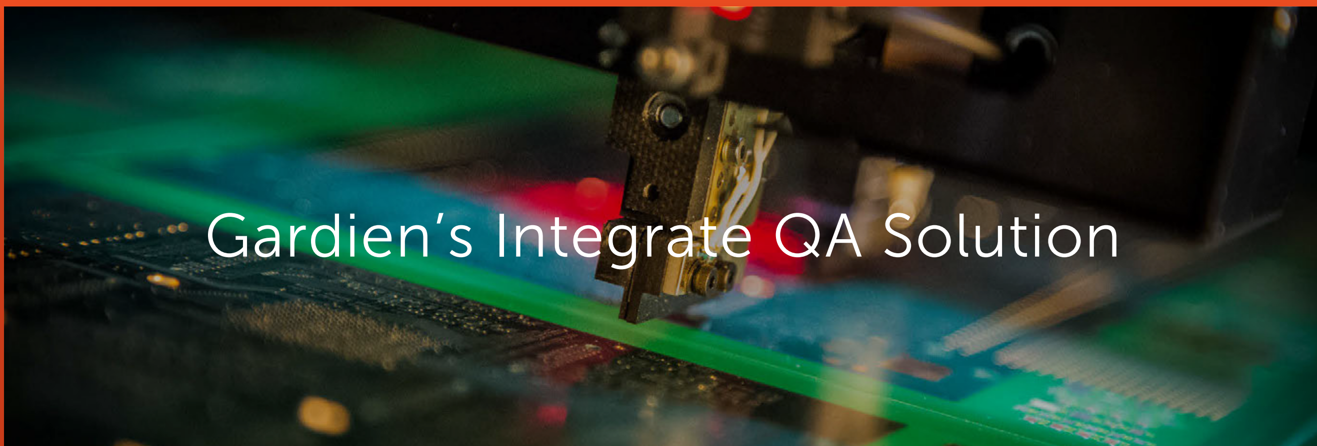

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FOD Awareness Area: Fabrication or maintenance areas within the facility where manufacturing or maintenance requires specific actions.

FOD Awareness Area controls:

- Clean as you go
- FOD barriers on all open lines and tubes when not in use
- FOD barriers on all electrical connectors when not in use

FOD Sensitive Area: Assembly areas where a foreign object could become entrapped or inaccessible within components where maintenance requires specific actions.

FOD Sensitive Area controls:

- Clean as you go
- FOD barriers on all open lines and tubes when not in use
- FOD barriers on all electrical connectors when not in use
- No food or drinks in area, water is acceptable
- FOD barriers on inlets and vents when not in use
- Identify the area with clearly visible markings

FOD Critical Area: Areas which contain an aircraft major assembly or in which the assembly /disassembly of engines or critical components occur, or a flight line. Any area where flight hardware is in place and exposure to foreign objects would potentially cause a system or product failure due to deterioration, malfunction or damage.

FOD Critical Area controls:

- Clean as you go
- FOD barriers on all open lines and tubes when not in use
- FOD barriers on all electrical connectors when not in use
- No food or drinks in area; water is acceptable
- FOD barriers on inlets and vents when not in use
- Identify the area with clearly visible markings and controlled entry/exit point
- Remove items in pockets above the waist, with the exception of pockets that seal, before contact with the aircraft
- Inventory loose items on belt as a tool (cellphone, pager, etc.)

FOD Program Controls and Implementation

AS9100 requires that manufacturers have a FOD program implemented, and Boeing has provided the following guidelines for what needs to be included[2].

Training

The primary objective of a FOD prevention training program is to increase employee awareness to the causes and effects of FOD, promote active involvement through specific techniques, and stress good work habits through work disciplines. A FOD prevention training program for employees associated with design, development, manufacturing/maintenance, assembly, test, operations, repair, modification, refurbishment, and maintenance is required as part of initial job orientation and on a continuing basis.

Training subjects include:

- Proper storage, shipping and handling of material, components, and equipment
- Techniques to control debris
- Housekeeping
- Cleaning and inspection of components and assemblies
- Accountability/control of tools and hardware
- Control of personal items, equipment and consumables
- Care and protection of end items
- Quality workmanship (“clean-as-you-go,” inspection)
- Flight line, taxiway and ramp control methods
- How to report FOD incidents or potential incidents

Housekeeping

Maintenance, manufacturing/maintenance and operational areas must remain clean. Employees should be informed that housekeeping is a part of their job and they will be grad-

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– Michael Doherty
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ed on their performance. Incorporate "clean as you go" as a required work ethic to prevent debris from migrating into flight hardware: Ensure that all production, maintenance and test areas meet "good housekeeping" standards that enhance foreign object elimination. This includes sweeping and vacuuming production areas as well as a regular schedule for sweeping ramp areas.

Ensure that the practice of Clean As You Go is practiced by all employees in all areas and functions of the company. This includes:

- The practice of removing generated debris from the aircraft, component or assembly at frequent intervals as work progresses to prevent the accumulation of foreign objects
- Clean the immediate area when work cannot continue
- Clean the immediate area when work debris has the potential to migrate to an out-of-sight or inaccessible area and cause damage and/or give the appearance of poor workmanship
- Employees will assure all foreign objects are removed at completion of a task, before the next planned operation or inspection point, and prior to work stoppage at the end of shift or delay

Parts Protection and Materials Handling

A well-established plan for material handling and parts protection can eliminate many potential FOD hazards. First, identify the specifics such as sensitive parts, assemblies, surfaces, areas, etc. Then, sequence events for packaging, handling, shipping and storage, and finally, evaluate cleanliness and care requirements.

Control Techniques:

- All employees should be trained to assure compliance with packaging, handling, shipping and storage requirements.
- Materials and accessories used in the packaging, handling, shipping and storage which have intimate contact with the part or assembly should be clean and free of contamination.
- Parts and assemblies shall be packaged in a manner that will preclude any chance of one item making contact with another during normal handling operations.
- Protective and packaging materials shall be chosen based on their ability to adequately resist penetration by tearing, parting or piercing from forces either external or internal during normal handling operations.
- Specific instructions for packaging/unpackaging/handling shall be established
- Protective devices (edge protectors, cam, plugs, covers, filters, rub strips) shall be clean and MUST BE secured to prevent accidental damage. Once installed, unauthorized removal of protective devices is prohibited. Removal should be authorized only through assembly or maintenance planning paperwork.
- Particular care must be taken with items that are subject to damage by electrostatic discharge (ESD). ESD can be considered FOD damage. The use of proper handling, grounding controls and devices and proper ESD protective packaging.

Consideration should be given to the visibility/detection of material used for protection so that the material in itself doesn't become FOD.

Tool Control

The primary objective of a positive tool control program is to eliminate accidents/incidents and loss of life or equipment due to tool FOD. There are numerous methods to facilitate accountability of tools (screwdriver, torque wrench, rivet gun, air hammer, etc.). These include but are not limited to the use of tool inventory lists, shadow boards, shadowboxing, bar coding, special canvas layouts with tool pockets, tool counters, chit system, tool tags, or consolidated tool kits. Unique control methods should be implemented for special tools used in checkout, test and operational environments:

- Inventory all tools used in the area at the beginning/end of shift
- All tools used in the area will be marked to identify source or origin
- Broken tools or tools missing pieces will be reported in the FOD reporting system as Lost Tools

FOD Walk or Sweep

This is the monitoring portion of the program, much like QMS internal audits. It involves a physical inspection and cleaning of an area or work center, generally done with a FOD Checklist that is completed during the walk. Findings must be reported, and action taken to correct any FOD concerns.

As with ISO, AS9100 is industry-agnostic and applies to any company building product for the aerospace industry. While some of the FOD guidance may seem specific to aircraft, the requirements apply just as much to the PCB industry. Where aircraft, hangar or other aviation-specific terms are used, substitute PCBs, work centers, etc. While this list is not 100% inclusive, it does contain the most critical requirements of a FOD program and should provide a blueprint for implementation of your own internal program. Good luck! **PCB**

References

1. SAE International
2. "Foreign Object Debris and Foreign Object Damage (FOD) Prevention For Aviation Maintenance & Manufacturing," Boeing.

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

System Might Detect Doctored Images and Videos for the Military

Purdue University is leading part of an international effort to develop a system for the military that would detect doctored images and video and determine specifically how they were manipulated.

"This team has some of the most senior and skilled people out there in the field, some of whom helped to create the area of media forensics," said Edward Delp, Purdue's Charles William Harrison Distinguished Professor of Electrical and Computer Engineering.

The project is funded over four years with a $4.4 million grant from DARPA. The research also involves the University of Notre Dame, New York University, University of Southern California, University of Siena in Italy, Politecnico di Milano in Italy, and University of Campinas, in Brazil.

"It's a very ambitious program," said Delp, the team's principal investigator and director of Purdue's Video and Image Processing Laboratory, or VIPER Lab. "We have plenty of work to do in four years. One of the things we are doing is bringing to bear a lot of important tools from signal and image processing, computer vision and machine learning."

A huge volume of images and video of potential intelligence value are uploaded daily to the Internet. However, visual media are easily manipulated using software tools that are readily available to the public.

"Now there is an unfair advantage to the manipulator," Delp said. "It's similar to an arms race in the sense that as better algorithms are able to detect doctored media, people are able to change how they do the manipulation. Many open-source images and videos are of potential use to the intelligence community, but how do you know those images can be trusted?"

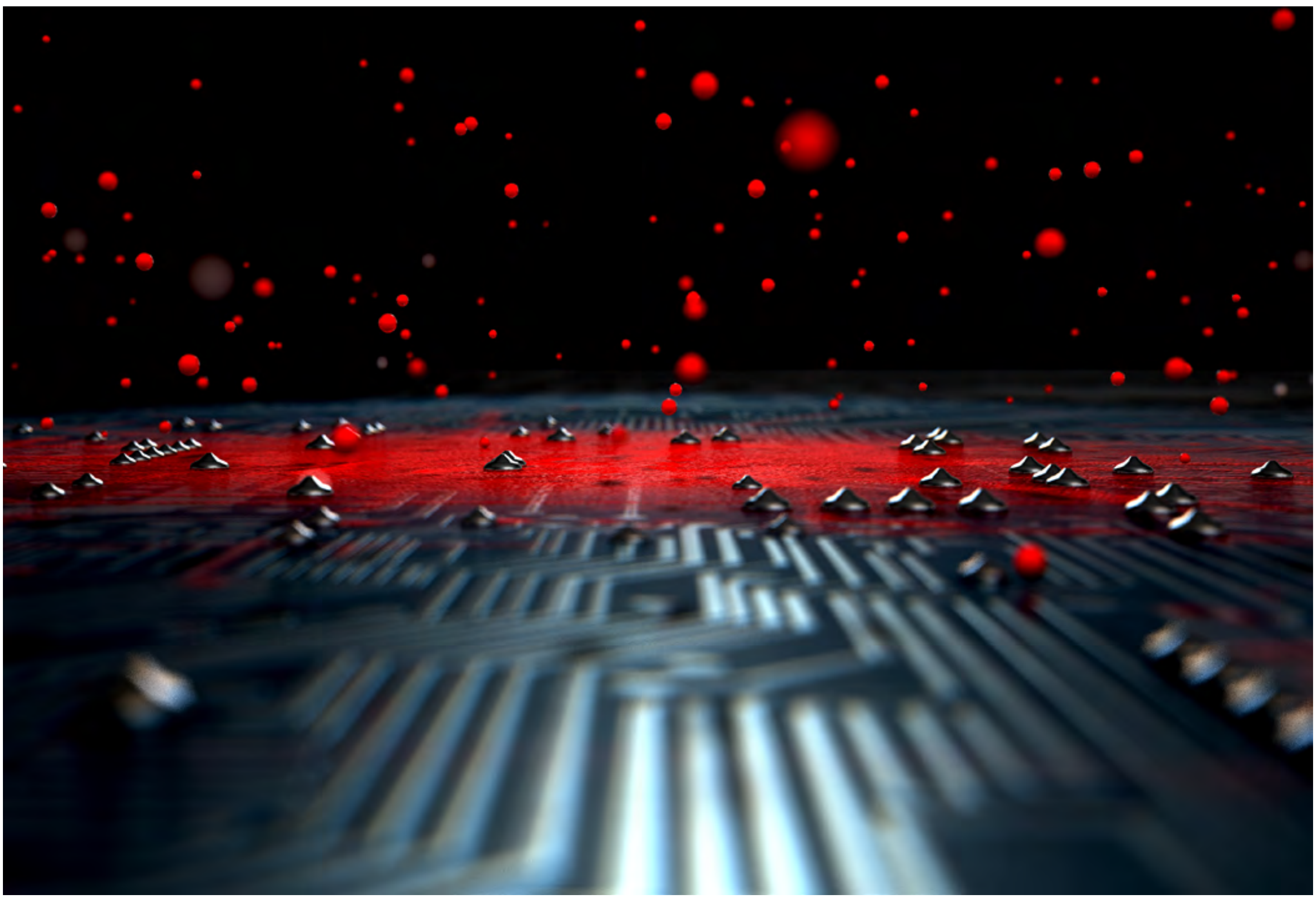
The researchers will strive to create an "end-to-end" system capable of handling the massive volume of media uploaded regularly to the Internet.

EPOXY: Supply Chain and Use in Electronics

by Karl Dietz

Recently, I reviewed the new 7th Edition of the *Printed Circuits Handbook,* which for the first time, includes a section on "Managing the Printed Circuit Supply Chain" (Part 2, Chapters 3–8 by Tim Rogers, including a contribution by Happy Holden). I was delighted to see this important issue addressed explicitly for the first time in this handbook since it is essential to the commercial success of PCB manufacture. The viability of a supply chain infrastructure has many aspects: evaluation and selection of suppliers, contract manufacture considerations, design for manufacturability, data formatting and exchange, process and quality control, auditing, testing, inspection, performance management, proximity of suppliers, warehousing, and many more.

Coming from the material and processing side of PCB fabrication, I tried to find a suitable and important material example to dig into, and I picked one of the most ubiquitous materials used in electronic packaging, namely epoxy resin. Needless to say, the above mentioned chapter on supply chain management cannot cover such a specific example but must focus on higher level issues. So I did my own digging. Since I planned to invest a limited time into this little study, I have to apologize for the somewhat anecdotal character of my findings and the fact that some supplier information may not be up to date due to recent mergers, acquisitions, name changes or other vagaries of the market place.



The use of epoxy resin as a component of base materials (also referred to as laminate, copper-clad laminate, or "CCL") is well known, but it may be allowed to highlight the basics of FR-4 base material construction:

The Manufacture of Laminate and Prepreg (Bondply)

The resin (in our case epoxy) is typically a thermoset resin. Resin and curing agent(s) are premixed and dissolved in low boiling solvents (ketones, esters, alcohols) and placed in a trough through which a continuous glass fabric cloth is guided. The dissolved resin, and dispersed fillers as may be the case, coat the glass fabric which travels up a "treating tower" through different temperature zones were the resin is thermally, partially cured to form the "prepreg." The solvent is evaporated and the dry prepreg is then rolled up into large rolls, cut up into sheets and then "laid-up" by sandwiching it between copper sheets that have been cut from a large roll of copper foil. Several of these packages are placed into the chambers of a lamination press where the copper clad laminate is formed by fully curing the resin and bonding it to the copper in a process-specific time/temperature/pressure profile. After the lamination process, the large CCL pieces are routed into smaller panels. The edges of the panels may be beveled for cleaner processing. Circuitized panels (innerlayers) may then by laid up to multilayers by alternating prepreg layers with innerlayers, topping the multilayer with a "cap foil" of copper. These multilayer lay-ups are separated by separation sheets and inserted into a multilayer press where the prepreg softens, conforms to the adjacent copper, bonds, and fully cures during the press cycle. After multilayer lamination, the multilayers are taken apart (broken down), their edges are cleaned, and multilayer processing continues (drilling, through-hole metallization, outerlayer circuitization, etc.).

Material Suppliers for the Fabrication of Laminate

The materials used in the manufacture of laminate come from a broad supplier base. There are less than 10 suppliers of glass fiber worldwide (source; PLUS 4/2012, pg. 809) and fewer glass weave suppliers. The production of glass fiber is very energy intensive and requires the periodic shutdown and re-cladding of furnaces which can cause 6–9 months of production loss. The best known glass weave supplier is probably Asahi-Schwebel. Resins are supplied by Nan Ya Plastics Corp., Hexion Specialty Chemicals, Dow Chemicals, The Sanmu Group, Hitachi, Mitsubishi Gas, Huntsman, and others. Specialty resins are supplied by a number of small customizing/compounding specialty chemical suppliers. Fillers come from a large supplier base. High-performance fillers are mostly supplied by Japanese companies (e.g., spherical, surface-coated silica fillers). Copper foil suppliers include Circuit Foil Luxembourg (now part of the Doosan Group, South Korea), Oak-Mitsui (part of Mitsui Mining & Smelting), Shanghai Metal Corp., Circuit Foil Corp., USA (became Yates, now JiangXi Copper Yates Copper Foil Co. Ltd.).

A Closer Look at the Epoxy Supply Chain

One can go further upstream in the supply chain for epoxy resin and assess the availability and quality of resin building blocks such as epichlorohydrin (and its raw material allyl chloride), Bisphenol A (and its raw materials acetone and phenol), as well as the various curing agents. But for the purpose of this little study I am resisting the temptation to trace the materials back to the proverbial "fire and coal" origin.

It is typical that the value-added steps of PCB fabrication and their inherent know-how reside with different companies, so that a chain of companies, forming various alliances, are involved in the transformation of basic material building blocks such as resins, reinforcement materials, curing agents, flame retardants, and copper to the final products such as copper-clad laminate, prepreg, dielectric film, or bondply. Exceptions to this market model are few (e.g., Nan Ya's vertically integrated FR-4 production). Thus, it is important for a resin supplier to this market to link up in some form to a formulator (i.e., compounder and customizer of dielectrics) to fully understand material requirements derived from processing techniques, OEM needs, end-uses, and to have access to specifications and test methods and facilities. In many cases the formulator of the dielectric may actually be the PCB fabricator. To illustrate this value chain, Figure 1 gives the example of the Epoxy value chain which serves as a realistic example for other resins as well.

To get a more complete picture of the epoxy supply chain's importance in electronic packaging, the following Figure 2 is an overview of the various applications.

Suppliers of epoxy-based laminates, including prepregs, resin-coated foils, dielectric films, and soldermask are listed below. Some of these

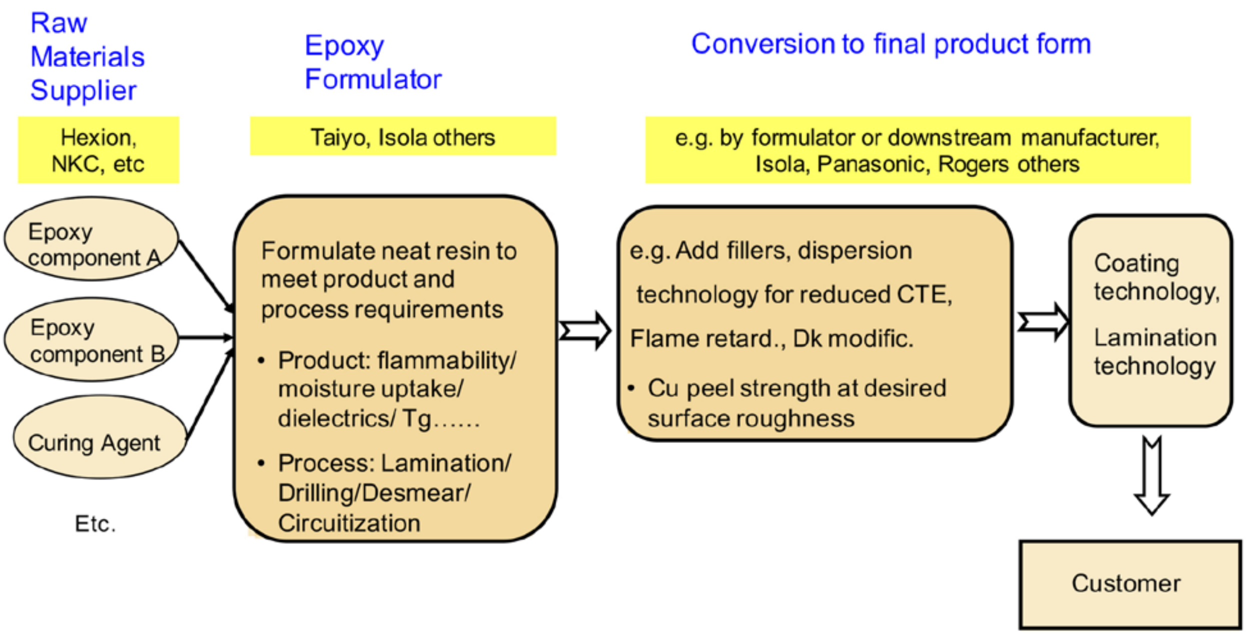


Figure 1: Example of value chain for epoxy.

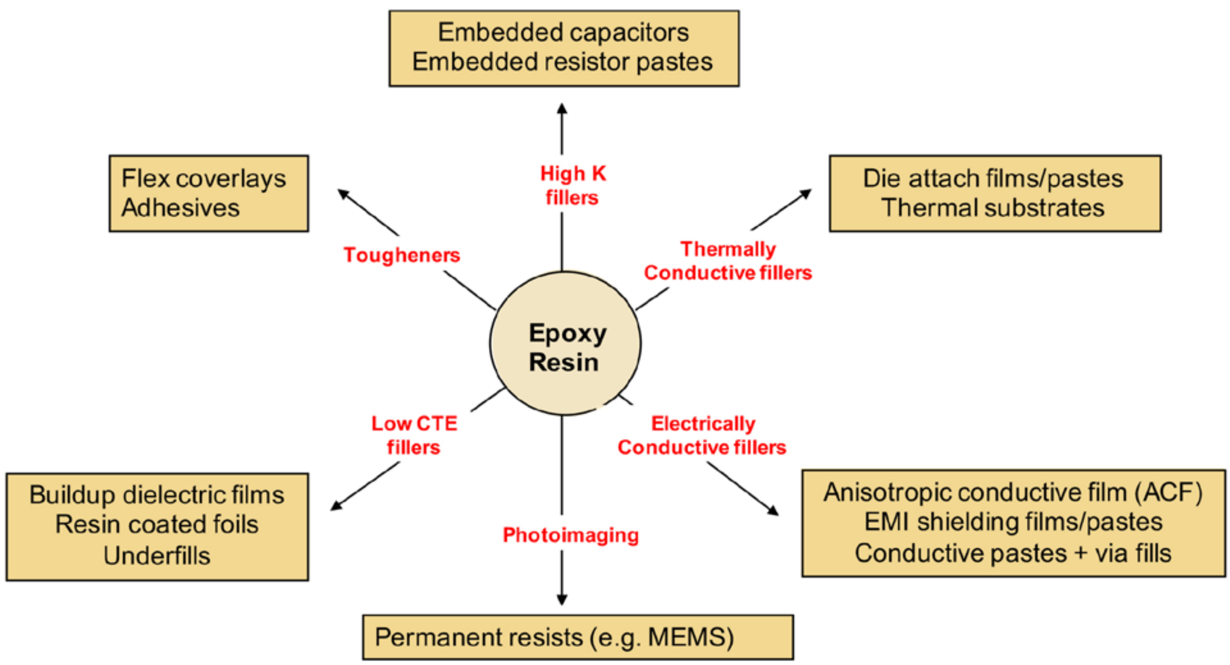


Figure 2: Example of epoxy resins as material building blocks for electronics.

suppliers also supply high-end laminates based on non-epoxy resins, or non-epoxy resins compounded with epoxy.

• Epoxy laminate, prepreg, and resin-coated foil suppliers, dielectric films, soldermask:
  – Nan Ya Plastic Corp. (Taiwan; vertically integrated)
  – Isola (USA/Germany)
  – Kingboard (China; vertically integrated)
  – Risho Kogyo (Japan)
  – Nikkan Industries (Japan)
  – Park Electrochemical Corp. (NELCO), USA
  – Taiwan Union Techn. Corp (TUC), Taiwan
  – Iteq (Taiwan)
  – Mitsubishi Gas Chemical Comp. (Japan)
  – Sengyi Sci. Tech (China; buying resin from Dow, Hexion, Huntsman)
  – Mitsui Chemicals (Japan; high Tg laminate)
  – Matsushita (Japan)
  – Hitachi Chemical (Japan)
  – S+S Technology Corp (Taiwan; licensed Driclad?)
  – Elite Mtl. Company, Ltd (Taiwan)
  – EIT (Endicott Interconnect Technologies), USA, captive
  – Taiwan Leader (Taiwan)
• Epoxy resins, adhesives, molding compounds, underfills, glob tops:
  – CCP (Chang Chun Group; Taiwan), joint venture with Sumitomo Bakelite; epoxy resin, molding compounds
  – Schenectady International (USA); epoxies for electronics
  – Namics Techn. Inc. (Japan); underfill, glob top encapsulants, adhesives, die attach
  – Shin Etsu Polymer Co., Ltd (Japan)
  – Shin Etsu MicroSi Inc. (Japan); molding compounds
  – Ajinomoto (Japan); build-up dielectric film
  – Taiyo Ink (Japan); soldermask
  – Sumitomo Chemical (Japan); epoxy resin
  – Sumitomo Bakelite (Japan); adhesive films, molding compounds
  – Epoxies, Etc... (USA); epoxy formulator
  – Epotek (Epoxy Technology Inc.) (USA); epoxy adhesives, die attach
  – Lord Corp. (USA); resin formulator
  – Epolab Chemical Industries Inc. (Taiwan)
  – AI Technology, Inc. (USA), die attach, tapes, epoxy flex substrate.
  – Ablestik (National Starch & Chem., now Henkel), Germany; die attach adhesives, underfills
  – Loctite (Henkel), Germany; encapsulants, underfills, molding compounds
  – Delo (Germany); chip encapsulants
  – CVC Specialty Chemicals (USA); specialty epoxy resins, elastomer-modified epoxies DuPont supplies multi-functional phenols to CVC
  – Master Bond Inc. (USA); chip encapsulants

Key Companies (laminate manufacturers)

The following summary (Table 1) lists some of the best known CCL manufacturers.

Company	Country
Kingboard	CH
Nan Ya	TW
Panasonic	JP
Doosan	KR
Iteq	TW
Isola	US
Hitachi Chem.	JP
TUC	TW
Mitsubishi Gas	JP
Sumitomo Bakelite	JP
Ajinomoto FT	JP
CCP	CH
Park	US
Rogers	US
Taiflex	TW
Innotek	KR
SMM	JP
Nikkan	JP
Hanwa	KR
Eternal	TW
LG Chem	KR
TAK	KR
Taconic	US
NHK	JP
Chin-Shi Ele.	TW
Denka	JP

Table 1.

This list includes manufacturers of all types of laminate (e.g., low-performance, high-performance, rigid, and flex laminates).

Summary

From a PCB fabricator's perspective, epoxy resin supply chain issues are of indirect concern as they become a subset of laminate quality, supply, and cost considerations. However, the performance and availability of epoxy resins and their building blocks affect laminate supplier selection profoundly, especially in view of changing base material requirements. Changing market environments with respect to uses of epoxy or copper in markets other than electronics affect prices of these materials for electronic uses but are basically beyond the scope of electronics supply chain management.

For example, the largest epoxy resin market is paints and coatings, not electronic applications, and it is difficult to predict the impact of health concerns about Bisphenol A on epoxy resin pricing and availability. Regarding copper, politics in Chile, the largest copper producer in the world, may have an influence on copper pricing but it is probably not worth worrying about it. Likewise, the changing market conditions for copper use such as increased demand in electric cars (three times as much as in a standard car, mostly for rotors) or the increased demand for epoxy in wind turbines are worth noting, but they are not actionable items for electronics supply chain managers. **PCB**

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

Inferring Urban Travel Patterns from Cellphone Data

In making decisions about infrastructure development and resource allocation, city planners rely on models of how people move through their cities, on foot, in cars, and on public transportation. Those models are largely based on surveys of residents' travel habits.

But conducting surveys and analyzing their results is costly and time consuming: A city might go more than a decade between surveys. And even a broad survey will cover only a tiny fraction of a city's population.

In the latest issue of the Proceedings of the National Academy of Sciences, researchers from MIT and Ford Motor Company describe a new computational system that uses cellphone location data to infer urban mobility patterns. Applying the system to six weeks of data from residents of the Boston area, the researchers were able to quickly assemble the kind of model of urban mobility patterns that typically takes years to build.

The system holds the promise of not only more accurate and timely data about urban mobility but the ability to quickly determine whether particular attempts to address cities' transportation needs are working.

"In the U.S., every metropolitan area has an MPO, which is a metropolitan planning organization, and their main job is to use travel surveys to derive the travel demand model, which is their baseline for predicting and forecasting travel demand to build infrastructure," says Shan Jiang, a postdoc in the Human Mobility and Networks Lab in MIT's Department of Civil and Environmental Engineering and first author on the new paper.

Electronics Industry News
Market Highlights

Programmable Ions Set the Stage for General-purpose Quantum Computers

To date, many research groups have created small but functional quantum computers. By combining a handful of atoms, electrons or superconducting junctions, researchers now regularly demonstrate quantum effects and run simple quantum algorithms—small programs dedicated to solving particular problems.

China Further Fortifies its Semiconductor Sector with Formation of High-End Chip Alliance

With the government's backing, key enterprises in China's semiconductor sector have just established a "high-end chip alliance" that fosters the formation of a vertically integrated industry ecosystem on a national scale.

Wearable Cloud Could be Less Expensive, More Powerful Form of Mobile Computing

Researchers at the University of Alabama at Birmingham are exploring the concept of a wearable personal cloud—a fully functioning, yet compact and lightweight cloud computing system embedded into clothing.

White House Advances High-Performance Computing Initiative

The White House last week released a new strategic plan to implement the National Strategic Computing Initiative (NSCI)—a supercomputing research effort—across government agencies.

What's Wasting Power at Home? Ask your App!

If you want to save on your monthly electric bill and reduce your greenhouse gas emissions at the same time, you might buy a new, energy-efficient refrigerator, water heater, or clothes dryer. But if you can only replace one of these, which will give you the biggest payback?

Accelerating Design Times for High-Performance Systems-on-Chip

A team of computer scientists and electrical engineers from four U.S. universities have been awarded a joint project with nearly $5 million in funding from the Defense Advanced Research Projects Agency (DARPA).

Connected Car Market to Grow at 31% CAGR to 2020

The newly published report on connected car market titled "The Connected Car Ecosystem: 2016 – 2030: Opportunities, Challenges, Strategies & Forecasts," says the use of telematics is already widespread with the growing adoption of applications such as fleet management, emergency calling, navigation, vehicle tracking and remote diagnostics.

Grid-connected Energy Storage Capacity Will Surge to 21 GWh by 2025

The global energy storage market is expected to double, from 1.4 gigawatt hour (GWh) added in 2015 to 2.9 GWh this year, offering unique growth prospects for many energy companies as global energy markets continue to cool. Global grid-connected energy storage capacity will surge to 21 GWh by 2025, according to IHS Markit.

Growth in Wearable Electronics Enabled by Advances in Assembly and Packaging

Strong market growth is predicted for wearable electronics fueled by new generations of wearables providing greater functionality in the same or smaller form factor, for the same or lower cost.

IPC Announces Development of Press-fit Pin Standard for Automotive Requirements

IPC has announced plans to start the development of a new standard intended to cover the qualifications and acceptance requirements for press-fit pin technology that includes the reliability needs for automotive and other industries, such as aerospace.

Take Social Media Seriously

by Barry Lee Cohen
LAUNCH COMMUNICATIONS

This September will mark the 10th anniversary of "the Zuck" (aka Mark Zuckerberg) and his band of college buddies unleashing Facebook membership from the scholarly confines of Harvard to anyone 13 years and older with a valid email address. For those of you with teenagers a decade ago, you've witnessed—and often agonized—what most would acknowledge as the advent of social media.

Currently engaged by over 1.7 billion active users, Facebook opened the floodgates to acceptance of a plethora of other social channels, including LinkedIn, which celebrated its 13th anniversary this year with its more than 100 million active users[1].

LinkedIn is no longer deemed a Rolodex (tell your teenager to Google it); it has become the essential social community for business. The significance and profitability of the channel is unquestionable and witnessed by Microsoft's pending $26.2 billion acquisition of the company to be completed later this year.

Yet with all this acceptance, documented analytics and testimonials demonstrating how social media has become an integral part of today's B2B communications, large chunks of the industrial sector remain hesitant in consistently integrating it as part of their marketing programs. Some B2B leaders claim that there is marginal to no value in investing in social media, and most alarmingly do not see the benefits of deploying it as a strategic tool to elevate their brand and establish thought leadership to the industries and markets they serve. All too often, such consideration ranges from

Six reasons why outsourcing CAM Engineering can be a great idea for you:

...and here is the delivered value:

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Overhead Cost	>30%	0%
Scalability	Limited	Unlimited
Redundancy	Variable	100% Bulletproof
Operational Efficiency	Status Quo	Continual Improvement
Total Cost	Fixed	Significantly lower

"In our company, the CAM department was the bottleneck. As a result of our working with Entelechy, we can now accept orders that we had to refuse in the past."

-Thomas Hofmann, CEO/Owner

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a patronizing smirk to "get a grip; social media is for kids."

Granted, social media first achieved its fame and Zuck fortune on B2C; however, when employed relevantly it has proven to be an important driver to elicit voice of customer (VOC) for B2B companies. Even with limited use, participation in discussion groups and commenting on your connections' postings further reinforces customer intimacy previously established in face-to-face discussions.

Those naysayers that continue to deny themselves the opportunity to further differentiate their culture, capabilities and products, should consider the loss of not seizing the power of LinkedIn to demonstrate the value of their organizations. Furthermore, some have become blind to their savvier competitors who are employing LinkedIn to collect valuable intelligence, while surveying the mindset and preferences of the industry landscape, trends and emerging technologies.

The savviest of your savvy competitors are regularly executing social media as part of their marketing plans, which includes dedicated personnel that have varying degrees of responsibility to administer, post, follow, and most importantly, interact with customers and prospects via discussion threads, messaging, and postings (individual, company, group). They are also regularly contributing content that is authored from within their organizations, as well as from third-party source materials that are often perceived as having higher credibility. These folks have witnessed the power of this tool to drive qualified customers and prospects to their websites and blogs, which often includes the downloading of technical articles, process guides and manuals. This documentation provides the compelling data and expert content that engineers and other professionals covet.

As reported in the IEEE Engineering360 research report, "2016 Social Media Use in the Industrial Sector," 65% of engineers and technical professionals maintain at least one social media account. Of this group, 54% use social media to find product reviews; 52% use it to keep current on the latest company/product news/technologies, and a surprising 43% use it to gain expertise[2]. As detailed within the report, social media is not preferred nor will it replace search engines and online directories that enable users to more easily locate specific subject matter. Although many of us love to share, tweet, and link, the report rightfully recognizes that social media is not a marketing program unto itself, nor is it a substitute for face-to-face interaction. However, social media is a powerful supplement for many of the traditional and digital tactics your company heavily invests in, ranging from trade show participation announcements to the launch of a new website.

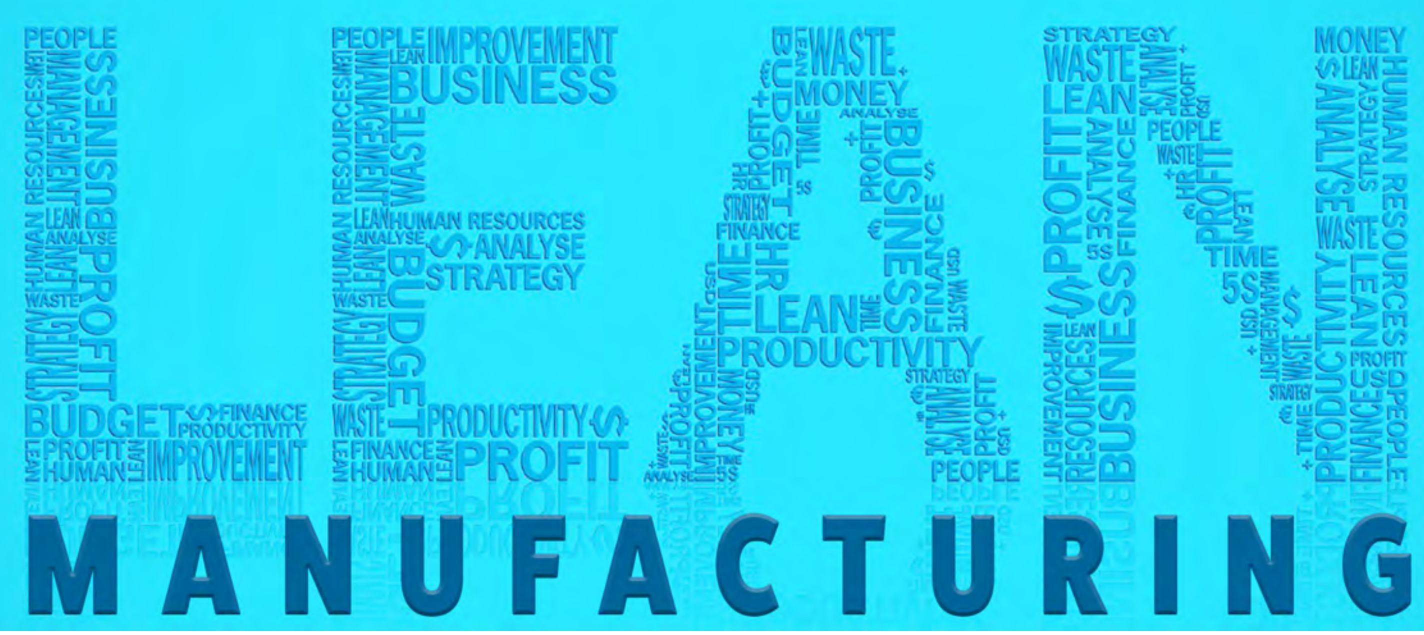
Just creating a LinkedIn page or any other social media channel is an empty pasta shell without the tasty content that will make your channels part of your customers' daily nourishment. Enticing and satisfying the intellectual palettes of your audience is critical. This is especially true of the under 30 crowd that increasingly rely upon social media to communicate and obtain work-related information. Unfortunately, there are far too many companies that launch a corporate page and watch it wither as there is little commitment to publish relevant and timely information that will engage their target audience—the whole reason for creating the channel in the first place. Silence is by no means golden, whereas the company's lack of social engagement may sometimes be extrapolated in a negative manner that expands well beyond our digital superhighway.

On this last point, all I can say is, "Ouch!" I can hear my inbox pinging with disgruntled emails. I have the distinct feeling some of these missives may not be ready for prime time posting. **PCB**

References

1. Wikipedia
2. IEEE Engineering360 Media Solutions

Barry Lee Cohen is president and managing director of Launch Communications. To read past columns by Cohen or to contact him, click here.



by Happy Holden

Lean doesn't have to exist in manufacturing alone. Lean is a fairly recent principle that can apply to all of our goods and services. For those of you not familiar with Lean, I recommend the free E-book *Survival Is Not Mandatory: 10 Things Every CEO Should Know about Lean* by Steven Williams, a regular columnist for I-Connect007[1]. He thoroughly explains Lean—its history, what it is, why it is important, and how to initiate a program. Steve uses a lot of humorous stories to illustrate his points. On one, he concludes with: "The moral of the story: If Team America doesn't start working smarter in the manufacturing sector, we will be destined to remain a service nation."

Another excellent article on Lean was written by Kathy Nargi-Toth in the October 2015 issue of *The PCB Magazine*[2].

Introduction

Steve's and Kathy's explanation of Lean encompasses:

- Lowering costs by eliminating waste of all sorts (materials, machinery, manpower, methods, measurements, and movements)
- Delivering as soon as needed to eliminate queues, waits and delays
- Six-Sigma quality goals—continuous improvements to zero defects

Lean Management Model

Current descriptions of Lean manufacturing all refer to Toyota Motor Company. While this is its origins and most useful example, car manufacturing is very complex and one involving assembly. I like to call this "the kinematic model" for Lean. This would apply to electronics assembly, as you can always back-up-a-step and repair or rework.

But printed circuit fabrication, like integrated circuit wafer fabrication, is a thermodynamic model, in that the manufacturing steps are irreversible; you cannot go back and un-drill a hole or un-plate the board. Like in thermodynamics entropy, the process goes only in one direction. Thus, Lean for these processes is slightly different from that of assembly.

The Total Lean Management Model aligns all the pillars of Lean in a systematic way under one umbrella, making Lean understanding, learning and execution a smooth methodology.

Lean Manufacturing Basics

The following is an excerpt from the Mindtools web publication on Lean Manufacturing: [3]

> *The Lean approach is based on finding efficiencies and removing wasteful steps that don't add value to the end product. There's no need to reduce quality with lean manufacturing—the cuts are a result of finding better, more efficient ways of accomplishing the same tasks.*


esi
PRECISION IN MOTION

To find the efficiencies, Lean manufacturing adopts a customer-value focus, asking, 'What is the customer willing to pay for?' Customers want value, and they'll pay only if you can meet their needs. They shouldn't pay for defects, or for the extra cost of having large inventories. In other words, they shouldn't pay for your waste. Waste is anything that doesn't add value to the end product. There are seven categories of waste that you should monitor:

1. ***Waiting****—How much lag time is there between production steps?*
2. ***Inventory*** *(work in progress)—Are your supply levels and work in progress inventories too high?*
3. ***Transportation****—Do you move materials efficiently?*
4. ***Over-processing****—Do you work on the product too many times, or otherwise work inefficiently?*
5. ***Motion****—Do people and equipment move between tasks efficiently?*
6. ***Defects****—How much time do you spend finding and fixing production mistakes?*
7. ***Workforce****—Do you use workers efficiently?*

Steps to Achieve Lean Systems[4]

The following steps are from Wikipedia's definition of Lean:

Steps should be implemented to create the ideal Lean manufacturing system.

- *Design a simple manufacturing system*
- *Recognize that there is always room for improvement*
- *Continuously improve the Lean manufacturing system design*

Design A Simple Manufacturing System

A fundamental principle of Lean manufacturing is demand-based flow manufacturing. In this type of production setting, inventory is only pulled through each production center when it is needed to meet a customer's order. The benefits of this goal include:

- *Decreased cycle time*
- *Less inventory*
- *Increased productivity*
- *Increased capital equipment utilization*

There is Always Room for Improvement

The core of Lean is founded on the concept of continuous product and process improvement and the elimination of non-value added activities. Use TQC and six sigma principles. The value-adding activities are simply only those things the customer is willing to pay for; everything else is waste, and should be eliminated, simplified, reduced, or integrated. Improving the flow of material through new ideal system layouts at the customer's required rate would reduce waste in material movement and inventory.

Continuously Improve

A continuous improvement mindset is essential to reach the company's goals. The term "continuous improvement" means incremental improvement of products, processes, or services over time, with the goal of reducing waste to improve workplace functionality, customer service, or product performance.

Management commitment, education and awareness, total quality control, and design of experiments form the foundations.

Zero Defect Manufacturing

ZDM is my thermodynamic model of Lean and has four pillars supporting its umbrella of Lean, built upon management commitment, education and awareness, total quality control (TQC), and design of experiments (DOE)/statistical process control (SPC), as seen in Figure 1.

- Predictive engineering/design for manufacturability (DFM)
- Demand pull production (JIT)
- Managing design data/computer-aided tooling (CAD to CAM)
- Design-flow processes/level schedules (TOC)

Just-in-Time (JIT)

The "flow" (or smoothness) based approach aims to achieve JIT, by removing the variation caused by work scheduling and thereby provide a driver, rationale or target and priorities for implementation, using a variety of techniques.

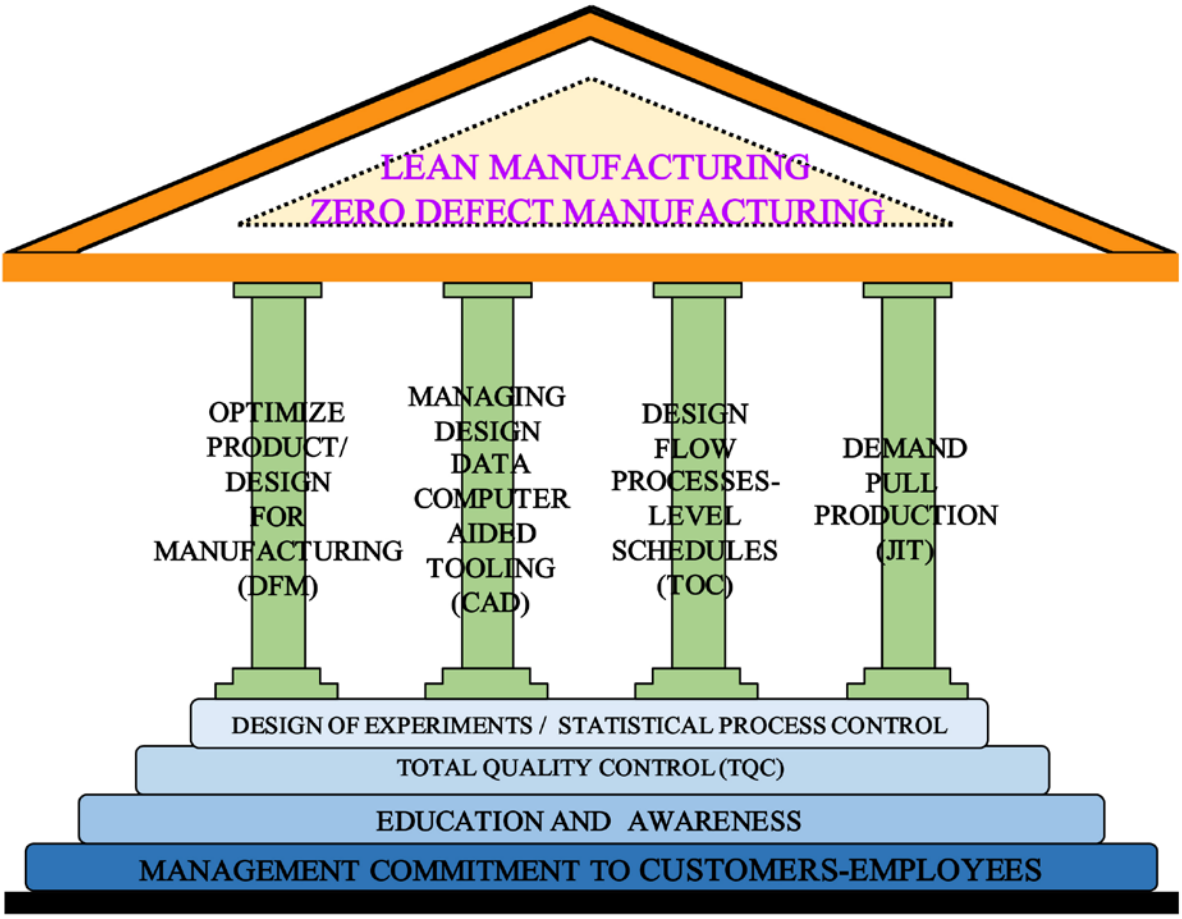


Figure 1: Lean manufacturing is built on four pillars: Demand pull production; level scheduled flow processes; design for manufacturing; and managed design data to manufacturing.

The effort to achieve JIT exposes many quality problems that are hidden by buffer stocks; by forcing smooth flow of only value-adding steps, these problems become visible and must be dealt with explicitly. These are just a few of the benefits of a solid JIT process:

- Fast improvement (a result of focusing all attention on one critical area (the system constraint)
- Improved capacity (optimizing the constraint enables more product to be manufactured)
- Reduced lead times (optimizing the constraint results in smoother and faster product flow)
- Reduced inventory (eliminating bottlenecks means there will be less work-in-process)

Design for Manufacturing/ Assembly (DFM/A)

DFM/A is essential to ensuring that products are being designed to utilize the highly automated, continuous-flow process[5].

Managing Design Data (CAD to CAM)

An all-digital chain of data is essential to utilize a continuous-automated process flow. This will be highlighted in a future column entitled "Predictive Engineering," scheduled for publication in the I-Connect007 Daily Newsletter later this year.

Design Flow Processes/Level Schedules (Theory of Constraints)

The Theory of Constraints (TOC) is a methodology for identifying the most important limiting factor (i.e., constraint) that stands in the way of achieving a goal and then systematically improving that constraint until it is no longer the limiting factor. In manufacturing, the constraint is often referred to as a bottleneck.

The TOC takes a scholarly approach to improvement. It believes that every complex system, including manufacturing processes, consists of many linked activities, one of which acts as a constraint upon the entire system (i.e., the constraint activity is the "weakest link in the chain"). The Theory of Constraints provides a powerful set of tools for helping to achieve that goal, including:

- The Five Focusing Steps (a methodology for identifying and eliminating constraints)
- The Thinking Processes (tools for analyzing and resolving problems)
- Throughput Accounting (a method for measuring performance and guiding management decisions)

Dr. Eliyahu Goldratt conceived the TOC, and introduced it to a wide audience through his bestselling 1984 novel, The Goal [6]. Since then, TOC has continued to evolve and develop, and today it is a significant factor within the world of management best practices. These strategies are seen in Figure 2.

The Toyota Way

In a Lean-manufacturing tutorial from The Art of Service[7] comes this explanation of the Toyota Way:

There is a second approach to Lean manufacturing, which is promoted by Toyota, called 'The Toyota Way.' In TTW, the focus is upon improving the flow of work, thereby steadily eliminating mura ("unevenness") through the system, and not upon waste reduction per se. Techniques to improve flow include production leveling, "pull" production (by means of kanban) and the Hei-

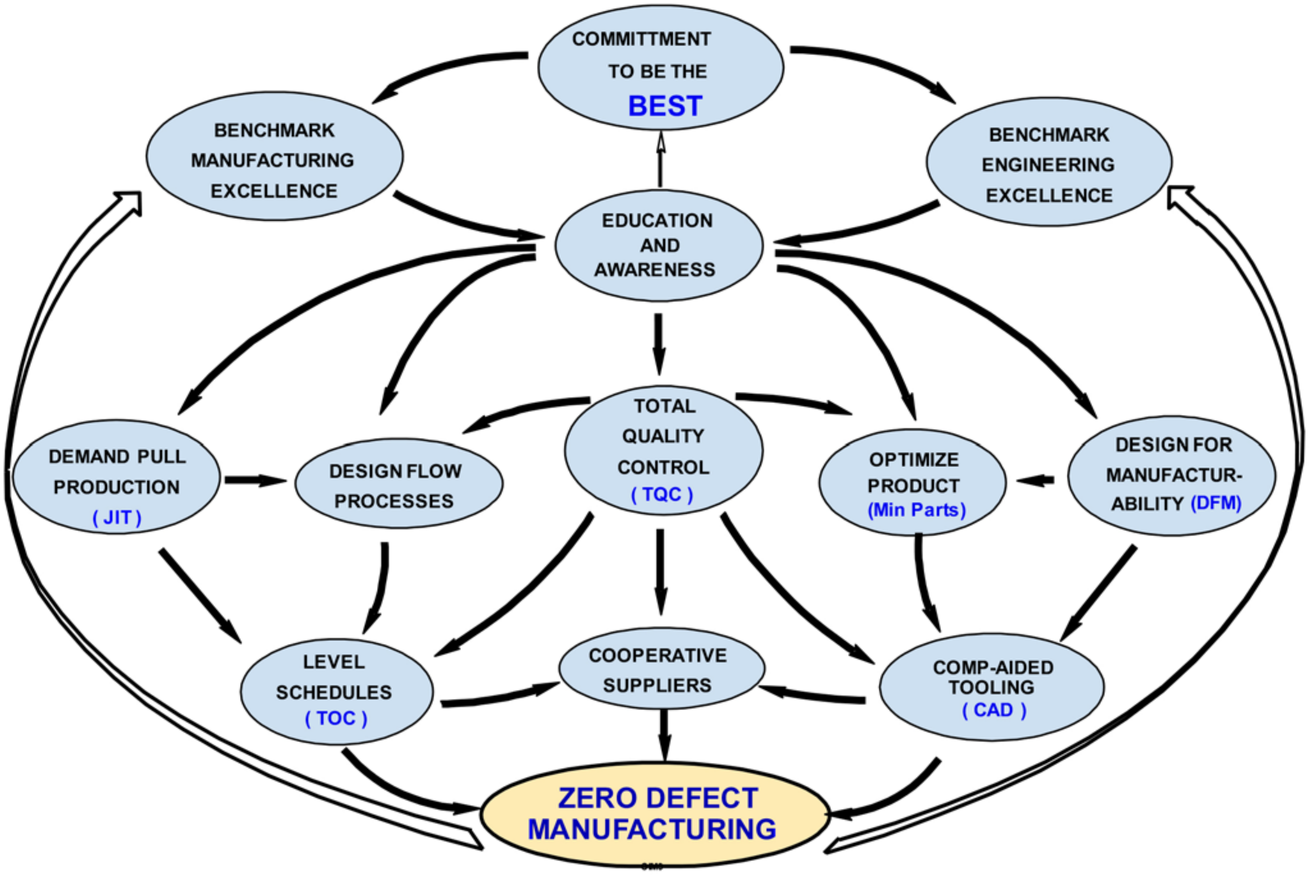


Figure 2: The goal of zero defects and Lean is a process of implementing other key strategies.

junka Box. Also known as the flexible mass production, the TTW has two pillar concepts: kanban, JIT, and jidoka or "autonomation" (smart automation = automation + people).

Kanban-Heijunka Box

These production processes are based on five related items (5Ss) describing workplace practices conducive to visual control and Lean production:

1. Seiri (sifting): *Go through everything in the work area, separating and eliminating what isn't needed.*

2. Seiton (sorting): *Arrange items that are needed in a neat and easy-to-use manner.*

3. Seiso (sweeping clean): *Clean up the work area, equipment, and tools.*

4. Seiketsu (spic and Span): *The overall cleanliness and order that result from disciplined practice of the first three Ss.*

5. Shitsuke (sustain): *Discipline to perform the first four Ss.*

Jidoka

In addition to smart automation, Jidoka is built upon standards and standardized work.

Standardized Work

Establishing precise procedures for each operator's work in a production process, based on three elements:

1. Takt time, which is the rate at which products must be made in a process to meet customer demand.

7 continuous steps versus 30

WHELEN PROCESS SEQUENCE (I/L)	
0	CAM
5	In Line Load/unload
6	Pre-clean /R
8	Inkjet Primary Image
15	Etch / R
16	Resist Strip (Print&Etch) /R
17	In Line Load/unload - Move

20 minute I/L print & etch

11 steps versus 19

WHELEN PROCESS SEQUENCE (Mult)	
1	In Line Load
2	Pinless stackup of layers / PP
3	Cu foil / prepreg
4	Vacuum lamination/cooling
5	Stack breakdown
6	X-ray drill tooling
7	AutoLoad / unload
8	Trim flash / Drill
9	Auto Load / unload – Move
10	Plasma desmear
11	Move

STANDARD I/L PROCESS SEQUENCE	
1	CAM
2	Film Plotting
3	Film processing
4	Film inspection
5	Film punching
6	Load
7	Clean / R
8	Microetch /R
9	Unload
10	Load
11	Resist application
12	Hold (cooling)
13	Exposure
14	Unload
15	Hold (polymerization)
16	Load / mylar removal
17	Develop / R
18	Etch / R
19	Strip / R
20	Unload
21	Load
22	AOI
23	Unload
24	Load
25	Lamination hole punch
26	Unload - Move
27	Load
28	Clean / R
29	Oxide / R
30	Unload

Table 1: Whelen Engineering's continuous innerlayer and multilayer process steps.

R = rinse

STANDARD MULTILAYER PROCESS SEQUENCE	
1	Load
2	Stackup layers (pap-rel-Cu-PP-Layers-PP-Cu-rel-paper)
3	Vacuum lamination / cooling
4	Stack breakdown
5	Trim flash
6	X-ray drill tooling
7	Load
8	Clean caul plates
9	Unload
10	Load
11	Drill
12	Unload
13	Inspect - Move
14	Load
15	Clean / R
16	Organic swell / R
17	Permanganate desmear
18	Permanganate recovery / R
19	Unload - Move

Table 2: Standard innerlayer and multilayer process steps.

2. The precise work sequence in which an operator performs tasks within takt time.

3. The standard inventory, including units in machines, required to keep the process operating smoothly.

Standardized work, once established and displayed at workstations, is the object of continuous improvement through kaizen. The benefits of standardized work include documentation of the current process for all shifts, reductions in variability, easier training of new operators, reductions in injuries and strain, and a baseline for improvement activities.

New Example of Lean for Printed Circuit Fabrication [8,9]

The new Whelen Engineering PCB factory in New Hampshire is an excellent example of Lean principles. In the process of automating the PCB flow and eliminating wastes, they produced a facility with zero effluents, thus also being an excellent example of green! The two went hand-in-hand.

Lower Costs by Eliminating Waste

Simplifying the multilayer PCB manufacturing process, as seen in Tables 1, 2, 3 and 4, eliminated 74 process steps but also the need for pre-clean and micro-etch process steps. Further reductions in waste were accomplished by implementing 17 actions as seen in Table 5 and Figure 3. The source for Tables 1–6 and Figure 3 is Reference #9.

WHELEN PROCESS SEQUENCE (O/L)	
	Loader
1	Debur
	In Line Load/unload
2	Conductive Polymer-Horizontal Cu Plate
	In Line Load/unload
3	Pre-clean
	30 Panel Buffer(FIFO)
4	Inkjet Primary Image
	In Line Load/unload
	30 Panel Buffer (FIFO)
5	Tin Plate
	FIFO Buffer
6	Resist Strip (Plate&Etch)
	90 Degree Turn
7	Etch
8	Resist Strip(Print&Etch)
	In Line Load/unload
9	Tin Strip
	In Line Load/unload

WHELEN PROCESS SEQUENCE (O/L) con't	
	UnLoad
	90 Degree Turn
20	HASL Post-clean
19	L/F HASL
18	HASL Pre-clean)
	90 Degree Turn
	In Line Load/unload
17	Final Cure
	In Line Load/unload
16	Legend Inkjet x2 with Robot
	In Line Load/unload
15	Solder Mask Develop
14	LDI with Robot
	In Line Load/unload
13	Solder Mask Tack Oven
12	Solder Mask Screen Coat
	In Line Load/unload
11	Oxide-Post-Dip
	In Line Load/unload
10	Oxide – S Mask Pre-clean

105 minute O/L plate & etch

R = rinse

20 continuous steps versus 63 batch steps

Table 3: Whelen Engineering's continuous O/L process steps.

STANDARD PROCESS O/L SEQUENCE	
a	CAM
b	Film Plotting
c	Film processing
d	Film inspection
e	Film punching
1	Load
2	Debur
3	Unload
4	Load
5	Clean / R
6	Microetch / R
7	Catalyst
8	Accelerator / R
9	Electroless Copper
10	Copper dragout / R
11	Dry
12	Unload –Move
13	Load
14	Resist application
15	Hold (cooling)
16	Exposure
17	Unload
18	Hold (polymerization)
19	Load / mylar removal
20	Develop / R
21	Unload – Move
22	Load
23	AOI
24	Unload – Move
25	Rack
26	Clean / R
27	Microetch / R

STANDARD PROCESS O/L SEQUENCE - Move	
28	Acid prep
29	Copper plate
30	Dragout rinse / R
31	Acid Prep
32	Tin Plate
33	Dragout rinse / R
34	Unrack-Move
35	Load
36	Resist Strip (Plate&Etch)
37	Rinse
38	Etch
39	Etch recovery / R
40	Tin Strip
41	Tin recovery / R
42	Unload – Move
43	Load
44	Solder mask clean
45	Solder mask coat
46	Solder mask cure
47	Unload
48	Load
49	Solder mask exposure
50	Unload – Move
51	Load
52	Solder mask develop
53	Unload
54	Load
55	Legend print
56	Unload – move
57	Legend cure
58	Unload
59	Load
60	HASL pre-clean
61	HASL
62	HASL post-clean
63	Unload

Table 4: Standard O/L process steps-manual.

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-Holly Olsen, Electronic Systems, Inc.

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Waste Reduction Actions	Impact
Reduce lot size to increase flexibility, lower inventory	Utilized single spindle auto-loaded drill/routers for lots of 3 panels.
Auto optical pinless layup for lamination	Eliminate pins, de-pinning, as well as caul plate cleaning and reduce labor
Inkjet for primary imaging	Eliminate pre-cleans, developer, tin plate cleaner, microetch, pre-dip, strip chemicals
Eliminate cleaners, microetches, predips, anti-tarnishes	Decreased wastewater system and chemical costs
Inkjet for legends	Eliminate screening or photo processes
LDI for solder mask	No artwork required/increased registration
Conductive polymer metallization	Eliminate formaldehyde from metallization of Cu
Closed loop resist strip process	>$20,000 in annual savings from chemical usage and treatment
Horizontal Cu pulse plating w/insoluble anodes	Huge waste reduction and improved thickness tolerancing. Control of roughness allowed elimination of microetching for adhesion as well.
Rotary oxygen plasma etch	Eliminate need for chemical desmear with solvents/permanganate/or plasma with toxic gases
Closed loop Cu recovery system	Eliminate chemical costs for etching and yielded a positive cash flow from recovered 99.99% pure copper. Also, stabilized etch rate to +/-2%, eliminated venting of ammonia to scrubber, and recovered etch rinse dragout back to etcher
Convert all first rinses to static drag-outs & increase flow rate of cascade rinses to compensate for less cascade	Decrease IX regeneration by 70%, while increasing concentrate waste dumps by 25%. Net reduction in total concentrate waste volume by 30%.
Increase temperatures of process baths if possible, and replenish evaporated loss from dragouts	Decreased concentrate waste volume by 25%
Closed loop F006 precursor rinse recovery process	Reduce F006 hazardous waste by 95%
Zero liquid discharge waste treatment	Eliminate permits, saved water
Eliminate fume scrubbing and vapor emissions	Hermetically sealed tanks with negative pressure/packed columns on ducts
Reduce the amount of chemicals used in processes. Eliminate chemical handling-any safety issues.	Monitor and replenish chemicals continuously. Use reservoirs as shipped from vendors.

Table 5: The 17 specific cost reduction actions (Lean) and their impact.

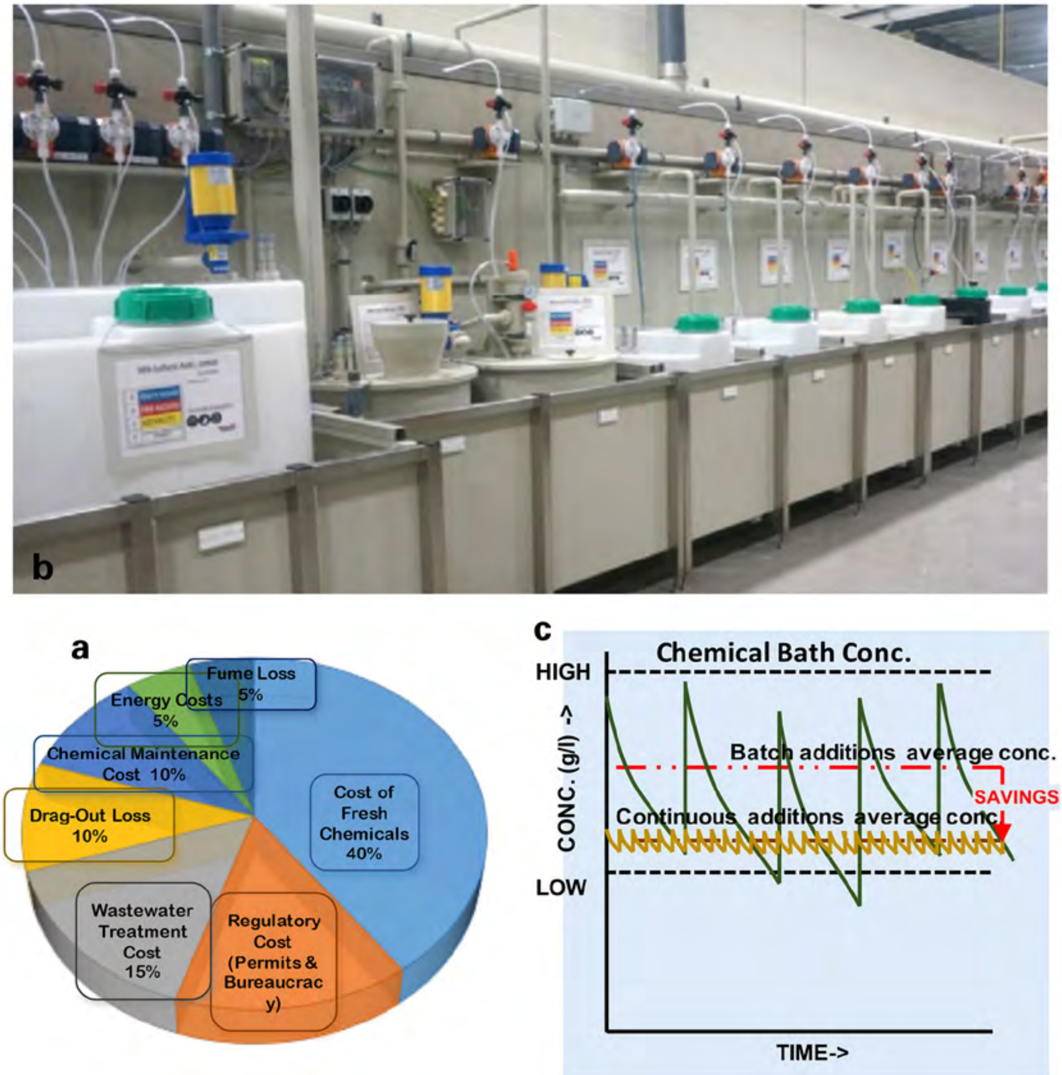

Figure 3: a) Fresh chemicals represent only 40% of the total chemical systems costs; b) automatic chemical dosing stations for processes; c) continuous monitoring and dosing allows the lowest level of operating chemical concentrations.[7]

Delivery as Soon as Needed

For high-volume, by eliminating queues, waits and delays, with a JIT flow process (total 38 steps), the Whelen automation can do lot sizes of three panels to lots of 50–100. As seen in Tables 1, 2, 3 and 4, there are numerous queue spots in the standard multilayer fabrication processes (a total of 112 steps) where a panel or lot of panels may be held (sometimes for hours or days). By eliminating 66% of the process steps the Whelen outer-layer process takes only 105 minutes from drill to final fabrication, instead of days or weeks. Standardizing the processes from image through etch allowed the automation of these processes into one continuous process for both innerlayers and outer layers.

Six-Sigma Quality Goals—Continuous Improvements

The high degree of automation eliminated handling and opportunities for defects as well as oxide growth and contaminations. The resulting process has an astoundingly high yield with very low labor. Lean waste in the form of water treatment is shown in Table 6 along with the ROI for the capital investments. Some

Process Bath	Recovery Method	Recovered Product	Capital ROI
Alkaline Etchant	Oxidation/Galvanic Cu	Fresh Etchant & Cu Metal	6-14 months
Acid Etchants	Oxidation/Galvanic Cu	Fresh Etchant & Cu Metal	6-14 months
Plating Electrolytes	Organic Destruction	Electrolyte minus Organic	2-3 months
Tin Strippers	Galvanic Cell	Etch Resist & Fresh Stripper	4-6 months
Microetches	Galvanic Cell	Fresh Microetch & Cu Metal	4-6 months
Oxide Alternatives	Organic Destruction	Fresh Chemical minus Organic	2-3 months
Resist Strippers	Membrane	Fresh Stripper & Contaminated Brine	2-3 months

Table 6: Methods of chemical recovery to regenerate chemicals, minimize waste treatment and the ROI for such systems.

Figure 4: Key recovery systems of ion exchange, evaporation, crystallization, reverse osmosis, and electrolytic copper and tin electrowinning.

of these systems are shown in Figure 4 and Figure 5.

Summary

The example of Whelen Engineering shows how Lean principles can go hand-in-hand with green principles. The results are lower costs (one-third to one-half the cost from China), decreased lead times (from four weeks to two days) and improved quality (no final inspection needed).

Numerous webinars and courses are available on Lean[8], as it is one of the skills that goes with TQC, and DOE. Further information about Whelen can be obtained by contacting Alex Stepinski through I-Connect007. **PCB**

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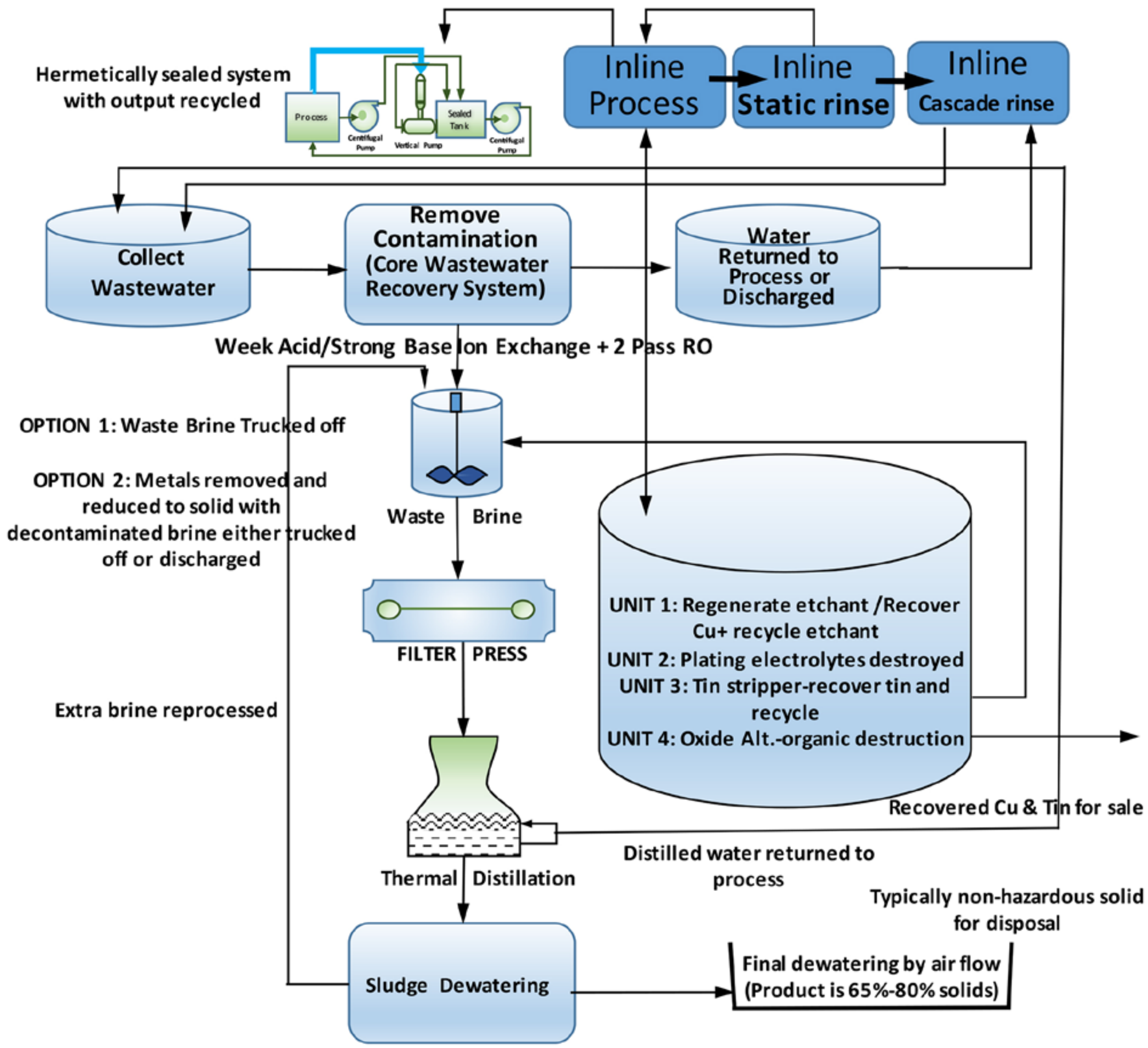

Figure 5: Recovery and regeneration of chemicals for processes, along with total recycle of water, including hermetically sealed ventilation system s provide for a rapid ROI.

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Happy Holden has worked in printed circuit technology since 1970 with Hewlett-Packard, NanYa/Westwood, Merix, Foxconn and Gentex. He is the co-editor, with Clyde Coombs, of the recently published Printed Circuit Handbook, 7th Ed. To contact Holden, click here.

Recent Highlights from PCB007

1 Shane Whiteside and Summit Interconnect: Aspiring to New Heights

A few weeks ago I was privileged to meet with Shane Whiteside in Anaheim, California, at KCA Electronics. Whiteside, former COO of TTM, has helped launch a new company—Summit Interconnect— which encompasses the recent acquisition of KCA Electronics and Marcel Electronics International. Once again assuming an executive role, this time as CEO and president, Whiteside shared his story, strategy and vision for this new chapter.

2 Karl's Tech Talk: Digital Imaging Update

Through the years, I have repeatedly covered and updated digital imaging in this column, from as far back as 1997 in CircuiTree, through a column in this magazine in November 2015. Several reasons for this extended coverage include the fact that technology had a slow, long incubation time that eventually led to accelerated improvements and acceptance for mass production.

3 Happy's Essential Skills: Project/Program Management

No matter what your job, you may have to manage, or play an active role in, a project at some point during your career. It takes a great deal of skill to do this well, but the time you invest in building good project management skills can pay off enormously.

4 A Day with Pete (Starkey)

Usually the one conducting the interviews, I-Connect007's own Pete Starkey recently found himself on the other side of the microphone when I spent time with him in his hometown of Market Bosworth, England. There, between hiking and gardening, we found time to discuss Pete's rich history in the PCB industry and the many changes and surprises he's seen in the manufacturing process over the years.

5 FTG: Focus to Expand

Firan Technology Group (FTG) is a Canadian circuit board and cockpit product manufacturer. With a newly established global footprint, they look now to grow within that footprint, particularly by way of acquisition. I-Connect007's Judy Warner and Barry Matties met CEO Brad Bourne at FTG's Chatsworth, California facility to learn more about the acquisitions, their success in China, and the overall challenge of working in the aerospace and defense market.

6 IPC Releases Final 2015 PCB Market Size Estimates and Growth Rates Report

The North American PCB Market Report, published last week by IPC, reported IPC's final estimates of 2015 market size for rigid PCBs and flexible circuits in North America. Although North American PCB production decreased 4.3% in 2015 to $2.9 billion, the PCB market grew 1.4% to an estimated $3.4 billion.

7 All About Flex: Considerations for Impedance Control in Flexible Circuits

Impedance can be thought of as a system's opposition to alternating or pulsing electronic current. The unit of measurement is ohms, the same unit of measurement in a direct current system. However, the components for calculating impedance are much more complex than DC resistance.

8 Weiner's World

This month's column has a higher percentage of IC coverage than normal for several reasons. The end of Moore's Law regarding transistor scaling will be dead by 2021 as will be replaced by 3D integration according to the International Technology Roadmap for Semiconductors (ITRS).

9 Inside Spirit Circuits

I was recently treated to a factory tour with Spirit Circuits' Managing Director Martin Randall, to learn more about their process line and how it has evolved over time. In the discussion following, I learned about Spirit's involvement in the China market and how they've structured their business to handle quick turn prototypes locally and high volume abroad.

10 Congressman Scott Peters Tours TTM Technologies' San Diego Facility

Today, TTM Technologies Inc. held a town hall-style discussion with Congressman Scott Peters (D-CA-52) on the legislative issues impacting the manufacturing industry. Executives and employees of TTM gave Congressman Peters a first-hand look at the work taking place in their San Diego facility.

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.

PCB West Conference and Show
September 13–15, 2016
Santa Clara, California, USA

Medical Electronics Symposium
September 14–15, 2016
Marylhurst, Oregon, USA

24th FED Conference
September 15–16, 2016
Bonn, Germany

ICT Evening Seminar
September 20, 2016
Hayling Island, UK

EDI CON
September 20–22, 2016
Boston, Massachusetts, USA

Geek-A-Palooza
September 21, 2016
Boston, Massachusetts, USA

EIPC Workshop on Reliability
September 22, 2016
Tamworth, UK

IPC India/electronica India 2016/ productronica India 2016
September 21–23, 2016
Bengaluru, India

IPC Fall Committee Meetings
September 24–30, 2016
Rosemont, Illinois, USA

SMTA International 2016
September 25–29, 2016
Rosemont, Illinois, USA

Manufacturing Day
October 7, 2016
An annual celebration of modern manufacturing meant to inspire the next generation.

electronicAsia
October 13–16, 2016
Hong Kong

TPCA Show 2016
October 26–28, 2016
Taipei, Taiwan

Electronica
November 8–11, 2016
Munich, Germany

FUTURECAR: New Era of Automotive Electronics Workshop
November 9–10, 2016
Atlanta, Georgia, USA

Printed Electronics USA
November 16–17, 2016
Santa Clara, California, USA

International Printed Circuit & Apex South China Fair (HKPCA)
December 7–9, 2016
Shenzhen, China

IPC APEX EXPO 2017 Conference and Exhibition
February 14–15, 2017
San Diego, California, USA

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Vias
Best ways to create them; making them conductive; how small can they go...

DECEMBER:
Sales and Marketing
Getting ready for 2017