Thinking & Designing in Three Dimensions
Our library is the bookmobile for the 21st century

Registered members of my I-Connect007 have direct access to our ever-growing library of eBooks, which includes a wide range of topics, from low-temperature soldering and conformal coating in harsh environments to thermal management and data package perfection. Registered users simply download new titles free with the click of a mouse. It's pretty awesome!

I-007eBooks.com
all flex
Flexible Circuits • Heaters • Assemblies

• Design application assistance
• Component assembly
• Fast response
• Quick delivery
Thinking and Designing in Three Dimensions

Designing a flex circuit on a flat plane is one thing but conceptualizing and realizing its final three-dimensional configuration can be challenging. Contributing authors offer plenty of help and advice in this issue, and our columnists, as always, provide their perspective on a wide range of flex and rigid-flex subjects.

10 Thinking and Designing in Three Dimensions  
by Ben Jordan

26 TTM on Flex and Rigid-flex PCB Challenges  
Interview with Clay Zha and Winnie Ng

32 Dan Gamota Discusses Flex and Alternative Substrates  
Interview by Patty Goldman and Andy Shaughnessy

46 Staying Current on Flex Manufacturing is Smart Business  
Interview with Brendan Hogan

COLUMNS:

18 My Flexible Story—Flex Circuit Development Through the Decades  
by Jan Pedersen

22 A Few Simple Lessons in Designing Reliable 3D Flex  
by Joe Fjelstad
DuPont offers a comprehensive, industry-leading portfolio of Pyralux® flexible circuit materials and systems designed to meet today’s and next generation design challenges.

The Pyralux® portfolio includes a diverse collection of core dielectric materials and customized dimensional constructions that enable the designer and manufacturer of complex circuits to deliver high performance solutions.

DuPont Pyralux® copper clad laminates, bondplys, coverlays, and adhesive systems offer excellent functional performance and high reliability and allow for the fabrication of thin, solderable, high density electrical interconnects for single and double-sided, multilayer flex and rigid flex applications.
ARTICLES:

50 Excerpt: The Printed Circuit Designer’s Guide to...Flex and Rigid-Flex Fundamentals — Designing Flex Circuits for First-Pass Success, Part 4
by Dave Lackey and Anaya Vardya

56 Manufacturing Rigid-flex Boards
by Bob Burns

72 Collaborative Design Using Empathy
Interview with Jeremy Blum

80 Method for Testing FPC Materials at High Frequency
by Yi-Chun Liu

COLUMNS:

8 Passionate People
by Patty Goldman

42 Exotic Materials: A Prerequisite for Next-generation Flexible Circuits
by Dominique K. Numakura

66 Don’t Build Flex That Doesn’t Flex
by Tara Dunn and Anaya Vardya

88 Ways to Conserve Flex Circuit Material in the Design Process
by Joe Fjelstad

DEPARTMENTS:

41 Flex007 News Highlights

90 Top 10 Articles and Columns

92 Events Calendar

93 Advertiser Index & Masthead

SHORTS:

45 A Safe, Wearable Soft Sensor

49 Excitons Pave the Way to More Efficient Electronics

55 Nanophysicists Develop High-performance Organic Phototransistor

65 Engineers Create Delicate Sensor to Monitor Heart Cells With Minimal Disruption

87 Paper Sensors Remove the Sting of Diabetic Testing
Innovative solutions for complex circuit board manufacturing

Click to see what we bring to each sector of the industry:

- RF/Microwave PCBs
- Power Electronics
- High-Speed Data
- Automotive Electronics
- Lamination
- Startups

Our technology produces what our customers dream!

www.candorind.com | (416) 736-6306
I’ve often wondered, “Are other industries like ours? Do people in, say, the food industry worry about “graying” and the need for young engineers and designers (think food packaging)? Do they get excited over new technology and argue passionately over specs? Do they work weekends, teach classes and webinars, spend endless hours of their own time on documents, write white papers, etc., all for the good of the industry? Do they work with their competitors to improve the industry via standards and specifications as we do? Would their companies approve of or embrace the networking opportunities at industry events? Do they do this even though they may be well past the traditional retirement age and not only do not have to work but often do this gratis?”

As part of the Hall of Fame Council, I am privileged to talk with many who are just as I have described above—and more. Plus, there are many other the giants in our industry not yet so honored—including a few with upcoming awards at IPC APEX EXPO (names still under wraps to be revealed at the conference) where they will receive some of the highest honors because of their tireless volunteer efforts. These people are positively passionate about their work in the industry and totally dedicated to it.

But I’m off the subject which, of course, is flex. This month, it’s about thinking and designing in three dimensions, so let’s focus a bit on that. This issue is especially for the designer who is starting on flex and rigid-flex and trying to visualize going from flat circuits to a finished product that is, well, any shape that can be imagined. How do you look at a flat circuit and know that it will fit into that tiny, odd-shaped box it is designated for? Let’s find out.

We start with an article by Altium’s Ben Jordan with much good information and advice on designing flex and rigid-flex circuitry for a specific configuration. With the use of a commercially available design tool with 3D-enabled software, one can confidently, as he says in so many words, “Jump in and design from the get-go in the foldable 3D environment.”

Next, Elmatica’s Jan Pedersen provides a light-hearted discussion, reminiscing on learning how to build a three-dimensional circuit including using “paper dolls” and the often many iterations to reach the desired outcome. He gets down to the nitty-gritty with a long list of tips to be mindful of during design.

Joe Fjelstad, Verdant Electronics, supplies a few lessons in designing three dimensional-flex circuits based on his experiences and lists some takeaways for those just starting.

In an interview with TTM’s Clay Zha and Winnie Ng, they discuss the differences in...
manufacturing flex versus rigid PCBs as their business in that arena grows. They also talk about HDI on flex as well as flex assembly.

In a wide-ranging conversation, Jabil’s Dan Gamota gives us his take on the current state of flex and alternative substrates and explains why modeling, automation, and process controls are key to flex manufacturing.

Our regular columnist Dominique Numakura of DKN Research wrote for this issue. He describes in detail the available material options for flex circuits—including the requirements for wearable electronics technology.

In a short interview with Publisher Barry Matties, Brendan Hogan from MivaTek Global discusses ways a designer can stay current on manufacturing technology and better design for flex. He also touches on direct imaging for reel-to-reel processing of flex.

American Standard Circuits’ Dave Lackey and Anaya Vardya continue with part four of their series of excerpts from the eBook on flex and rigid-flex, focusing on the data package and explaining a number of requirements unique to flex and rigid-flex.

Printed Circuits’ Bob Burns has written a great article on how the manufacturing of rigid-flex PCBs is both similar and different from manufacturing rigid boards and flex circuits. He takes us from front-end engineering through final preparation for assembly.

Tara Dunn, Omni PCB, teams up with ASC’s Anaya Vardya to share a story on flex that didn’t, um, flex. They continue with a clear discussion on the types of copper foil, grain direction, bend areas, balanced construction, and how to ensure one’s flex circuit design will survive final installation.

In an interview conducted at the recent AltiumLive event, Jeremy Blum of robotics company Shaper discusses his first-ever hand-held CNC machine. He answers the question as to how the Shaper Origin—originally designed for woodworking hobbyists—relates to the PCB industry. He further discusses the importance of communication between design and manufacturing, supplier and customer, and his most important tool—empathy.

Now, for you test engineers, we have a technical article by Yi-Chun Liu from Uniflex Technology on a reliable method for testing flex materials under high-frequency and high-speed conditions. Their test results also show the lowest insertion loss was achieved using a liquid crystal polymer dielectric. Take a look.

Drum roll, please, for one more column by Joe Fjelstad. I guess Joe has more knowledge to impart than a once-a-quarter column allows, so he has supplied us with a second column for this issue. This column is on designing your circuit to optimize material utilization on a panel array—thus, saving material costs. He concludes with a statement that applies to much more than saving material: “In summary, the decisions made by the flex circuit designer...will have an impact that lasts the entire [design-through-assembly] process.”

This is one packed issue, but there’s a lot going on in our industry, especially on the flex and rigid-flex side. Our next issue (April), we will examine the entire design-through-final-product process with flex in mind. In the meantime, keep up to date with our sister publications Design007 Magazine, PCB007 Magazine, and SMT007 Magazine, as well as our daily and weekly newsletters. Register and sign up for any or all of these free publications here to have them delivered right to your inbox. FLEX007

Patricia Goldman is managing editor of Flex007 Magazine. To contact Goldman, click here.
Thinking and Designing in Three Dimensions

Feature by Ben Jordan
ALTIIUM

This article aims to encourage interconnect designers who design for flex or rigid-flex circuits to use the modern CAD tools at their disposal for getting flex done right the first time. While modeling PCBs in 3D is not new, and all the major PCB EDA vendors offer some form of 3D modeling and integration, it is still a rare circumstance that flexible circuit designers use 3D CAD modeling. Most still prefer to design in 2D spaces and build paper dolls.

There are some pretty significant advantages to using 3D-folded flex circuits and multi-board modeling in CAD such as ensuring correct board shape. You can also fold geometries before having to cut even one piece of paper, and avoid building an expensive prototype only to find the flex portion was slightly too long or short or components on the final assembly interfere with each other once it’s all in-situ. Call me Captain Obvious!

These issues happen because of the disjoint between the design in our heads and the design in CAD. It’s important to recognize that in our own designer’s mind, we are already trying to think in three dimensions—mentally animating assembly processes and folding—and equally important, to recognize the need for capturing that inside view to validate and verify that it can actually work using the tools at our disposal. With plenty of margin and lots of experience, it might work out okay, but there’s no substitute for an accurate model to test.

Less obvious are the secondary and tertiary issues that can be highlighted and effectively dealt with by using 3D-enabled PCB and multi-board system design software. And by that, I mean taking a truly iterative design approach as opposed to the more typical linear method of creating the board outline in MCAD, importing to the PCB editor, developing the component placement and routing, then re-exporting to MCAD. The following are just a few areas where thinking and designing in three dimensions will make a nice improvement to your workflow.
Printed circuit performance is a function of synergy.

Robust electronic materials are crucial to high performing printed electronic systems. Alpha's suite of innovative, mutually compatible electronic materials enable designers and engineers to conceive, develop and deliver state-of-the-art electronic circuits for end applications, such as capacitive sense & touch structures, advanced sensors, smart labels and other flexible printed electronic circuits.

- **Innovative Products**
  - Silver Ink
  - Carbon Ink
  - Dielectric Ink

- **Salient Features**
  - High conductivity, better spread
  - High abrasion resistance
  - High K, UV curable

**Let’s get started.**

Working together, we will be able to develop novel solutions. Let us help you improve the reliability, compatibility and overall performance of your device.

alphaassembly.com
Stackup Planning

Most experienced PCB designers consider the layer stack as a cross-section of the board build-up of materials, and that makes perfect sense. We think of the lamination cycles, and how the PCB will be constructed at the fabricator. But there’s more to it than layers of dielectric and foil—especially when it comes to flex and rigid-flex.

Will components be mounted on the flex stack portion? Will you have vias in both the rigid and flex sections of the board? Will you use plated through-hole parts that require plated holes all the way through?

Modelling your stack for a rigid-flex board is the first part of the design. Before you come to parts placement and routing, you at least need to develop and visualize the layer stack as a starting point. Yes, it may change during the design—if you realize you can reduce the layers of copper, you’ll definitely want to try—but you need to at least begin with something not too different from what is actually going to be constructed to place and route the board efficiently.

Being able to visualize the full rigid-flex stackup in 3D with thickness scaling is an indispensable check for validating what you had mentally pictured your rigid-flex construction to be (Figure 1). When you model the layer stack cross-section in 3D along with your defined via structures, some very interesting things are revealed:

- Thicknesses of materials may look very different in reality than what you imagined; for instance, you may not have accurately envisioned just how thick adhesive layers in a flex stack can be, which has implications for thermal properties, assembly, and signal integrity you would perhaps not otherwise explore before prototyping.
- You may be counting on flex layers for ground and power capacitance, but without a field solver, even just the visual check can alert your intuition that it’s not going to be enough (unless you make the layer stack asymmetric to draw copper pours closer).
- Placement and adhesion of stiffeners may not be what you expected.
- The 3D view can show you how physically difficult it might be to manufacture it; seeing clear cross-sectioned views can help you understand the additional manufacturing steps.

Rigid-flex Board From Assembly

Like any PCB design, begin with the end-product in mind. The most common practice that I anecdotally encounter—even to this day—is that the industrial designer feeds mockups to the mechanical engineering team/designer who defines the 3D mechanical enclosure from which...
comes the physical space constraints. The initial board shape and concept of component placement is derived at first from mechanical CAD (MCAD)—usually as a DXF/DWG file—which only supplies a two-dimensional outline of the overall flattened board shape (Figure 2a and b).

MCAD has been used by many to plan the flex by using “sheet metal” modeling. This allows the mechanical engineer to design the overall board substrate shape to a single thickness in a folded state, which is then flattened to provide the 2D panel outline of the rigid-flex board. This allows the designer to place and route the rigid-flex board in 2D PCB design software.

It’s an acceptable method, but suffers the following significant flaws:

- The PCB designer still must use paper doll mockups to check in-situ folding and component placement, which is a time-consuming—and usually frustrating—process
- When changes are needed, the iteration must always begin in the MCAD tool flow with a re-export of board outlines, and an import into PCB CAD with the associated component and routing moves taking much longer
- The PCB designer has very little immediate visual feedback regarding component placement or folding—it has to rely entirely on the designer’s imagination; while we know PCB designers have an excellent imagination, they are still human (enough said)

Oddly enough, many flex PCB fabricators still urge designers to make a paper doll mockup (Figure 3) of the flex boards from a 1:1 assembly drawing print-out cut out with scissors and folded into the target installation...
shape to verify the form and fit. Even with 3D modeling in your tools, if it makes you feel better, go ahead, but it won’t give you component clearance checking. For that, you need your EDA tools to physically analyze the assembly.

Planning Fabrication, Folds, and Installation

This is the part where most designers have a fairly intuitive grasp of flex design. We are already thinking in three dimensions here—it’s the impetus for the whole exercise. But because it’s natural, it can lead to a false sense of security in one’s own ability to mentally plan the shape of the board and how it will fold.

Modeling in 3D CAD grants us confirmation of what we envision is manufacturable. Beyond that, it prevents many real manufacturing and assembly problems such as poor panel utilization, component interferences, flex interferences, and difficult or impossible installation into the final product assembly.

The major professional EDA tools can do this, so why not jump in and design your rigid-flex boards from the get-go in the 3D-foldable environment? This lets the designer visualize the folded assembly directly with placement and routing to reveal any mismatches between the mental image of what the design should be and the physical instantiation of it (Figure 4). This immediate visual feedback will instantly reveal problem areas and allow for fast iterative adjustment, directly alleviating:

- In-situ component interferences
- Impossible flex folds and bends (ever imagined a flex circuit only to find that the flattened panel was folded back onto itself?)
- Insufficient or excessive flex circuit length (this is a problem frequently discovered during costly prototyping runs!)
- Poorly-oriented outlines resulting in bad panel utilization
- Slow iteration cycles (MCAD → ECAD → place/route → review → MCAD → ECAD)

In short, the PCB designer has the power and freedom to model, check, and make all adjustments directly. Designing and modeling in 3D from the ground up will also lead to better rigid-flex board outlines because the PCB designer can quickly explore alternatives. For example, using a sideways folded broad flex instead of a lengthways folded long-thin flex may reduce layer count while also saving panel space for multiple transversely rotated panel instances (Figure 5).

Figure 4: Natively modelling the rigid-flex assembly in 3D for design and planning.

Figure 5: 3D modeling of rigid-flex (left) leads to better panel utilization (right).
Cicor is a technology partner in printed circuit boards, printed electronics, hybrid circuits and electronic manufacturing services with 10 production sites worldwide.
Modeling the rigid-flex PCB assembly in its full context is invaluable. The board shown in Figure 4 is shown mounted in its multi-board assembly context in Figure 6. By modeling the whole multi-board assembly, changes to the length and shapes of flex connectors can quickly be determined. This example is an inertial measurement unit from an autonomous quad-rotor drone design. The flex circuit was chosen to provide vibration isolation from the main board, which is mechanically mounted to the rotor arms, thereby using the flex circuit for physical low-pass filtering of the inertial measurements.

In this assembly, with the enclosure models hidden, everything fits together nicely. However, bringing in the enclosure models from their associated STEP files and running a clearance/collision check directly in the PCB design tool immediately shows where the top housing model interferes with the folded flex circuit. Note: STEP stands for “Standard for the Exchange of Product model data,” from the ISO-10303 standard, and is used for the interchange of 3D mechanical models (usually components) between mechanical design software and PCB design software. The collision highlight is shown with a cross-sectional view in Figure 7.
image can lead designers to better signal and power integrity because you can clearly see new modes of crosstalk and return-path current directions from the folded signal paths. And of course, in the age of wireless everything, rigid-flex offers new options for RF and antenna geometries that are not limited to the traditional rigid PCB structures.

Conclusion
I’ve only scratched the surface, but I hope this article encourages both designers and PCB manufacturers to take the time and learn the 3D, rigid-flex, and multi-board design capabilities of the CAD tools they have at their disposal. Thinking and designing in three dimensions will dramatically reduce the iteration time and cycles, reveal issues earlier in the process, help you design a cost-effective, manufacturable product, and even improve your placement, routing, and signal integrity.

Ben Jordan is senior manager of product and persona marketing for Altium. He is a computer systems and PCB engineer with over 20 years of experience in embedded systems, FPGA and PCB design.
My Flexible Story—Flex Circuit Development Through the Decades

PCB Norsemen

Feature Column by Jan Pedersen, ELMATICA

Social media platforms like LinkedIn and Facebook have made it simpler for all of us to remember birthdays, events, and avoid the always painful “I’m so sorry I forgot our wedding day” issue, but they also affect our professional careers. For all of us who have signed up for a LinkedIn account, you have probably found that you are celebrated every time your employment is changed. Some anniversaries are correct, while others are not. Just before Christmas, Editor Patty Goldman congratulated me for 26 years at Elmatica, which actually is correct, and asked if I could share some thoughts from my long experience in this exciting industry. Some things have changed a lot in the past few decades, but others? Not so much.

Serious Papercutting

My flex story started a few years earlier working as a rep for UK-based Flex-Ability Ltd. (now Merlin).

In those days, we used purely adhesive materials, and the challenges we met and tried to solve were mechanical in most cases. My message to customers was, “Usually, we find a solution, so bring all your crazy ideas—even those you think are impossible—and we will sort it out together.”

DFM for flexible circuits became one of my favorite tasks. Every customer had special needs, and we almost always found a solution that worked for the company and our customers. A typical scenario could be a tight construction where the customer wanted a flex tail out from a ZIF connector with a sharp bend through narrow areas where no one thought a PCB could go.

You might wonder how we tested this in the old days when computer-based 3D simulations were not a possibility. Simple! We took a piece of paper, scissors, and started to cut the paper into the shape of the flexible PCB we had in mind. Next, we glued this to samples of the rigid PCB and started to simulate the application. We examined not only how it fit into the application, but we also went through the manual assembly process and found areas where the paper was torn. Then, we improved the model and made assembly notes until we were good to make a real sample. It was rough, honest, handcrafted work.

Figure 1: Elmatica has experienced increased demand for both flex and flex-rigid in the last few years.
FLEXIBILITY NEVER LOOKED SO GOOD

FLEX SOLDER MASK
BY TAIYO

PSR-9000 FLX03G LDI

- Designed specifically for Orbotech LDI equipment
- Dark green glossy finish
- Fast exposure time
- UL listed VTM-0 on 2 mil polyimide
- Straight sidewalls

Phone [775] 885-9959 • www.taiyo-america.com • info@taiyo-america.com
Curls and Waves in More Than ‘80s Hair

I always asked the customer to give me 3D drawings of the FPC that showed how the FPC should be used in the application. During the 1980s, many people requested semi-flexible, or bend-to-stay, circuits. Rogers introduced a material called Bendflex, and I recommended this material for applications where a single bend with no sharp folds was required. However, this material did not receive enough attention for Rogers to continue producing it, so it was taken off the market after a decade or so. I still have not seen material with the properties we had with Bendflex unless you choose an aluminum base.

Surviving Dynamic Movements

I remember one success story related to the early design of disc drives reading and erasing heads. I brought Steve Holding from FlexAbility to Norway for a brainstorming meeting with our local disk drive OEMs, and we started investigating what was needed to survive dynamic movements with sufficient flexibility in combination with a new level of track width and density.

We tested out how available copper structures and grain direction affected flexibility and dynamic movements, and tuned the design and material choice to meet the required bend cycles. These early developments ended up at a global product owner and were transferred to Asia for mass volume production.

Since Day 1 of my first contact with flexible circuits and DFM, early involvement in guiding product development has been the key to success—and it still is!

Some Things Never Change

Back in the days, we created some simple design rules that I still find very useful. Some of the parameters are very conservative today, but if you want to produce a low-cost flex, these parameters still apply:

• Flexible materials are subject to slight shrinkage during the manufacturing process; thus, allowance must be made when determining minimum distances between groups of holes
• Circuit pad design should take into account a method of anchorage; this can be by pad filleting, Mickey Mouse ears, or utilizing the plating in the hole on the PTH circuits
• Ninety degree track bends should be avoided
• Route tracks between holes tangentially to gain maximum space; where possible, route these tracks on the component side and increase solderable land on the solder side
• Avoid having rectangular holes, as this can increase tooling costs; this applies to both base and covercoats
• Lands around via holes should be as large as possible
• Avoid via holes in bend areas
• Where the circuit is required to bend, tracking should follow the direction of the bend; do not track across a bend and design the circuit to be single-sided in areas with dynamic bends
• Generally, covercoat apertures should be designed to be smaller than through-hole component lands by an approximate 0.2-mm diameter; when considering the hole size in relation to the solderable land area, the same rules as those used for a rigid PCB apply
• Ground plane areas should be cross-hatched to improve bondability when using copper screens, and consideration given to silver polymer-loaded inks when overall circuit thickness is critical
• All inside corners must have a radius; in these cases, a copper tear stop should be incorporated into the design as an added safety feature to guard against tearing or cracks propagating across a flexible circuit
• When routing your traces in a double-sided flex, it is best to stagger the traces to prevent an I-beam effect; with the conductors stacked, you run the risk of compression issues when bending to install
Lots of Prototyping and Testing

If you have read some of my earlier PCB Norsemen columns, you probably understood that my heart pounds for PCB standards. At Elmatica, we value transparency and predictability, and IPC standards for PCB contributes to this, aligning the industry by following the same set of guidelines.

When I started with FPCs, the focus was not on standards but tests and failures. It was all about finding the solution and having the knowledge and experience to know what was working or not. The customers relied on the suppliers to find their way around the challenges offered to them and the right solution for that exact flex circuit. The result was often a large number of prototypes and endless rounds of testing.

I remember how satisfying it was to find a solution for a customer who had been elsewhere and was ready to throw the entire project in the bin. Now, the situation is different. Being a part of the development of several IPC standards, I often get that “throwback Thursday” feeling. It’s quite funny to spot how many of our early recommendations are implemented into IPC-2223D.

Impedance: A Lesser Challenge With Improved Base Material Stability

Today, we see more and more flex circuits with controlled impedance. This was a big challenge in the ‘80s. With the adhesiveless materials we have now—with improved base material stability and thickness tolerances—signal characteristics are much more predictable than with the adhesive-based materials we had before. In fact, some of the most advanced circuits with the smallest tracks and gaps are made on flexible materials.

In my work with IPC developing a standard for medical applications, we see a trend in applications such as pacemakers and defibrillators where flexible polyimide materials are widely used. Whereas flexible design in my early flexible days (no, I was not a yoga master back then either) followed more or less the same design rules, the situation in 2019 is quite different. We see a big difference between those simple designs typically manufactured in volumes with general tolerances compared to those extreme high-end designs where dedicated state-of-the-art manufacturing equipment is required, and IPC Class 3 is barely a starting point.

Thinking in Three Dimensions Is Still Vital

In both ends of the design scale, a 3D understanding of the application is vital to provide sufficient DFM support, not to mention the specification. A complete specification (preferably digital) together with a 3D drawing is crucial to give a complete picture of the FPC and secure a product in compliance with the customer’s expectations. It was like that in the ‘80s, and it still is today. Happy flexing! FLEX007

Jan Pedersen is a senior technical advisor at Elmatica. To read past columns or contact Pedersen, click here.
There is an old and familiar adage that goes something like this: “If the only tool in your tool chest is a hammer, you tend to see every problem as a nail.” We all have a tendency to stick close to the familiar and use the tools we know to create solutions to problems confronting us; we’re only human. Unfortunately, using only familiar tools limits our ability to come up with optimal or even superior solutions. Hopefully, what follows will help you avoid some of the traps conventional wisdom doesn’t always give guidance on.

But first, having written extensively over the years about flexible-circuit technology, I still try to find fresh ways to think about flexible circuits and their construction and use. In the process of thinking about what I might say here, a fun book I read in high school more than half a century ago came to mind. The title of that book is Flatland: A Romance of Many Dimensions by Edwin A. Abbott [1]. In full disclosure, and as one might guess from the extended title, the book is not about geometry but is a rather entertaining read. I found it to be a useful book for stimulating thought.

In the book, almost every male character in Flatland has two major dimensions—X and Y—and many possible sides (thus, they have area), but they can only be perceived as lines when looked at from the reference of the planar world in which they exist. Women, on the other hand, are depicted as being basic lines, and are required to make noise as they move about through Flatland should they be encountered head on and appear as a simple point. The protagonist (a square) encounters both Lineland and Pointland, but the encounter with a sphere from Spaceland is where the entertainment really begins. Trying to convince others of another dimension is no mean task, one learns. Many humans are resistant to accepting the teachings of science. The book proved useful over the years to a number of prominent scientists (including Carl Sagan) seeking to help the layperson understand the
Since 1987, we have been dedicated to developing innovative high-density interconnect solutions for all electronics industries for our customers worldwide.
multidimensional space they envisioned and were attempting to explain.

That function of envisioning the not-always-easily perceived is summoned here, but for a much less complex purpose than defining space and time. My specific purpose is, “How to tease a three-dimensional circuit from a two-dimensional copper-clad panel and do so reliably?” That should be job one in nearly every flex-circuit design. So how does one carry out the task and make 2D into 3D reliably? Here are some suggestions. Be warned in advance that there are no pat answers to the question posed. Each design inevitably has its own set of requirements and challenges, but there are a few steps that are common:

1. **Define the end-product shape, size, and volume:** This is the primary constraint for the design—the canvas for the painting. An individual or team has the job of defining the shape and volume of the product. Often, that job is constrained in some manner either by limitations of space where the electronics are going to be put to use or by a mandate from marketing or management. Steve Jobs, it has been said, was intimately involved in the design of the iPod and iPhone in terms of the size and shape and other design features along with its functionality. He did not execute the design and manufacture by himself, however. He created a significant challenge for designers, and flexible circuits were vital to achieving the goal. In fact, the use of flexible circuits was arguably crucial to making it happen as they were indispensable to the interconnection of the various high-density connecting elements of the electronics in the product (Figures 1 and 2).

2. **Identify all components and make selections carefully:** Many years ago while working for a major aerospace company, I was part of a group tasked with making a circuit that needed to fit in a very small predefined space. To say that it was difficult was to understate the case. The devices chosen for use with the design were rated for reliability, but they were very large. It was as if someone had measured the volume of each of the individual components and their collective volume, and, also knowing the volume of the space available and seeing they matched, they decided it was possible. It wasn’t quite that bad but it seemed that way. Moreover, the design chosen was a rigid-flex, which was not very common at the time and the processing was not well understood. The product was built and had several overlapping flex arms designed to interconnect to bulkhead connectors inside the space. Trying to assemble the circuit was a nightmare, and because there was little additional length on the arms, many of the circuits broke during the assembly process. It was eventually solved by a combination of selecting different components and getting some relief on the size of the box by making it slightly larger. The takeaway is that the early decisions can have a knock-on effect of significance.

3. **Use paper doll mockups of the proposed layout:** Available CAD tools can lay out circuit patterns and allow them to be modeled for interferences in the application. However, a simpler method—at least for first-pass approx-
imation—is to create a paper model of the assembly design to see what traps might lie in the road ahead. This will be instructive in determining roughly how much extra length might be required to provide a service loop, which not only facilitates assembly but also creates some intrinsic strain relief in the circuit. Later, when the layer counts that might be required and the construction are defined, it can be repeated using materials of similar thickness and stiffness to the anticipated construction. This will expose any previously unforeseen potential for buckling or kinking of the circuit during assembly.

4. Use no right or acute angles in the flex-circuit outline: Stress risers are anathema in nearly every mechanical design, and with flexible circuits having a foot in an electrical, electronic, and mechanical world, stress risers are no less important. The first and arguably most important thing one must do is to make sure that right or acute angles be avoided everywhere possible in the circuit outline. The interface between the rigid and flex circuit is one spot where it is not really possible, and this should ideally be dealt with by providing some strain relief at the interface. Commonly, this is a bead of some resin or elastomer along the edge. I have seen failures occur at this interface, and I suspect other veterans of flexible circuits have as well over the years. This was not meant to be an exhaustive treatise on the topic. As I am certain every other flex circuit engineer has, I have a number of anecdotal experiences that involve nuanced elements of the design and assembly process that have resulted in failures, but these are some important ones in my opinion. I would add that when you experience failure—and it is likely you will at some point—embrace the moment. These are teaching moments and lessons that will not be forgotten.

References

Further Reading

Joe Fjelstad is founder and CEO of Verdant Electronics and an international authority and innovator in the field of electronic interconnection and packaging technologies with more than 150 patents issued or pending. To read past columns or contact Fjelstad, click here.
One of the biggest bareboard manufacturers in the world, TTM Technologies (TTM), has seen a recent surge in flex and rigid-flex demands from their customers. In this interview, Clay Zha, Vice President of Technology Solutions of TTM’s Mobility business unit, and VP of Corporate Marketing Winnie Ng discuss the differences in manufacturing flex versus traditional PCBs, and the increasing need for rigid-flex HDI boards.

Barry Matties: Clay, can you give us a quick overview of TTM?

Clay Zha: TTM is probably one of the top three PCB manufacturers in the world. If you’re only considering the bare PCB, we’re probably the leader in the world, and right now, we have 29 manufacturing sites across the world. We offer not only rigid PCBs, but also flex and flex assembly, rigid-flex, and EMS solutions. Also, after the acquisition of Anaren, we offer radio-frequency (RF) modules and components as well.

Winnie Ng: As you mentioned, in 2018 we completed the integration of and acquired the company called Anaren. They are a manufacturer of RF and microwave components. We broadened our product horizon and are now positioned for not just PCB manufacturing but also RF and microwave components and assembly for future technologies.

Matties: Let’s talk a little bit about flex and rigid-flex capabilities. First, since you are focused on the mobility business, what sort of percentage of your business is in the flex and rigid-flex space?

Zha: It’s about 20% of the mobility business.

Matties: Flex is certainly one of the faster-growing segments. Do you see that in your overall business as well?

Zha: Especially in 2017, we’ve seen a huge demand from the market because a lot of people require more flexible and reliable connections with thinner, high-density connection devices. That’s where we see the drivers coming from. Some of them come from the signal integrity challenges...
Challenges in flex circuitry require that all materials are designed to work together.

For the first time, a single source has your solution.

Low stress copper metallization • Solderable final finishes • Low temp solders
Flex-compatible oxide alternatives • Encapsulant & attachment materials
Semiconductor advanced packaging

EXPERTISE
Industry experts working side-by-side

CO-DESIGN
Products created to optimize all material interfaces

SERVICE
Solving problems with an industry-wide perspective

www.macdermidalpha.com
considerations, and others from the compact assembly needs. You can eventually form a small device with a lot of components and 3D assembled in a very limited geometry with reliable signal transmissions; these are the two areas where we see people adopting rigid-flex and flex.

**Matties:** You’re in an interesting position because you deal with the people integrating flex into their products.

**Zha:** For PCB manufacturing, we mainly deal with their PCB interfaces. We rarely deal with their system-level designers, but we did talk about why they require this or what they look for, so we may have some understanding.

**Matties:** We constantly hear that collaboration from system design to the fabricator and assembler before designing the board is critical and that companies would wind up with a better product overall if they followed that path. Is that the case?

**Zha:** That is true, and I agree with that point. If the PCB manufacturer can work with customers with early involvement in terms of flex assembly or rigid-flex design, that will definitely help the cost, quality, and reliability of the products.

Flex material is very different than the material used for rigid products. There are also a lot of manual handling processes during flex or rigid-flex manufacturing. For example, how do you design the cavity inside, how do you want to remove the cap of the cavity, and what kind of connection are you trying to realize? All these considerations are going to be linked to the cost, quality, and challenge of manufacturing the FPCs. Early involvement will improve the understanding of the manufacturing process and the final product needs from both parties and put considerations of manufacturability of board and final assembly before the product is designed. It is not straightforward as with rigid PCBs; without communication and careful consideration, a very small design feature that may not be necessary to the function could cause a huge difficulty for the fabricator and could eventually become a yield and cost issue. It’s quite different from traditional rigid PCBs we manufacture at other plants right now.

**Matties:** Where is the growth you’re experiencing coming from? Is it coming from customers using flex for the first time?

**Zha:** From our experience, most of our customers are not actually using flex for the first time, but rather we are seeing more project teams within their organization start to adopt flex and rigid-flex technology. Even within one organization, there may be some individuals who are quite familiar with flex products, but there may be other teams that just started and are puzzled about the whole process, materials properties, etc. From our current situation, I would say probably half of our customers have a good understanding of flex and rigid-flex, and the other half are less experienced with flex/rigid-flex or are working with it for the first time.

Even with the half who understands flex, flex assembly, and rigid-flex processes, their understanding of it is not as deep as their knowledge of rigid PCBs. Usually it involves a lot of our rigid-flex/flex field application engineers’ early involvement efforts to provide design consultations and the education they need.

**Matties:** When you talk about educating customers, what do they lack the most? I know you are talking about manufacturing process knowledge as well, but what is really needed overall?

**Zha:** It starts with the base material used for flex and rigid-flex products; most of it is poly-
imide-based that is far different from normal FR-4 materials. The stack-up, mechanical and chemical processes used, signal integrity, overall product reliability, and even storage and assembly conditions are all impacted by this material change. However, the most difficult part will still be the manufacturing process. Especially with rigid-flex, many of the processes are customized based on different design features and requirements. There is a lot of engineering and know-how involved; normally it requires the manufacturing process experts working together to get to the optimum solution with the least compromises from original design needs. Even for PCB companies like us, we still need training on our manufacturing considerations, not to mention the customers. Luckily we have a strong engineering team from both the manufacturing end and customer end and they sync all the time and can work seamlessly to address the requirements and needs of our customers.

Matties: With this area growing and a lot of material issues, I would think that there are a lot of education needs. Now, in terms of the flex offerings, I see you do quite a bit, from single-sided all the way to rigid-flex HDI. Are you seeing more of a trend around the HDI?

Zha: For HDI, it has started booming not only for rigid-flex but also for rigid. Part of the reason is that it is component-driven because most of the components are getting to a level where you have to route with microvias. There’s no way you can route with PTH holes simply because the through-hole and off-pad design are too large for those kinds of pitches. Another reason is that we’re seeing the needs coming from signal integrity considerations, especially for 5G. With HDI, you can use the microvia structure to form a very good termination at the different layers with high density routing so that you don’t have too much loss on the stubs. You also don’t want a signal going through the power and grounding in the middle where you’re going to generate a lot of noises to your signal. In that sense, I see a lot of requirements on HDI for both rigid-flex and the rigid section.

Matties: And you said you’re doing assembly as well for the flex and rigid-flex products. One thing we hear is flex assembly is quite challenging if the board is not configured or laid out properly. What should a buyer know when it comes to the assembly process?

Zha: Yes, and that’s the reason why we have flex assembly in-house, which is normally required in the flex products. That’s mainly because the flexibility of the material itself makes it hard to handle. Usually, the rigid assembly house can’t or doesn’t want to handle it because it doesn’t fit their high volume, high-speed environment. Thus, only very specialized assemblers on the flex side can handle these kinds of materials.

Matties: What advice do you give your customers when it comes to the assembly?

Zha: What we see is that the flex assembly is really happening at the flex manufacturer side, like an in-house service. Usually there are not a lot of components on the flex portion; most likely, there are a few connectors here or there from the main components and most of the functional components are on the rigid portion.

Matties: Clay, you mentioned that TTM has 29 facilities. Do you have flex-dedicated facilities, or is it just embedded in other manufacturing facilities?

Zha: We do have an independent flex operation, but it’s located in the same building as one of our rigid shops. We have our TTM Guangzhou (FPC) operation inside the TTM Guangzhou
(GME) factory where GME is our largest rigid HDI manufacturing site in Guangzhou, China.

**Matties:** You’re doing large-volume flex manufacturing, correct?

**Zha:** Yes, depending on how you define large volume. Within the entire flex and flex assembly industry, we are not among the largest vendors who are very large size and only focused on flex and flex assembly. But when you talk about rigid-flex and flex assembly, we do manufacture a considerable number of devices—up to a million pieces for quantity.

**Matties:** We’ve talked about collaboration and material. Is there any other advice that you would offer for lowering cost, increasing yields, and reducing cycle time?

**Zha:** First, I would suggest that you consult your PCB manufacturers even before you create your stackups, and work with them on the tradeoffs of different designing features because that is going to save costs in the long run.

Secondly, to save the cost on “install flex,” it can be treated differently from dynamic flex. With a relatively large bending radius and a relatively lower amount of bending in install flex, there is a possibility to consider semi-flex technology, for which you can use FR-4 material instead of just polyimide material. With this technology, you would still be able to realize 3D installation but of course with some tradeoffs on bendability.

We offer all three different types of technologies (dynamic flex, install flex with PI material, semi-flex with FR-4 material), so comparing them from a cost or process manufacturability perspective, semi-flex will be lower cost and easier to build compared to the traditional rigid-flex process.

**Matties:** So, really understanding your application can drive the cost down—or up, if you’re not careful?

**Zha:** Definitely. Even which layer you make your flex circuit or how large you open a cavity matters. For rigid-flex, there are a lot of engineering considerations in the building process. A very small difference can generate a lot of headaches where they have to mitigate the risk by using a more complex process flow, and it’s going to add to the cost. Thus, early involvement is key to rigid-flex design.

**Matties:** Is there anything that we haven’t talked about regarding flex and rigid-flex that you feel we should discuss?

**Zha:** Regarding the flex material itself, the dimensional stability is not as good as rigid material. Therefore, for designers should not expect rigid-flex and the flex circuits to have similar design features as rigid. That’s one of the most common mistakes we see. People simply change a part of the PCB into flex and don’t understand why they suddenly have design rule change issues because the dimensional stability of the polyimide material is worse than FR-4 materials. That’s one thing I think we need to caution the designers about as well. The main message I’m trying to convey is rigid-flex design and manufacturing need early involvement and compromises or optimizations from both sides to realize good quality and low-cost products.

**Matties:** Clay, we certainly appreciate your expertise and all of your years of service in this industry. Thank you so much for spending time with us.

**Zha:** Thank you, Barry.

**Ng:** Thank you.
JOIN IPC’S JOB TASK ANALYSIS COMMITTEE

Make sure your voice is heard on the critical issue of skills gap in the electronics manufacturing industry. Help IPC define the workforce skill requirements needed for today and the future.

Join IPC’s Job Task Analysis Committee (JTA) to help address the skills gap and provide training and career opportunities for your employees.

Why Join JTA?

• To address the skills gaps in your own company.
• To ensure that your staff will be well trained moving forward.
• To decide which jobs need focus and which skills are most important for your industry.

Help us help you shape IPC education and certification offerings that keep your company moving forward and improve recruiting and retention.

For further information, please contact Dave Hernandez, senior director of learning and professional development, at davidhernandez@ipc.org.
Dan Gamota has spent his career in electronics manufacturing. Dan has been at the forefront of some of the most cutting-edge processes and technologies since he started at Motorola decades ago. Now as the VP of manufacturing technology and innovation for Jabil, Dan gave us his take on the current state of flex and alternative substrates and explained why modeling, automation, and process controls are likely to be key ingredients in the recipe for manufacturing non-FR-4 boards in the future.

Patty Goldman: Dan, tell us a little bit more about yourself and your background.

Dan Gamota: I’ve spent 25 years in manufacturing and innovation. I started at Motorola when cellular phone commercial adoption was ramping up. I was on a team tasked with developing a scalable manufacturing process for an elegant microelectronics technology—bare die assembly (e.g., flip chip, C4)—which IBM had licensed to Motorola. Motorola was seeking to take that technology, which was developed and commercialized within a vertically integrated company (IBM), and prepare it for mass adoption by OSATs and PCBA services suppliers. Motorola was tasked with establishing the industry supply chain while moving from an elegant, well-controlled, low-volume product process that had to be closely monitored (multiple in-line testing platforms) to ensure high yield to one that was compatible with high volume SMT manufacturing (few testing steps) for mobile devices (i.e., cellular phones, pagers, two-way radios).

Early on, that gave me an appreciation for electronics manufacturing, automation, and process control. In the early days of SMT, you had to ensure that there was a significant amount of discipline on the design side: DFM, process guidelines, and material selection.

My active involvement with SMT and advanced microelectronics manufacturing lasted until about 2001. I was fortunate to have experienced the critical operational facets for
2017 OVERALL ON TIME DELIVERY (OTD): 94.96%

Tramonto Circuits takes OTD very seriously. Our overall delivery rate, including prototype, production and assembly, is 94.96%!

2017 OVERALL QUALITY: 97.35%

In addition to OTD, Tramonto Circuits takes quality very seriously. Our total quality rate is 97.35%. Nearly 100% of circuits shipped meet all specifications and requirements.
about seven years of a well-controlled and well-established manufacturing environment. In 2001, the Motorola CTO Dennis Roberson was seeking to disrupt the way that we assembled electronics and the products that we could design. With his sponsorship and my direct boss, Dr. Iwona Turlik, we started on this path of manufacturing innovation. We thought, “Instead of having a rigid circuit board, could we use other materials for the circuit board? Could we use flexible materials such as textiles, polyesters, and paper, or stretchable materials such as silicones and polyurethane based soft materials? Could we use toughened glass that we could bend and form to any desired shape?”

Goldman: What was it like learning that you could basically do whatever you want to do? Was it harder, easier, or just liberating?

Gamota: I would say all three. Motorola was seeking to identify what was the next great innovation to differentiate our wireless products portfolio. And the first thing when you think about flex and conformal is larger displays to enhance the mobile devices experience. The market seemed committed to helping realize a new technology that would allow people to have large 19-inch diagonal screens on their mobile devices that they could open up, roll up and put in their pocket.

Motorola fostered an environment that allowed people to fail while innovating, but fail fast and make changes quickly. They promoted an environment that had individuals trying to do things that had never been done before, so there probably wasn’t as much anxiety as you might see elsewhere in a VC-backed start-up. Also, at this point, I was involved in an entrepreneurial activity within Motorola where there was a sense of urgency to commercialize a product; the team worked 24/7 driven by enthusiasm rather than threat of venture closure. We were competing against the likes of Plastic Logic, Organic ID, and Poly IC—the darlings of the venture capital world in terms of startups. However, we didn’t have that do-or-die ultimatum hanging over our heads since Motorola was supporting us.

We had access to large teams of engineers across the Motorola enterprise (semiconductor, cell phone, pagers, 2-way radios, automotive, etc.). Also, we were able to partner with other large companies like Xerox (XRCC and PARC), DuPont, and Dow, to establish the best team. Further, because Motorola was a large vertically integrated electronics company, we were able to seek support from individuals that had experienced the early days of semiconductors and mobile electronics products.

For instance, when we were trying to design circuitry using printing methods and inks, we went to Barry Herold, a 30-year veteran at Motorola who was known for his early IC innovations. Barry is credited with many innovations that contributed to the success of ICs as far back as the two-inch wafer. We had these wonderful mentors who kind of had a second coming; they were rejuvenated.

The search for the new FR-4 started my second stage of manufacturing innovation. From 2001–2010, we experienced a significant drive to integrate electronics into products that historically had no electronic content, which opened up people’s imagination to where electronics ultimately would be placed. That vision has driven the design of wearables and other types of on-body systems that we’re starting to see today including those products providing physiological monitoring of athletes and individuals who want to understand how their body performs. Also, other types of new systems requiring non-FR-4 substrates are being driven by the healthcare and medical fields offering point-of-care diagnostics functionality. You’re going to continue seeing the introduction of new materials (soft, stretchable, flexible, conformal, etc.) that historically had no presence in the electronics industry.
Our team was called the “Dream Team.” We combined a veteran group of experienced talent with a rookie group of individuals who did not know the technology barriers of the past. The team believed that we were going to launch a multi-billion-dollar business based on novel products realized by a portfolio of innovations—designs materials, processes, manufacturing equipment.

**Goldman:** When you were designing some of those early flexible or rigid-flex boards, there must have been a lot of failures and having to do it over again until you caught on to it such as the direction of the copper grain at flex points and things like that. Am I right?

**Gamota:** You’re right. It was the days of MacGyver because people were fabricating a bottom-gate transistor using any materials you had available. We had people using a Juicy Fruit gum wrapper, paperclip, and semiconductor ink to make a transistor. They looked at everything in an open transistor and IC design world where you simply required a conductive material for the gate, dielectric material for the gate insulator, another conductive material for the source and drain, and a material that had semiconductor-like properties.

When we would visit printing services companies—because ultimately, we were going to use printing equipment such as a screen printer, gravure, or flexography—we would go to their shelf of inks that they were using for graphic arts printing, and we would look at the ink chemical compositions. We learned that in graphic arts printing (e.g., a magazine) several of the inks used have electrical properties. Some inks are great conductors while others are great insulators. Except for not having a semiconductor ink, the printers had all the necessary materials to print transistors as well as the process know-how to align and print very fine features necessary for electronics. They knew how to ensure that transistor structure layers were pinhole-free and how to achieve sub-50 micron registration from printed layer to printed layer.

It seemed like everything was going to align perfectly, and the only thing that was a potential concern for us was the semiconductor material. The advancements in semiconductor material electrical mobility were a little bit tempered and the materials weren’t as high performing once you took them out of a well-controlled environment—a chemistry lab. Once you moved the material into a manufacturing or NPI environment, you lost a couple orders of magnitude in mobility performance. You still have these issues today when transitioning technologies from lab to fab. Also, we lack the ability to consistently print 1,000 transistors and ensure that all 1,000 provide the same electrical performance.

That’s where the deficiency of printed transistors lies—robust high mobility semiconductor inks. Printed transistors would have a very difficult time replacing silicon based transistors. Once we realized that printing 1,000 transistors that all worked within a certain operation window would be very difficult and we observed the cost coming down quickly for silicon-based ICs, an all-printed transistor-based circuit was no longer an option. This was the start of flexible hybrid electronics (FHE).

Today you see flexible hybrid electronics (printed electronic devices combined with silicon-based devices assembled on a flexible substrate)—enabling the design and manufacture
of products having unique form factors. The form factor is enabled because the substrate is no longer rigid but can be flexible, stretchable, and conformal. The use of FHE building blocks also enables flexibility in the design layout itself—you can still have one component or a few components that are silicon-based that provide the necessary functionality (e.g., computation speed or TX/RX performance for communications) while integrating printed elements to build your product.

Another critical set of design rules which were established for FHE was related to the copper traces on the substrate. These stringent design rules did not allow us to realize some of the products that we wanted in the past. Today, there are new materials (e.g., inks) that are being developed that may expand the product opportunities. These materials can conform to rough surfaces and planarize them to achieve the necessary flatness. For a long time, we were limited in the number of different products that we could develop because we were constrained by the lack of a smooth base conductive trace surface.

For a long time, we were limited in the number of different products that we could develop because we were constrained by the lack of a smooth base conductive trace surface.

**Gamota:** All of that is doable. The packaging materials that are used, whether it’s the materials for candy wrappers or materials that are used for cereal boxes have surfaces that are pristine and perfect for electronics integration. But to me, for the most part, those are not the ones that are going to take us to the next realm. What I see moving us forward are stretchables.

When you talk about silicone materials which can deform in millions of directions, that’s where the excitement lies. Many of these stretchable substrates are being investigated for digital tattoos that we put on our arms for perhaps monitoring our body’s core temperature. That’s great, but just wait until you can build a suite of sensors that you can place inside a person’s body to monitor their heart rate or the stresses on their organs or artery walls.

That’s the electronics journey that we are experiencing. There are some hurdles associated with it, but people are establishing guidelines to identify the substrates and their critical properties such as biocompatibility and stretchability. Now, we just need to appreciate the other criteria that are necessary to insert these products into our body to achieve the desired functionality and long-term performance.

**Shaughnessy:** We always thought that copper was going to hit the wall before now, and we keep seeming to be able to make FR-4 do more and more. Do you think it will get to the point where we finally run out of a use for FR-4, or we have to start using some of these boutique materials or others?

**Gamota:** I have history on my side, right? If I go back to my experience developing flip chip technologies at Motorola, everybody was predicting that flip chip was the future because wire bonding technology was reaching its limit. I wouldn’t say it happened overnight, but in two years, I went from thinking wire bonding was dead to the introduction of ball-grid arrays (BGAs), micro BGAs, and chip-scale packages. What I learned is that you never can say a technology is going to go away with a high level of

**Andy Shaughnessy:** What are some of the more interesting substrates and surfaces that you’re working with or that you see coming online in the future? Futuristic types always talk about putting printed electronics on every cereal box, which would light up when you walked by on the grocery aisle.
Your Passport to Global PCB Sourcing

We are pleased to announce that with the same fine service, quality, delivery and attention to detail that our customers have grown to rely upon, we are now adding a complete global solution to meet all of your needs, both today and in the future.

Our Solutions:

- FLEX & RIGID-FLEX
- HDI / MICROVIA
- COMPETITIVE VOLUME PRICING
- PRE-QUALIFIED OFFSHORE PARTNERS
- QUICK-TURN PROTOTYPES
- COMPLEX MULTILAYER
- MIL-SPEC PRODUCTION
- SPECIALTY MATERIALS

MORE INFO
Global PCB Sourcing
PDF DOWNLOAD

FREE BOOK DOWNLOAD
www.007eBooks.com
confidence unless you amass a large volume of data to support the prediction. Although well-respected technology thought leaders were making these predictions, the data they were using did not include input from all the industry stakeholders.

Also, I observed firsthand the commitment and drive of engineers. Engineers like challenges. If you tell an engineer that their future is quickly disappearing and that they need to find something else, they will innovate and extend the applicability of the technology. I feel that the introduction of new substrate materials with unique properties is fueling innovation and expanding the electronic product landscape. At this time, we are not replacing FR-4; it still has a significant amount of life.

**Goldman:** I’ve seen that in basic circuit boards where it was said that we’d never see another single-sided board.

**Gamota:** I agree. Never say never. If you look at the wearables industry, most products today are single-sided. Single-sided is mandated because the biggest pain point for designers is the connector and its durability when the substrate to which it is attached is deformed. No one has developed a connector that can withstand the strain experienced by wearable electronics, limiting designs to a single-side topology. It is suggested that double-sided topologies will not be realized until connectors are developed that use self-healing materials that relax to their initial state after being subjected to multi-axis deformation. Although single-sided is the standard today double-sided should be available in the future if history is repeated. There hasn’t been enough focused innovation around the connector. Today, engineers are trying to leverage well-established connectors like buttons (e.g., conductive materials) and other types of known connectors. Many in the industry are predicting the introduction of novel connectors to address the gaps based on public reports of R&D efforts.

**Shaughnessy:** Flex manufacturers have told me that the only problems designers usually have is with the simple stuff. They get all the SI right, but then they put the connectors in the wrong spot on the bend of the flex or too close to the edge. Some say that the assembly for flex or rigid-flex is the worst part.

**Gamota:** Exactly, and that is the area where I think leveraging the digital twin tools that we’re starting to see will help designers overcome these common problems. As the digital twin tools ingest larger product data sets, the designers will have the ability to simulate the product design, product manufacturing process, and product in-field performance in the virtual world. In the future designers will be able to identify potential failures using a digital twin provided they have access to the data. The development of an accurate digital twin could have a significant impact—the number of physical products built for the design, engineering, and product validation testing could be drastically reduced (reducing indirect and direct labor time and cost). There would be no need for the building of tens, hundreds, and even thousands of physical products to test under different environmental and mechanical conditions. Once we can collect accurate representative data sets and feed it back into the digital twin tools we will be able to optimize the design, process, and performance of the product. With the adoption
and enhancement of digital twin tools you’re going to start seeing improvements in those simple things such as product failures due to connector location.

Shaughnessy: Have you done a lot of work with ceramic substrates?

Gamota: Yes, but that work has been mostly for photonics modules. It’s interesting that you ask because we’re updating the iNEMI Roadmap chapter on flexible hybrid electronics, and there was a comment regarding the inclusion of ceramic substrates in the chapter. We originally included ceramics in the roadmap because if you go back in time, ceramics were the preferred substrate for the first generation of printed electronics. Ceramic and metal inks were screen printed on a ceramic substrate and subsequently fired. Ultimately, a decision was made to remove the established ceramic substrates from the next edition of the roadmap chapter and instead focus on novel flexible glass substrates and glass/polymer composite substrates.

I’m intrigued by the potential of these materials to withstand high dynamic loading in aggressive temperature, humidity and liquid environments. These substrates will provide designers with new product opportunities.

Shaughnessy: I remember right after 9/11, we started seeing a lot more of these round designs on ceramic, and they couldn’t tell us what it was for because it was for a Tomahawk missile that had to withstand Mach 2. Do you know of any other material that is that durable?

Gamota: I have to admit that the answer is no. I sometimes am concerned that we may not be as open to trying new things as we once were. Today we are limited by how much time we are given to succeed due to the shorter product commercialization cycles, and therefore, we haven’t tried to exercise the limits that have been placed on some of the materials we use. I’m not sure who’s actually responsible for leading the development of those high performance materials outside of the traditional defense and aerospace suppliers. I believe that IMRE in Singapore at one time included the development of these materials in its R&D project roadmap. In the United States, perhaps the national manufacturing innovation institutes such as NextFlex may be investigating potential material compositions to provide the necessary durability.

A possible catalyst to accelerate the development of these substrates is the desire for space exploration. I don’t know how long it’s going to take, but we’ve already started hearing about the supply chain to Mars and what that supply chain will require. People are debating questions such as “Are you going to build products here on Earth and ship them up to Mars? Or will you ship the BOM to Mars and build the product there?”

Are you going to build products here on Earth and ship them up to Mars? Or will you ship the BOM to Mars and build the product there?

That’s going to be a game changer. I don’t know when that’s going to happen, but if we continue to have visionaries such as Elon Musk and Jeff Bezos, we are going to see more challenges placed on the materials that we use for electronics. Perhaps most of the R&D activity will be performed by companies such as Boeing, Rockwell, and the other large companies that provide electronic systems to go into space. However, limited information has been discussed regarding the advancement of these high performance materials.

Goldman: That’s a relatively small market.

Gamota: Agree. Today it is a very small market, but everybody says, “Don’t look at the acorn today; look at the oak tree tomorrow. The oak
“tree is civilization in space.” I don’t know what the timing will be, but the opportunity is massive.

**Shaughnessy:** Dan, is there anything else you want to mention?

**Gamota:** I truly believe we are in a situation where we will see significant growth in electronics manufacturing innovation. Presently, it’s being slightly tempered because of the shortened timelines that we are given for transitioning ideas to product realization. We may see an increase in the diversity of available substrates and the functionality that those materials give us to realize some of the products, but it’s all going to have to wait until we can accelerate the industrialization process and leverage digital building blocks such as digital twin tools.

Things are good, but they could be better, and they’re only going to get better if we have the appropriate digital tools with accurate data sets for us to build models and simulations in a virtual environment before investing in the prototyping and manufacturing of physical products.

I have a question for you both. Do you feel that electronics manufacturing has deviated from encouraging only revolutionary technologies to accepting evolutionary technologies?

**Gamota:** You said the magic word—SMT! Two months ago, I met with an executive at an SMT equipment supplier, and we had a similar conversation about SMT. For 20+ years in SMT, components and devices for pick & place assembly have gotten bigger and smaller, but the fundamental process has not changed. Is SMT ready for a disruption? The executive stated that it appears that no one is thinking about it. He remembers a time when vertically integrated companies like Motorola and IBM had the bandwidth and assets to drive manufacturing innovation in search of what’s next. They had teams of engineers seeking novel assembly processes. He felt that once those companies stopped having dedicated advanced manufacturing technology groups that designed and built equipment to support internal manufacturing of products, manufacturing innovation kind of stopped.

Perhaps it is time to revisit existing manufacturing technologies such as SMT. How would you go about bringing together the appropriate people to start the dialogue? It doesn’t have to be a major disruption in SMT manufacturing. However, at some point, you should see a jog in the SMT road.

That is the kind of dialogue we should have at IPC APEX EXPO and Happy Holden is the type of person with the experience to lead the conversation. He is known as an expert on manufacturing innovation. Happy is credited with introducing several broad industry adopted revolutionary manufacturing technologies. He could facilitate the discussion for why we continue to use established manufacturing processes with little interest in change.

**Shaughnessy:** Dan, I really appreciate you taking the time to talk to us today.

**Goldman:** This is thought-provoking information. Maybe we can continue this conversation at IPC APEX EXPO 2019.

**Gamota:** That would be great. Thank you. FLEX007
Ventec Expands ThinFlex Inventory in Europe

Ventec International Group Co., Ltd. is expanding its ThinFlex inventory to multiple European locations with full cutting capability in both Germany and the UK.

All Flex Expands Rigid-Flex Capabilities with Pluritec X-ray Drill/Rout Optimizer

All Flex purchases new Pluritec Inspecta HPL X-Ray Drill/Rout Optimizer & two EVO-2S Automated drill/rout systems to expand rigid-flex capabilities.

IPC Executive Forum on Advancing Automotive Electronics

The forum features such worldwide notables as Dr. Udo Welzel, team leader of automotive electronics, engineering assembly and interconnect technology at Robert Bosch GmbH, who will present “Enabling Connected, Electric and Automated Mobility: Challenges for Assembly and Interconnect Technology.”

Nano Dimension Partners with Productivity Inc.; Expands Reseller Network

Nano Dimension announced a new reseller agreement with Productivity Inc., significantly expanding the company’s North American channel partner ecosystem.

Flexible Electronics Market to Witness Enhanced Application

The global flexible electronics Market is estimated to touch $87.21 billion by the completion of the prediction period. It is estimated to develop at a substantial CAGR for the duration of the prediction.

FLEX 2019 and MSTC to Highlight MedTech, Transpo and IoT

Flexible and printed electronics innovations and autonomous mobility sensors will take center stage as more than 700 attendees gather for 120 market and technical presentations, 70 exhibits and four short courses at the co-located FLEX 2019 and MEMS & Sensors Technical Congress (MSTC) in Monterey, California, February 18-21, 2019.

Amphenol Invotec Reaffirms Status as an ESA-Approved Supplier

Amphenol Invotec, a leading European manufacturer of advanced PCBs, is pleased to announce that it has successfully extended its European Space Agency (ESA) qualification for the supply of sequential rigid polyimide boards to November 2020.

IDTechEx Highlights World Firsts in Printed Electronics in 2018

With the end of the year in sight, it’s interesting to look back and review what has been new in the world of printed electronics in the last 12 months. This analysis is taken from the new IDTechEx Research report, “Flexible, Printed and Organic Electronics 2019-2029” covering the entire sector in great detail, based on analyzing the industry for over 15 years.

Challenges in Flex Circuit Assembly

In a recent I-Connect007 survey on flex circuits, we asked the following question: What are some of the challenges that you face utilizing flex circuits? Here are just a few of the replies, edited slightly for clarity.
More than 20,000 results populate on an Amazon search for wearable technology. There is no question that wearable electronic devices have created a new electronics market, especially those earmarked for medical and healthcare. Wearable devices demand 3D flexible wiring, so flexible circuits are an appropriate solution for these devices. Wearable electronics require different performances from their circuit makeup compared with traditional flexible circuits. Previously, we advised customers to design flexible circuits according to the standard design guide to optimize performance and manufacturing yields. Wearable electronics changed our way of thinking relative to these new performance prerequisites.

3D wiring is one of the major features of typical flexible circuits because of the flexibility from the base materials. However, you are limited to the number of material choices for traditional flexible circuits. Designers create circuits with only a small selection of materials available. Polyimide film is one of the limited choices for high-temperature processes such as soldering and wire bonding. It has a good balance as the dielectric material for traditional flexible circuits; however, it is not comfortable to wear polyimide films when used in clothing. Comfort is everything in wearable technology, but the low moisture permeability from plastic films does not provide this comfort when the films are attached directly to the skin. Film color is also a deterrent where artistic value is compromised from the eyes of the consumer. The base materials require higher dimensional stabilities to increase process yields in high-density circuits, but healthcare devices need elasticity when attached to the body. Thus, a conflict exists with base materials.

Exotic materials have been developed to satisfy these new requirements for traditional flexible circuit technologies. The materials are not necessarily new products but rather modified to generate some unique performances. A few examples are listed here.
When it comes to flex and rigid-flex, we wrote the book!

From simple flex, including long flex boards, to complex rigid-flex, we have the experience and expertise to solve even the most demanding projects.

Our flex experts are so passionate about flex, they wrote a book to help you better understand the basics of this emerging technology.

Call us today for a consultation about your specific flex and rigid-flex needs.

Download our flex eBook
Transparent polyimide films were developed by several chemical companies over the last few years. Some have equivalent physical properties as traditional polyimide films, but they can still absorb small amounts of light. Copper-clad laminates of films without a glue layer are available through electroless plating or sputtering. Typical flexible-circuit manufacturers can generate transparent circuits using a standard photolithography and chemical etching process. The new flexible circuit looks similar to a PET-based circuit due to its transparency, but it has enough heat resistance when soldering and wire bonding (Figure 1). This could serve as the flexible substrate for optical modules, but more trials are needed to achieve transparent conductors. Material choices have included ITO film, silver nanowire, and micro-metal mesh; unfortunately, none provide a perfect solution. Customers have to choose one from limited candidates.

Another example of modifying existing materials involves elastic circuits with rubber-based substrates. Meandering lines are created on a thin urethane sheet through a photolithography and chemical etching process or screen printing of conductive ink (Figure 2). They require a copper-clad laminate with rubber-sheet via thermal lamination or electroless plating. Copper foil provides high conductivity, but elastic glue should be used as the bonding layer during the thermal lamination process. Electroless plating does not require a glue layer for reliable bond strength (this is an advantage), but it requires a special surface treatment before the electroless plating to secure a dependable bonding strength with conductors.

Silver paste screen-printed on an elastic substrate is the best solution as long as the applications do not call for large current. Since the matrix material of the thick-film conductors is a soft plastic (such as epoxy and urethane), the printed conductors have a higher flexing endurance compared to metallic copper foil conductors. The new elastic circuits could be considered a valuable alternative for medical and healthcare modules attached to the skin. The demands for materials on wearable elec-
tronics include a soft cotton-like feel, the ability to absorb moisture, biological decomposition such as starch films, etc.

The last example involves active electronic circuits as opposed to passive electronic circuits. With the introduction of new exotic materials, the traditional manufacturing line is capable of producing active devices. Figure 3 shows an example of a flexible EL display produced through a screen-printing process. Most of the equipment is very popular in the manufacturing of flexible circuits. Electronic luminescence (EL) material and transparent conductors are the exotic materials used in this construction. The more active devices that are dreamed up, the more the need for new exotic materials. Some of these materials include photovoltaic cells, primary and secondary batteries, flexible displays, sensors, actuators, and more. Every new and exotic material brings us closer to flexible electronics. We believe that flexible electronics and printable electronics working in tandem will generate new values for wearable electronics.

**Dominique K. Numakura** is the managing director of DKN Research LLC. To read past columns or contact Numakura, click here.

---

**A Safe, Wearable Soft Sensor**

Children born prematurely often develop neuromotor and cognitive developmental disabilities. The best way to reduce the impacts of those disabilities is to catch them early through a series of cognitive and motor tests. But accurately measuring and recording the motor functions of small children is tricky. Toddlers tend to dislike wearing bulky devices on their hands and have a predilection for ingesting things they shouldn’t.

Harvard University researchers have developed a soft, non-toxic wearable sensor that unobtrusively attaches to the hand and measures the force of a grasp and the motion of the hand and fingers.

One novel element of the sensor is a non-toxic, highly conductive liquid solution. “We have developed a new type of conductive liquid that is no more dangerous than a small drop of salt water,” said Siyi Xu, a graduate student at SEAS and first author of the paper.

“It is four times more conductive than previous biocompatible solutions, leading to cleaner, less noisy data.”

(Source: Harvard John A. Paulson School of Engineering and Applied Sciences)
Feature Interview by Barry Matties
I-CONNECT007

Brendan Hogan, managing director of smart electronics manufacturer MivaTek Global, discusses how to better design for flex, and ways designers can stay current on manufacturing technology that can impact their flex boards.

Barry Matties: First, can you tell us a little bit about MivaTek and what you do?

Brendan Hogan: Miva Technologies has developed a new method of using DLP and LED. About six or seven years ago, we replaced the laser technology with a DLP-LED technology with a lower cost of operation and all the obvious drivers to do that. We’ve evolved very quickly over the last four to five years to get better market penetration in the U.S., Europe, and parts of Asia now. We’re starting to expand more rapidly. One of the benefits of our technology is that it maps into many different platforms, and is pretty simple to map in a new platform. So, that gives us a lot of specialty application opportunities.

Matties: How do your products fit into the flex area?

Hogan: A lot of the flex applications we currently do largely deal with A/B registration—the precision with which you can have the two sides run a check to each other for signal-to-noise ratio or certain performance criteria, and how that end circuit performs in applications. That’s a more conventional application. In the last 12–16 months, we’ve been developing systems for reel-to-reel that have implications for flex and things like LED shadow mask and other reel-to-reel type applications. We see a lot of activity in Korea and China related to reel-to-reel, so that’s one of the main directions we’re headed.

Matties: If an OEM and their system designers are looking at integrating flex into their products, what considerations should they have in terms of imaging and technology that might help them improve either their overall quality or strategy?

Hogan: A significant element of direct imaging in general—whether you’re talking about
MivaTek or anybody else—has to do with removing the A/B registration from an operator standpoint, and moving it into a digital camera-driven technology. You have better repeatability and control over your line width so that you can have a more predictive circuit at the end of the day. The other aspect with some of our systems is that you can go to larger and have longer cabling to reduce the connectivity from one circuit to the next. Thus, you don’t need connectors and can have much longer ribbon cables if you have a more extensive format system.

**Matties:** How does his designer learn about this or integrate this into their thinking?

**Hogan:** That’s a job for us in the marketing department to make sure we get out there and start writing more technical articles. The latest development of reel-to-reel technology is only starting to hit the market. We should be doing a better job, I suppose, of direct access through fine magazines like your own.

**Matties:** Thank you for that. What are the major points that they should consider when you say, “We need to tell the story more for them to understand us?” What is critical for them to know?

**Hogan:** Perhaps doing broader research than only talking to the circuit producer would help, so looking at some other standards and trying to understand what technologies are out there. The hard part about things like equipment technology is that as they emerge, a select few know about it. It’s very difficult to access the entire market simultaneously, so it’s kind of the job of the designer to be aware of what’s coming so that they can get into the design pattern. There’s a significant lag in the design loop—the lag time between design and production for the producer. By the time it hits the market for them, the product may be already outdated in terms of manufacturing technology and the best approach.

**Matties:** If somebody is looking at bringing flex into their product mix for the first time, do you have any advice for that?

**Hogan:** Well, that’s an interesting discussion because the transition from rigid panels to flex is an art form—it’s another animal. Participation in some of the industry groups is a valuable asset. Tap into the existing knowledge that’s out there, like IPC APEX EXPO in the U.S. or HKPCA in China, which both have a variety of training sessions on trade information. Establish best practice for that transition. There are a lot of new technologies and manufacturing methods coming. We participate in an organization called the CHIPS consortium, which is a group that formed to find new manufacturing methods. It’s out of the University of California, Los Angeles (UCLA) in the U.S. We’re also part of a group with Apple and Google trying to find lower-cost methods for manufacturing these high-tech products. Participation in those groups seems like a cost factor because it’s not the high priorities that we’re all driven by, but it adds a lot of benefits for long-term planning.

**Matties:** I would think that when most designers look at information sources, they don’t look at a direct imaging supplier to a PCB fabricator. What lessons can they learn by talking to somebody like yourself?

**Hogan:** It’s a duality where we need to get better educated about the problems of the end user—not bypass our customers, but partner with our customers to better understand their problems at the customer level. Then, their
end user also has to get some access to us. I think trade shows are one route—that’s often where we get to talk to the end users by participating in panel discussions and so forth. We’re in that pattern trying to manage growth, and unfortunately, one of the things that gets lost in the shuffle is the outreach. We could probably do a better job at that ourselves.

Matties: Is there any other advice that you feel we should share with a systems designer or a flex designer?

Hogan: I would recommend more collaboration at the multi-tier of the manufacturer—not only at that level. The smaller the producer, the more challenging it is to gain access to manufacturing methodologies—our approach versus the many other ideas in the marketplace beyond what we have. So, it has to be very challenging from that aspect. Working with their customers to work with their supply chain to be sure their supply chain is reaching out is probably a good early step.

Matties: Brendan, I certainly appreciate your insights, and we’ll be sure to share those with designers. Thank you very much.

Hogan: Thank you. I appreciate your time.
Editor’s Note: This is the fourth in a series of excerpts from the eBook. The first three issues of Flex007 Magazine carried Part 1, Part 2 and Part 3.

It All Starts With the Data Package

The fundamental purpose of this series is to provide in an abbreviated form a discussion of key matters related to the design and manufacturing of flexible circuits to help designers avoid delays during manufacturing. Here is a summary of the critical bits of information designers should understand to ensure a desired outcome on the first pass. The points of discussion here are general and not exhaustive. As has been said in earlier sections, the diversity of design makes every product unique. With that caveat, the following is a list of items generally deemed important when designing flex and rigid-flex circuits.

Product Class Definitions

Having an upfront statement of the intended use of the flex circuit will help to frame the expectations in terms of reliability and cost. Defining the class of the product lets the manufacturer know which added controls to apply to the manufacturing process and the level of care required in the inspection process to ensure that the customer gets the right product.

Specified Materials for Circuit Construction

While there are only a limited number of flexible circuit materials in wide use, there are many potential candidates; therefore, a need to constrain the options to meet expectations. When specifying materials, the designer should inform the manufacturer of the type of base polymer to be used, and the type of adhesive desired if an adhesiveless laminate is not to be used.
In a multilayer construction, it is highly recommended to use only adhesiveless flex laminates. The designer also needs to define the type and nature of the copper weight to be used. Normally the copper for flex is a foil that is rolled and annealed; however, some of the thinner copper weights (sub-1/2 ounce) are typically only available in electrodeposited copper and not recommended in a dynamic design. It is also important to specify the nature and type of coverlayer material and stiffeners to be used. In short, specify any material that is to be used in the construction and stay with the final part must be identified.

Hole Pattern with Sizes and Plating Requirements

Holes are not always required for flex circuits, but they are usually required for vias or for making connections to leaded components or connectors. Thus, documentation must specify the size, number, and location of any holes required for the circuit design (Figure 1). This data is easily extracted from digital design files and will be critical to the vendor to determine the cost of the manufactured circuit.

<table>
<thead>
<tr>
<th>DRILL CHART</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL UNITS ARE IN MILLIMETERS</td>
</tr>
<tr>
<td>FIGURE</td>
</tr>
<tr>
<td>+</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>☯</td>
</tr>
<tr>
<td>◆</td>
</tr>
</tbody>
</table>

Figure 1: Example hole size table.

Conductor Layer Count

The majority of flexible designs have only a single metal layer, but a substantial number of flex circuits feature two metal layers. Multi-layer and rigid-flex circuits are less common, and there is a need to provide layer counts for the circuit design. Layer count is perhaps the most obvious indicator of overall circuit complexity and is important for quoting and production planning purposes.

Circuit Design Artwork

Proofing circuit artwork and checking the design against various design rule requirements and objectives (e.g., design for manufacture, design for reliability, etc.) are important and necessary conditions for release to manufacturing. Ideally, the information is supplied in a digital form in one of the major CAD formats. The best format is ODB++. The CAD information provides a definition of what the circuit will look like, where terminations will be located, and how they will be shaped. It is also important in case the design needs to be modified or adjusted by the flex manufacturer to compensate for processing. The final design contains information needed to provide an accurate and realistic quote.

Cross-sectional View of Circuit Construction

A cross-sectional or side view of the finished circuit provides the manufacturer with a scaled view of construction materials. The cross-section also lets the quality control department know what to inspect in terms of circuit layout since it offers a means of predicting overall thickness (Figure 2).

Coverlayer or Covercoat Opening Locations

Coverlayer and covercoat openings physically define the features that need to be accessed to attach components, interconnect, or testing probes (Figure 3). It is key that the documentation package defines all such locations accurately. It is different than designing a solder mask layer since mechanical tolerances, coverlayer adhesive squeeze-out and location tolerances have to be considered. It is important to note that any surface mount or openings with 90° corners usually means the coverlayer must be laser cut and cannot be done on conventional CNC equipment. This would be a cost added to the design; however, it cannot be avoided in many cases.
Circuit Outline with Dimensions and Datum Features

The physical outline of the finished circuit needs to be accurately documented to define the periphery of the flex circuit material relative to the circuitry itself. The outline data is used to:

- Directly singulate the circuits from a panel by soft tooling via numerically-controlled routing machines, cutting blades, lasers, or water jet cutters
- Create hard tooling including steel-rule die-punch tools and/or Class A tool-and-die punch set technology

The datum features are important reference points to facilitate measurement of the circuit features, especially the outline. It is best if datum features are called out based on the part’s internal physical features rather than its external features. This allows inspectors to base their measurements on real features rather than imaginary points outside the part. Multiple datum features are recommended if space allows.

Multiple datum features are also important because flexible materials are dimensionally less stable than rigid materials used for circuits. Features on flexible circuits, especially those of larger size, often move relative to each other, and the circuit may shrink or grow during processing making predicting the precise
location of features increasingly difficult over long distances. On a localized basis, and/or with smaller flexible circuits, the effects are not so great, and the part can more easily meet requirements. This approach does not sacrifice any tolerances. It is simply a means of recognizing and accounting for flex circuit manufacturing dimensional variances. Figure 4 illustrates the benefits of multiple datums.

**Marking Requirements**

The increased use of automation in manufacturing minimizes the need for marking in many applications. However, some designs can still benefit from marking despite the added cost. When marking is used, the documentation package must accurately define where to locate markings on the circuit. The choice of ink type and color must also be defined.

**Bend, Flex, and Crease Locations**

Flexible circuits are typically bent or flexed in some manner. Knowing where the bending is to occur is important, especially when the flex circuit is to be used in dynamic applications. In dynamic flex applications, the grain direction of the copper foil should be accounted for in manufacturing. It has been shown that there is a difference in the dynamic flex life of circuits fabricated with the bend going with the machine direction and those where bends are made transverse to the machine direction.

Accurate bend or flex information also informs the engineer or technician where and in which direction to bend the circuit, resulting in easier installation. It is also beneficial to define the location of permanent bends and/or creases that may be needed, which can be accomplished in a couple of ways. If a marking step is required, special indicating features in the marking circuit artwork can be printed onto the coverlayer or while marking is applied.

This facilitates assembly by providing information as to which direction a bend must take. For example, dotted lines can be used to indicate bends in one direction, and solid lines can indicate bends in the opposite direction. Similar features can also be made in the metal as part of the circuit. Because there are no common standards for this task, the fabricator’s manufacturing engineers should be able to provide some guidance based on their experiences.

**Stiffener Locations and Bonding Requirements**

Stiffeners are commonly used to support components mounted onto flexible circuits. When a design requires stiffeners, the documentation package must include size, construction, location, and the preferred material to be used to bond them to the flexible base material of the circuit. If any special strain relief techniques are required, such as an epoxy bead along flex-to-rigid transition, this should also be noted. The cross-sectional view should also show any strain relief as discussed earlier.

![Figure 4: Flex circuit with multiple datums.](image-url)
Figure 5 shows a diagram of a flex circuit with stiffeners. Stiffeners are used for assistance with connector insertion or component placement rigidity. The stiffener and coverlayer termination points should overlap to avoid a stress point, helping to reduce the chance of traces breaking and cracking.

**Tolerances for Manufacturing**

Manufacturing tolerances should be provided in the documentation data package. Traditionally, the manufacturing tolerances are covered in design documentation which provides a complete description of the finished product. Most documentation formats provide a tolerance block near the title block for the drawing. The tolerances called out in the tolerance block should accurately reflect the application of the finished flex product. Flex and rigid-flex designs are subject to meet criteria listed in IPC-6013, which is specific to flex circuits.

**Special Electrical Testing Requirements**

The electronics industry is continuously moving to ever higher operating speeds, and special tests are needed to ensure performance. Electrical testing requirements such as characteristic impedance validation, high-voltage potential withstanding, or other non-standard tests should be identified and defined in the documentation. Conditions of testing and test point locations should also be clearly identified.

**Special Processing Requirements**

Special and/or non-standard processing requirements are occasionally required for flexible circuit designs and should be clearly outlined in the documentation.

**List of Applicable Standards and Specifications for Reference**

Standards and specifications are a unique type of glue that provide a consistency that holds the industry together. All relevant specifications that will be used to test, evaluate and accept or reject the product should be cited in the documentation package. For flex products, the acceptability criteria are listed in IPC-6013.

**Bill of Materials for the Circuit**

A bill of materials (BOM) relative to the final assembly should be included in the documentation package. The BOM may not be necessary for production, except in the case of a turnkey manufacturer. Although the various hole and surface-mount device (SMD) patterns will give clues to the component types used, they are...
not fully informative, and some components or component types may require special attention.

This list of documented items is comprehensive, but not exhaustive. Since each design is unique, it is inevitable that there will be some information that varies depending on the product. Designers and product engineers will often place special requirements on individual flex circuit designs. The key takeaway here is that the documentation package should be as complete as possible to ensure, to the highest degree possible, that the product will be right the first time. Once again repeated here for emphasis, the documentation package provided to the fabricator is the primary means of communication, and its clarity and completeness will prevent confusion, loss of irrecoverable time, and unnecessary expense.

Conclusion

Flex and rigid-flex circuits have proven their utility and value in countless products since their introduction. It is likely that they will continue to be chosen and used to help facilitate and improve the ever-expanding range of electronic products in use around the globe today. However, as has been shown, there are many issues related to their design and manufacture that require proper consideration and expertise to fully address. We recommend that those about to embark on a flex circuit project seek expert consultation to ensure first-pass success. FLEX007

Visit I-007eBooks to download your copy of American Standard Circuits’ micro eBooks today:

- The Printed Circuit Designer’s Guide to Flex and Rigid-Flex Fundamentals
- The Printed Circuit Designer’s Guide to Fundamentals of RF/Microwave PCBs

Dave Lackey is vice president of business development at American Standard Circuits.

Anaya Vardya is president and CEO of American Standard Circuits.

Nanophysicists Develop High-performance Organic Phototransistor

Researchers from the Physical Institute and Center for Nanotechnology (CeNTech) at the University of Münster, headed by Prof. Dr. Harald Fuchs, together with colleagues from China, have developed a novel thin-film organic phototransistor (OPT) array based on a small-molecule (2, 6-diphenylanthracene—DPA). It has a strong fluorescence anthracene as the semiconducting core and phenyl groups at 2 and 6 positions of anthracene to balance the mobility and optoelectronic properties. The fabricated small-molecule OPT device shows high photosensitivity, photoresponsivity and detectivity.

“The reported values are all superior to state-of-the-art OPTs and among the best results of all previously reported phototransistors to date. At the same time, our DPA-based OPTs also show high stability in the air,” says Dr. Deyang Li.

Dr. Saeed Amirjalayer adds, “By combining our experimental data with atomistic simulation, we are, in addition, able to explain the high performance of our device, which is important for a rational development of these devices.”

The WWU researchers believe that, therefore, DPA offers great opportunity towards high-performance OPTs for both fundamental research and practical applications such as sensor technology or data transfer.

The research was published in the latest issue of Nature Communications. The work was funded by the German Research Foundation.

(Source: University of Münster)
This article will discuss how manufacturing rigid-flex boards is similar to manufacturing conventional rigid boards and flex circuits, and describe areas where it differs. My previous columns shared why rigid-flex circuit boards cost more than conventional boards, applications where rigid-flex boards provide a superior packaging solution, and what a designer needs to keep in mind when designing rigid-flex boards for manufacturing.

Rigid-flex manufacturers use the same equipment and processes that you find in hardboard and flexible circuit manufacturing, but they are typically adjusted to meet the unique nature of these composite constructions. As a rule, the processes and techniques are much more conservative to increase manufacturing yields.

Combining thin, flexible laminates with soft rolled-annealed copper cladding, coverlayers and bondplies with adhesive bonding resin, glass-reinforced laminates, and no-flow prepregs require a longer and more conservative manufacturing cycle. The materials used have very dissimilar dimensional stability properties and also move dissimilarly with changes in humidity, temperature, and processing. A lot of care and attention is used to get these materials to move in unison and provide you with a stable end product.

We will walk through a typical rigid-flex manufacturing cycle step by step to explore how the processes come together to build a high-reliability packaging medium.

**Front-end Engineering**

Once your design is complete, it is time to put it on the floor. A lot of engineering work goes into the front end to accommodate all of your requirements. Since rigid-flex boards are folded and used in three dimensions, there are usually far more dimensions and other requirements that must be met to make your design successful. A typical rigid-flex designer will spend a couple of days to a week in front-end engineering and quality assurance to work out the details of your design requirements.

One of the most critical steps in creating a rigid-flex product that cannot be emphasized enough is involving the supplier from the beginning during your design phase. This activity helps to ensure the customer that the rigid-flex
INTRODUCING THE CapStone™ ADVANTAGE

Double your flex PCB production throughput and reduce processing costs up to 30%.

Leverage new technology for higher quality and yield.
CapStone combines ESI’s latest-generation laser control capabilities with market-leading robust laser technology to provide breakthrough performance without sacrificing quality or precision.

Capitalize on your investment.
Now you can extend your processing capabilities and cost-effectively address even the most demanding customer requirements.

esi®

learn more about CapStone at esi.com
will perform as desired. Successful rigid-flex designs are always the result of collaboration between the designer, fabricator, and often the assembler as well.

Once the front-end engineering work is complete, it is released to the floor. A simple rigid-flex design will have five or more travelers, and sometimes as many as 30. Each traveler is for a subcomponent that gets built to completion before being combined into the final assembled circuit board.

A straightforward rigid-flex usually will have five travelers:

1. Coverlayer and/or bondply materials
2. Flexible copper-clad laminate layers
3. Glass-reinforced hardboard layers
4. Glass-reinforced no-flow or low-flow prepreg material
5. The traveler for the finished assembly

To see how they come together, and each of the process sequences, refer to Figure 1.

**Coverlayer and/or Bondply**

Coverlayer is used to protect the circuits in the flexible sections of the board. It performs like a solder mask, but is designed to withstand hundreds of thousands of flex cycles without failure or degradation. Coverlayer is comprised of a thin dielectric (usually 0.001” or 0.002”) of polyimide, polyester or other film with a thin layer of adhesive. The adhesives are usually 0.001” or 0.002” but can be thicker depending on the thickness of the copper circuits that will be encapsulated. Adhesives are typically acrylic, epoxy, polyimide, or a blended resin. Bondply is similar to coverlayer, but it has adhesive on two sides and is used to bond the flexible layers together in the flexible sections of the board.

---

**Figure 1: Rigid-flex simplified process flow.**
Ideally, coverlayer and bondply should only extend 0.050–0.100” into the rigid sections of the rigid-flex board using a technique called cut-back coverlayer. The reason for this is that the adhesives used on coverlayer and bondply have a higher Z-axis CTE rate than the other materials used in rigid-flex constructions. This higher Z-axis CTE rate can put undue stress on vias during assembly and other thermal excursions. As a rule, the adhesives also do not drill, desmear, etchback, or plate as well as flexible and glass-reinforced laminates and prepregs. There are exceptions of course, but rigid-flex manufacturers will try to use a cut-back coverlayer technique whenever they can, and especially for high-reliability “never-fail” applications (IPC 2223C, 5.2.2.2).

The coverlayer and bondply pieces need to be cut to size so that they are only in the flexible sections of the board. They are usually cut with steel-rule dies, lasers, or CNC drilling and/or routing machines with the choice based on the size of the pieces and/or the dimensional accuracy required. Once the coverlayer and bondply are fabricated, they are kitted and held until the flexible layers are completed.

**No-flow or Low-flow Prepreg**

The no-flow or low-flow prepreg that is used to bond the final package together is fabricated at the same time as the coverlayer and/or bondply. The material is somewhat similar to standard prepregs with a couple of exceptions. No- and low-flow prepregs are designed to flow very little, so that the resin does not flow out onto the flexible areas of your design. Standard flow prepregs should not be used in rigid-flex designs. The prepregs used in rigid-flex manufacturing are thin and generally limited to just two glass styles: 1080 and 106. They can be sensitive to handling damage because if they get dented or creased, it can deprive a section of the board of enough resin to encapsulate your circuits.

Once the no-flow prepreg is sheeted and kitted, we then fabricate the sheets to match the design of your board. Wherever there are flexible sections in your rigid-flex design, we will cut an opening in the no-flow prepreg accordingly. Designs that are very small or have lots of flex arms will have so many holes cut in them that they can look like doilies and be almost as hard to register! The no-flow prepreg is then staged until the flexible layers are completed.

**Flexible Laminate Layers**

The copper-clad flexible layers that will be the circuits in the flexible layers of the board are fabricated similarly to standard glass-reinforced copper-clad laminates. Two exceptions are that the flex layers are usually pretty thin (0.001–0.003”) and clad with a wrought, or rolled-annealed, copper foil and the surface cannot be cleaned using conventional equipment.

Rolled-annealed copper foil is very, very soft and is easily dented during handling. Care must be taken to not dent the material either with handling or automated equipment processing. A dent can cause issues with imaging your circuits faithfully, or it can pull one of the registration targets out of alignment just enough that it will affect the registration of the flex layers to the rest of the package. Registration targets must be used throughout your entire package to get dissimilar materials to register to one another. Any target that is pulled out of its location ruins the rest of the package.

Flexible laminates are too thin to use conventional scrubbing equipment to clean the surface before applying photoresist, so flex and rigid-flex manufacturers will typically use a chemical clean process line to condition the copper surfaces. Once the flex layers are finished, they go through AOI and tooling for lamination similar to hardboard layers, and end up in lamination for coverlayer and/or bondply application.

**Assembling Coverlayer and/or Bondply**

The pieces of coverlayer and bondply are placed on what will become the flexible sections of the board, and are tacked in place. Placement is done by hand, which can be tedious; depending on your design, this can take hours, days, or even longer to complete a job. Layup of the coverlayer and/or bondply is usually completed in a cleanroom to reduce
the incidence of foreign objects getting under the coverlayer, which would result in scrap (Figure 2).

Laminating the Coverlayer and Bondply

When the flexible layers are complete with the pieces of coverlayer and bondply in place, the flexible panels are placed in a “lamination book” with a release film and steel separators. The materials are then laminated at temperature under pressure and a vacuum to press and adhere the coverlayer and bondply to the flex layers. This creates the cut-back coverlayer feature into your design for high-reliability packaging (IPC 2223, 5.2.2.2).

The lamination cycle is typically more conservative than for hardboards and/or flexible circuits as the temperature and thermal ramps are designed to reduce dimensional movement as much as possible. The layup folks in lamination will typically use materials that conform easily and help to drive the coverlayer and bondply into the circuits to create intimate contact and complete encapsulation.

Fabricate Glass-reinforced Laminate Layers

The hardboard layers run in parallel with the flexible layers and follow much the same processing as you would see in rigid-board manufacturing. Key differences are that, for consistency, we use chemical cleaning here as well. Using a chemical clean line on the flex layers and a scrubber on the glass-reinforced layers would just induce more issues with mis-registration of the dissimilar layers. Another key difference is that, after imaging and etching the circuitry, the windows in the layers are routed out, corresponding to the flexible areas of your board. Similar to the no-flow prepreg, designs that are very small or have a lot of flex arms have a significant amount of the material removed, which can make them difficult to register because they have lost much of the material that comprises their support.

Final Lamination

All of the components—flexible layers, glass-reinforced layers, and prepreg—are kitted and ready for final lamination. This applies to a straightforward rigid-flex process sequence, but other designs that are more complicated will be covered in a future column.

The layers are then layed up in the lamination book again, with the no-flow prepreg, in the order of your layer stackup. At this stage, we are laminating a board that is 0.040”, 0.062”, 0.093”, etc., and now eight, 10, or 20 layers deep. The conformal materials become even more essential for getting the resin to flow enough to encapsulate the circuits in the whole book. Often, there will be so much extra conformal material in each opening that only one panel per press opening can be laminated. Hardboard manufacturers will typically get eight to 12 panels per opening; thus, our capacity can be significantly reduced per press load. Again, the lamination process cycle is very conservative and is meant to get the no-flow prepreg to flow enough to encapsulate the circuits without flowing out onto the flexible areas of the board.

There are three things to know about lamination and no-flow preps. The first is that the prepreg is designed to not flow, which can make encapsulating thicker copper circuitry and planes more challenging. Half-, one-, and two-ounce copper layers are usually fine; however, with the latter, more prepreg may need to be added to encapsulate the two-ounce copper circuitry fully. Three-ounce and greater copper thicknesses can be very difficult to encapsulate.
With original content dedicated specifically to flex system and PCB designers, electrical engineers and those responsible for integrating flex into their products at the OEM/CEM level, you won’t want to miss a single issue of *Flex007 Magazine*!
completely and will show up as low-resistance shorts (due to moisture-containing air) at electrical testing.

Second, if your design has high- and low-pressure areas adjacent to one another, it can be very difficult to get enough pressure on the lower pressure areas to get them to yield. An example would be a board where one side of the design is eight layers of copper with many of them being ground planes, and immediately adjacent to that area is four layers of all signal. It can be difficult to get enough pressure on the area of the board with four signal layers. An example would be pad stacking of non-functional pads on high layer-count boards. The pads form a very high-pressure area, and immediately adjacent to that is a very low-pressure area where air pockets will form.

Third, because we use lamination materials that are designed to conform to the surface of the board, the surface of a rigid-flex board will have far more topography than a typical rigid board. Rigid boards often come out of lamination with a very smooth surface as the outer layers of the board are right up against the lamination separator plate. Rigid-flex boards will more typically have a surface that can vary by ±0.005”, which will affect subsequent processing, particularly filling through-holes for via-in-pad applications.

Outer Layer Drilling

After lamination, your boards go to drilling to add what will become the plated-through-holes. The drilling operation is identical to drilling conventional PCBs but with much more conservative parameters.

The internal layers of a rigid-flex construction have conventional HTE copper foils, glass-reinforced laminate, the polyimide base material of the flex laminate, and rolled-annealed copper foil on the flex. Each material has an optimum feed and speed for the drill, hit counts for the drills, and stack heights for the machine, but they each are also different from one another.

The rolled-annealed copper foil is very soft. If we are too aggressive on any parameter, it will tear rather than drill the copper foil, resulting in nail-heading—a drilling defect. Similarly, any tearing or gouging along the flex-to-rigid interface will result in a plating condition called “folds” where there is a localized area of plating weakness that will fail during thermal excursions or when faced with other stressors.

Laser Drilling of Microvias

Earlier, we mentioned that the surface of your boards will have some topography that can be as great as ±0.005” from peak to valley. The same is true for any blind via pads that you are trying to reach successfully from the outer layers of the board with a laser via. They can vary across the panel in their vertical position from the laser beam. Lasers are similar to cameras in that they have an ideal focal length. If the beam is too close, the via will receive too much energy and mushroom. If the focal length is too far and the via is incomplete or has some remaining resin on the surface of the via pad, that will result in an open circuit. Care is required to find the correct laser recipe to drill all of the vias with the correct energy accurately.

Fabricating Filled Through Vias for Via-in-Pad

Fabricating filled through-vias in rigid boards is a very common technique for providing designers with a via-in-pad solution, providing greater densities in their design, and is especially helpful in high-density areas like BGAs. The surface topography that is typical to rigid-flex constructions, along with the cavities created in the panel by the flexible areas, make fabricating filled through-holes on these boards very difficult and low yielding. We do build them, but every effort should be made to rout your boards in such a way as to not need filled vias for via-in-pad. To understand why, we will review how via filling and planarizing are accomplished on a rigid-flex board.

After plating copper into the via-fill holes, the via-fill materials are epoxy based and are conventionally squeegeed out onto the panel under pressure to force the via-fill material
into the holes. The pressure drives the via-fill material into all the low-lying areas of the panel including the flex cavities. The material then hardens and needs to be removed. In a rigid board where the surface is very smooth, a deburr machine or sander is typically used to sand the excess via-fill material off the surface.

With rigid-flex, if we go too aggressively at sanding the via-fill material off the surface, one can sand through the copper on the elevated parts of the outer layers at the same time. If that copper is removed, the panel must be scrapped. To accommodate this delicate process, much of the work, inspection, and re-work is done by hand. Via-filled boards typically yield 30% less than an equivalent rigid-flex board and take weeks of extra time to get them to yield adequately.

An additional consideration for rigid-flex manufacturers is the copper plating wrap requirement on via-filled boards for high-reliability applications (IPC 6013, 3.6.2.12.1). The wrap requirements specify how much copper must remain on the surface after planarizing the via-fill material off the surface. To accommodate this requirement, fabricators will often plate extra copper onto the pads of the via-filled holes. This extra copper plating adds to the reliability of the via. At the same time, this makes it more difficult to image and plate higher density trace/spacing on outer layers that are typically needed for BGA routing.

### Outer Layer Imaging and Copper Plating

I previously mentioned that the outer layer copper surfaces on a rigid-flex will typically have some topography that needs to be overcome. Also, if you think about a production panel, there are now areas in the panel that are rigid board and areas that are flexible. The rigid areas will usually be significantly thicker than the flexible areas of the board, forming depressions or cavities in the surface of the panel.

These two aspects require rigid-flex manufacturers almost universally to use vacuum lamination to apply their photosresist and direct imaging to image the outer layers of the board. The vacuum lamination pulls the photosresist into intimate contact with the surface of the board, which is critical to achieving good yields in imaging and subsequent plating operations. Direct imaging is critical because if you were to use conventional phototools and printers, the phototools are distorted by the flex cavities during vacuum lamination, and your features will be far off of where you need them to be. This is especially true with small boards that have many flex cavities across the panel, making it virtually impossible to scale the phototool to match the distortion created during vacuum pull-down of the phototool.

### Routing and Scoring Rigid-flex Boards

There are a few different techniques for providing singulated rigid-flex boards and rigid-flex boards supported in arrays for assembly. Singulated rigid-flex boards are usually, but not always, cables with connectors on each end (Figure 3). Parts that require more extensive assembly are usually provided in an array to hold the...
rigid-flex part stable, similar to a hardboard, during the assembly processes (Figure 4). The rigid sections of the board are usually routed with conventional router bits and/or end mills depending on the thickness and material composite, and they are usually routed on conventional PCB routers similar to hardboards and flex circuits.

The flexible sections of the boards can be machined using lasers, conventional routers, steel-rule dies, and specialized CNC equipment. When using laser and steel-rule dies, care must be taken to be sure that those cuts match up well with the routed edges on the rigid sections of the board. Flex and rigid-flex boards have a greater degree of dimensional movement than hardboards, so usually your perimeter file(s) will need to be scaled to match the material movement of the composite—both the conventional router for the hardboard areas and laser or mechanical routing of the flexible areas of the board.

A rigid-flex board usually has far more features to cut in the rigid and flex sections than you would see in hardboards or even most flex boards. A typical job will spend hours and sometimes days routing the flex and rigid sections out. This is particularly true in arrays with a large number of parts (Figure 4). Scoring can be used in rigid-flex manufacturing, but often does not give desirable results. The panels score just like a hardboard would, but there is still flexible laminate buried in the material layup. The flex material bends rather than breaks, which can make it difficult to get the parts out of the array.

**Strain Relief or Beading**

High-reliability rigid-flex boards often use strain relief or beading along the flex-to-rigid interface (IPC 2223, 5.2.9). Beads of a somewhat soft resin are placed by hand along the transition points where the flex goes into the hardboard sections. The beads reduce the amount of stress—particularly on circuits—at the transition points. It is used in dynamic flex applications where a board is expected to last hundreds of thousands of flex cycles with-

![Figure 4: Rigid-flex boards in an array for assembly.](image-url)
out failure, or in high-reliability applications where every method of improving reliability and survivability is employed to be sure your package never fails. Another application is useful on boards that use a “pouch” manufacturing technique, which will be discussed in our next column. Boards manufactured with a pouch construction will need a strain relief bead almost universally.

Strain relief beads are placed by hand using a mechanical syringe. The adhesives vary from single- and two-part systems, but most are sensitive to heat. If baked, the adhesive will run out onto the flex area of your board. Most adhesives are then air dried, which can take up to eight hours to cure completely. A rigid-flex design with six flex arms will have 24 beads, which can take quite a bit of time to complete, and then need to air dry, adding to the lead time of your order.

This article described how rigid-flex manufacturing differs from hardboard and flex circuit manufacturing on a straightforward rigid-flex construction. My next column will discuss difficult constructions, how they are accomplished, and what are the tradeoffs in cost and yield time.

Bob Burns is national sales and marketing manager for Printed Circuits LLC. To read past columns or contact Burns, click here.

A collaboration between the University of Tokyo, Tokyo Women’s Medical University, and RIKEN in Japan produced a functional sample of heart cells with a soft nanomesh sensor in direct contact with the tissue. This device could aid the study of other cells, organs, and medicines as well as pave the way for future embedded medical devices.

One way or another, research on the heart is fundamentally important to us all. When Sunghoon Lee, a researcher in Professor Takao Someya’s group at the University of Tokyo, came up with the idea for an ultrasoft electronic sensor that could monitor functioning cells, his team jumped at the chance to use this sensor to study heart cells, or cardiomyocytes, as they beat.

For this research, collaborators from Tokyo Women’s Medical University supplied a healthy culture of cardiomyocytes derived from human stem cells. The base for the culture was a very soft material called fibrin gel. Lee placed the nanomesh sensor on top of the cell culture in a complex process, which involved removing and adding liquid medium at the proper times. This was important to orient the nanomesh sensor correctly.

With three probes, the sensor reads voltage present at three locations. Thanks to the multiple probes, researchers can see the propagation of signals, which result from and trigger the cells to beat. These signals are known as an action or field potential and are extremely important when assessing the effect of drugs on the heart.

“Whether it’s for drug research, heart monitors, or to reduce animal testing, I can’t wait to see this device produced and used in the field,” said Lee.

(Source: University of Tokyo)
Don’t Build Flex That Doesn’t Flex

Flex Talk
by Tara Dunn, OMNI PCB
Co-written with Anaya Vardya, AMERICAN STANDARD CIRCUITS

One of the primary advantages of moving to a flexible circuit design from a rigid board is the ability to package the flex in three dimensions, bending or folding into imaginative configurations and saving precious space in the final package. While flexible materials are robust and can withstand many flex cycles, nearly everyone can share a war story about the flex that didn’t originally perform as expected with copper cracking after installation.

I [Tara] remember an example from my early days in flex fabrication. We had built a fairly simple, double-sided flex with FR-4 stiffeners on both ends. After installation, the customer contacted us because the copper was cracking while it was being bent. In that case—and most cases even today—fabricators often have only a 2D view of the design. After some investigation of how the flex was being used, we made several recommendations to improve the performance of the circuit. Materials were adjusted, traces were re-routed to keep all of the traces on one layer in the critical bend area, polyimide stiffeners were added to guide the bend exactly where it needed to be in the unit. Rather than plating electrodeposited (ED) copper onto the more flexible rolled-annealed (RA) copper, we button-plated and only plated ED copper on the pads and plated through-holes. The end result? Success! No more cracking.

Stories like this are not uncommon. Fabricators have quite an arsenal of tips and tricks to help improve flex life and avoid damage to flex materials during installation and use, yet are often building the circuits without knowledge of how it is going to be used in the final application. While our intention is to share some of the common methods of improving flexibility, we also want to strongly encourage everyone to communicate the flex and bend areas in the fabrication drawings or have discussions with your fabricator prior to release to take advantage of the knowledge they have to draw from and improve the performance of your new design.

Electrodeposited (ED) Copper Foil

ED copper is formed by electrolytic deposition onto a slowly rotating polished drum from a copper-sulfate solution. When an electric field is applied, copper is deposited on the drum as it rotates at a very slow pace; the slower the pace, the thicker the copper. The
Addressing the Latest Research On:

- Advanced Packaging & Processes
- Automotive Systems & Hardware
  - Cleaning Technologies
  - Heterogeneous Integration
  - Inspection & Test Techniques
- Interposer & Packaging Technology
  - Materials & Reliability
  - Nanotechnology Applications
  - Trends, Roadmaps, and more...

February 11-14, 2019
Kauai Marriott Resort & Beach Club
Kauai, Hawaii

Register Today!
www.smta.org/panpac
side against the drum provides the smoother finish (Figure 1).

**Rolled-Annealed (RA) Copper Foil**

RA copper foils are created by successively passing an ingot of solid copper through a rolling mill and then applying high temperature to anneal the copper (Figure 2). RA copper foil has higher ductility and elongation than ED copper, which is why it is best for bending applications.

**Grain Direction Matters**

RA copper is primarily used in flexing and bending applications. Circuit direction and orientation on a manufacturing panel are critical to maximizing the flex life in dynamic flexing applications. Grain direction is positioned perpendicular to the bend axis because bending across the grain direction will inherently negate the advantage of the elongated grain structure.
Routing in Bend Areas
In addition to the conductors being perpendicular to the bend axis, it is also critical that the conductors do not traverse in the bend area (Figure 3).

Button Plating
When dealing with multilayer flex applications that require a lot of bending, it is important to specify that button plating or via-only plating is required. Typically, when plating copper in the plated through-holes, the fabricator will be plating the full panel. This plating process uses ED copper, which is not as flexible as the RA copper foil. This can impact the flexibility of the circuit in applications with tight bend radius or dynamic flexing requirements. When button plating is specified, the fabricator will plate only the copper pads and through-holes—not the full panel. Many cracking failures have been resolved once the process to manufacture the flex circuit has been changed from plating copper on the circuit layers and vias to a via-only plating operation.

Balanced Construction
The construction should be balanced from its centerline including copper, dielectric, and adhesive thicknesses. An unbalanced construction will cause stress to occur in one direction, decreasing flex life.

Minimum Bend Radius
Even though flex circuits are very pliable and flexible, there are limits to their flexibility. If the bend radius is too tight, the result can be delamination and conductor fracture (Figure 4).

Figure 3: A poor versus a robust flex area design.

Figure 4: Bend radius illustration.
There is a rather complex formula to determine an acceptable bend radius but as a rough rule of thumb:

- **Single-sided and double-sided flex applications**: The minimum bend radius should be six times the overall thickness; as an example, if the overall thickness of the flex circuit is 0.012”, the minimum bend radius should be 0.072”

- **Multilayer flex and rigid-flex with bonded inner layers**: The minimum bend radius should be 12 times the overall thickness; as an example, if the overall thickness of the flex circuit is 0.030”, the minimum bend radius should be 0.360”

### Multiple Flex Layers on a Rigid-flex

For improved bending, inner layers should not be bonded together in the flexing area; this is typically referred to as “loose leaf” construction. Figure 5 illustrates a 14-layer rigid-flex where the inner layers were not bonded together to improve bend radius.

### Crosshatched Copper Shielding

Using a crosshatch pattern rather than a solid copper shield can greatly increase the flexibility of a flexible circuit. This can be customized by removing more or removing less material based on design needs. Crosshatching can also be applied in just the critical bend areas leaving sections that are not exposed to bending and flexing as full copper layers.

### Conclusion

As mentioned earlier, this is certainly not an exhaustive list of all the options available to improve the flexibility of a design but is a good list to review when working on a design and a place to start discussions with your fabricator. Most everyone can tell their tale of the “flex that didn’t flex.” This short list will help decrease the odds of that occurring. We strongly encourage early and clear communication about flexing and bending requirements with your fabricator who can provide suggestions for your specific application. **FLEX007**

_Tara Dunn_ is the president of Omni PCB, a manufacturer’s rep firm specializing in the printed circuit board industry. To read past columns or contact Dunn, click here.

_Anaya Vardya_ is president and CEO of American Standard Circuits. To read past columns or contact Vardya, click here.

Visit _I-007eBooks_ to download your copies of American Standard Circuits’ books today: _The Printed Circuit Designer’s Guide to… Fundamentals of RF/Microwave PCBs_ and _Flex and Rigid-Flex_.

---

*Figure 5: Completed PCB flex belts separated.*
WHAT DO ALL OF THESE LEADING COMPANIES HAVE IN COMMON?

They all benefit by advertising with us—PCB007 China Magazine.

Should your name be on the leaders' list?

GET STARTED NOW!
Collaborative Design Using Empathy

Interview by Dan Feinberg and Barry Matties
I-CONNECT007

One of the guest speakers at AltiumLive 2018 was Jeremy Blum, director of engineering at Shaper—a robotics company that integrates computers with handheld power tools. Shaper Origin is the first hand-held computer numerical control (CNC) machine, which is a computer-controlled cutting machine that can be used for woodworking. But how does it relate to the electronics manufacturing and PCB industry? In this interview with I-CONNECT007, Jeremy answers that question, speaks about the importance of communication in the design to manufacturing (DFM) process, and explains a surprising tool he uses over and over to improve their products—empathy. Their new, accessible product will empower and inspire you to get creative.

Dan Feinberg: Jeremy, that was a very good presentation.

Jeremy Blum: Thank you, I appreciate that.

Feinberg: Your device is fascinating, but what brings you to AltiumLive?

Blum: All the electronics in it are designed with Altium. I’ve been going back and forth with Altium for quite a while now about ideas on how to make the software better. As I mentioned in my presentation, I collaborate very closely with the mechanical engineers at Shaper. Origin is a tightly, electromechanically integrated product. I kept running into hurdles where it didn’t seem like there was a great workflow for how to do something I wanted to do, whether it was fitting something into a constraint that the mechanical engineers had given me or trying to communicate to them how I needed to do something electrically. Thus, I’ve been talking to Altium for a while about ways to improve their software. I’m an Altium power user, so it’s nice to be at an event where I can talk to people who use the same software I do, identify with the successes and
Why Rigid-Flex?

- Extremely reliable
- Excellent in harsh environments
- Greater packaging density
- Ultra-thin, ultra-light packaging

Why Choose Us?

- Experienced rigid-flex our focus since 1997
- Complex, high-reliability rigid-flex our specialty
- State-of-the-art equipment
- We are easy to work with
- Provide design assistance as required
- The most extensive UL qualification available
- Mil spec certified: MIL-PRF-31032, Mil-P-50884
- ISO 9001 2015, ITAR, JCP 4532 certified

Visit Our Website for Rigid-Flex Design Aids

Contact Printed Circuits Today! 888.844.8416

printedcircuits.com
the trials that I have had, and learn from them; hopefully, people can learn some things from me, too.

Feinberg: That’s interesting. This is the first time I’ve been to one of their events. Regarding advances, you’re the second person I’ve spoken to where I’ve asked, “Do you talk with the customers and suppliers who make the stuff and have to make it work?” I find it impressive when they do.

Blum: With the complexity of modern products, you need more information to make good products, and that comes down to understanding who’s going to use the product at the end of the day, and who’s making every component in your supply chain. You need to have a strong relationship with them, understand them, and be able to work with them, which saves a lot of time and money at the end of the day.

Feinberg: It’s as though you were going to engrave a new type of metal and you decided not to talk to the metal manufacturer. Wouldn’t that be crazy?

Blum: Yes, you have to understand the design constraints you’re going to be working with.

Barry Matties: Interestingly, one of the primary comments we hear from people in the supply chain is the lack of communication, up and down, from the design phase forward. You’re reinforcing that you’re not using the linear design model, right?

Blum: Understanding how the supplier is going to supply components or do some element of your manufacturing chain is important. I empathize with other engineers who have difficulty in those communications. I do too. Sometimes, I wish I could just live in a bubble and say, “Here’s the thing I’m going to make. I’m going to design it, and then I’m going to kick it out the door, and it’s going to come back perfect.” The unfortunate reality is that the world is not like that, and the sooner you accept that and realize what the world is actually like, you can get better at having those conversations. You quickly realize that having them earlier is only beneficial.

Matties: What motivated you to make this unit? Was there a void or an opportunity in the market?

Blum: I joined Shaper three years ago. The original technology for our product spun out of a Ph.D. program at MIT where the two co-founders were working on it. The initial idea behind the product, as with most things, was that Alec—one of the co-founders—had a bunch of tools, tried to make something, realized he was terrible at it, and said, “Wait, I’m a computer scientist! Maybe I can use robotics or computer vision to help me.”

The first thing was to develop this technology. Then, it was figuring out if this technology had applications outside of just making folks less bad at woodworking. Are people interested in this tool? That’s when he found there was a huge void in the market. The
The power tool industry is not one that I would call particularly technologically complex or really in the 21st century. There are lots of great products out there, but are they truly taking advantage of recent technological advances to make incredible things? We felt that technology could be applied to help address a hole in the marketplace where people want products like this, both with hobbyists—where people want more accessible tools—and professionals who want more powerful tools that let them do things faster.

It’s just like Altium—electrical engineers want better tools from Altium so they have a way to make better circuit boards. Woodworkers and professionals want better woodworking tools to help them make better products, furniture, and other goods, and we saw a way that we could use our technology to meet that need.

**Feinberg:** When you look at some of the things that you’ve made and what the technology is capable of doing, it’s amazing.

**Blum:** It goes back to the question you asked me earlier about why I’m here. Part of the reason why I’m here is because we used Altium to design the electronics in Shaper Origin. The other reason why I’m here is that engineers love making stuff! The people who are at this conference are here because they like making things. Their day job might be designing things in Altium, but I bet a lot of them want to be more hands-on in other parts of their lives. They want to do repairs around their house or build their own furniture, toys, gifts, etc. These people tend to overlap heavily with engineers in general, such as electrical engineers who are designing circuit boards, because these people have a creative energy that sometimes needs the right tools. I think your point is good. It’s interesting to see a bunch of woodworking at an electrical engineering conference—basically, a PCB design conference—but it resonates with the types of people who are here.

**Matties:** The tool is the limiter or the skill to use the tool.

**Blum:** There is something to be said for holding a tool in your hands and being involved in the process of making something. It completely changes your emotional connection to what comes out at the other end. I’m not a skilled woodworker by any means. I know a lot more about it now than I used to because it is a necessity for my job. Now, I make furniture, gifts, and complete projects around my house with Shaper Origin. There’s something to be said about how you can make a gift with this product, hand someone a gift, and say, “I worked on this. I held the machine, thought about the design, implemented it, and made it happen.” That’s an important feeling for a lot of people.
Feinberg: What I find so fascinating about the tool is it’s X, Y, and Z—not just X and Y.

Blum: We call these digital joints [shows sample projects].

Matties: It’s quite ornate. The puzzle piece is just brilliant, and the tolerance is amazing.

Blum: The tolerance is one of the really interesting things about the tool. To make a joint like this, you have one design file cut in the positive and negative. When you cut the negative, you start with a perfect interference fit. Origin is extremely precise. You can cut a piece, find that it barely doesn’t fit, and because it has a perfect interference fit, you can shave off 1/1000 of an inch; it will let you do that. It’s so little you can’t even feel it cutting anything, but when you try to put the other piece in again, it fits perfectly. You can keep doing that until you get the fit that you want. This is very difficult to do any other way.

Matties: What are the stripes or the dominoes for?

Blum: That’s ShaperTape, which is a proprietary tape that we’ve developed, and it’s how the system does its visual tracking. The tape is key to the accuracy of Origin and how it knows where it is in 3D space. Basically, this is our mechanism for augmenting your workpiece. It can be a flat piece of wood or an existing piece, like a desk—it doesn’t matter. If you put tape on a flat surface, Origin scans it, and then has a complete 3D understanding of where it is in that space. We did a lot of custom development work on the tape. We had to teach a manufacturer how to make this tape. It has a unique, non-repeating pattern on every row of tape, and based on the way you lay it out, it’s statistically guaranteed always to have a unique layout of those dominoes.

Let’s say I’m in a makerspace with 10 people sharing this product with works in progress. I can take this over to another project. As soon as it doesn’t see the tape anymore, it loses where it is in space. As soon as it comes back here, it remembers exactly where it was and what design files are linked to this tape. If I have another project that’s in progress and has different tape on it, when I pop it over there, it’s going to remember all the exact design files that are on that and exactly where they are.

Feinberg: Without erasing it?

Blum: Yes, it’s all saved on there. You can erase it if you want, but you can work on a virtually infinite number of projects simultaneously and keep going back to them.

Matties: When you were designing the circuits, what’s the level of complexity of the electronics?

Blum: It’s an electromechanically complex product. You can guess that from the form..
IPC Global Marketplace is an innovative buyer’s guide that enables electronics industry professionals to easily locate the products and services they need to effectively run their business.

With its intelligent search technology, mobile responsive design, and enhanced company profiles, IPC Global Marketplace take the user experience to the next level, all while putting your company in front of the “right” professionals in our industry. It’s the place to see and be seen.

IPC Global Marketplace is available on IPC’s website, www.ipc.org or directly through ipcglobalmarketplace.com.
factor. There are 10 rigid PCBs, and that’s a function of the form factor requirements of Origin—the camera and display both need to be in one plane, and there are also handles, encoders, controls, motors, the main processing unit, the spindle motor, and the controller for the Z-axis. I don’t have 20-layer boards in there with blind and buried microvias and things like that. What makes this complex is the integration between lots of boards fitting in electromechanically, which was the biggest challenge, along with making it highly manufacturable, repeatable, and testable.

Each tool is individually calibrated as it goes to the factory because we have to get the visual system perfect. This means designing the electronics to enable automatic calibration routines in a fast and efficient way in the factory.

MATTIES: What was the cycle time from concept to being ready to go to market?

BLUM: The earliest prototype of this tool from eight years ago included a single-axis correction prototype. For many years, it was an academic project. I joined about three years ago to help make it manufacturable. At that point, there was a prototype that had cameras fitted on, an external computer, and a bunch of stuff that allowed testing of the user interaction flow, but it was not manufacturable. About a year and a half ago, we started a pre-sale campaign to look for people who wanted to buy it, and then it started shipping to people a year after that. We first shipped the tool to people in October 2017. We fulfilled the orders for all of our pre-order customers. Then, we paused sales so we could expand our manufacturing capabilities to better meet demand. Origin is now available for sale again in the U.S. and Canada at shapertools.com.

Matties: When you were looking at the manufacturing, what was the greatest challenge in finding a supplier to meet your needs?

BLUM: It’s kind of a weird product—it’s simultaneously a robot, power tool, and computer. It was challenging to find manufacturing partners who had reasonable expertise in those three things. Most manufacturers just focus on one of those things. We had to train our contract manufacturer on the processes for building a product like this, and we’ve developed all of our own factory test fixtures. We spend a lot of time at the various factories in our supply chain teaching them how to make this product and its various components effectively.

FEINBERG: So you have someone manufacture the entire device for you.

BLUM: It’s like any other complex product. There are hundreds of parts in Origin. Some vendors are making subassemblies for it. However, there’s one place where the whole thing comes together—the final assembly location—which is where we do all the testing and calibration.

Feinberg: Do you do it, or do you have it made for you?
Blum: We partner with a contract manufacturer who manages the day-to-day manufacturing of Origin. We work very closely with them to set up that factory and give them the capabilities they need. Different parts of Origin come from different places. Origin leverages a global supply chain—there are parts from all over the place. The spindle motor, for example, we developed in partnership with Festool. Festool is a German power tool company. If you ask any professional woodworker, “What is the best power tool I can get?” they will say Festool. We’re thrilled to work with them. We co-designed this router spindle with them, so that part is made in Germany.

Matties: What advice would you give to a young product designer?

Blum: Empathy. It’s so important, and I was bad at it for so long. It’s a tough skill to learn. You have to force yourself into it, and it’s challenging at times. However, if you understand how the other people on your team are thinking about approaching a problem and how your customers are going to approach your product, it will help give you way more insight into how to design that product effectively.

Matties: Is there anything that we haven’t talked about that you think we should share with the industry?

Blum: The big thing is this is a tool for professionals, but it’s also a tool for tinkerers and people who want to get into woodworking in their garage and maybe don’t have all the space to have a full woodshop. If you want to get into it and you’re an electrical or a design engineer who wants to be doing more hands-on stuff, then you want Origin. It’s a good tool for you, and it’s available to buy now from our website.

Matties: Jeremy, we certainly appreciated your presentation. Thank you for your time for this interview.

Blum: Thank you very much. My pleasure.
Method for Testing FPC Materials at High Frequency

Abstract
The advance of wireless communication necessitates a higher speed and a wider frequency band. Because the majority of the band uses are tightly packed in frequencies at <6 GHz, the application of millimeter wave at >30 GHz has become a key technology for future development. Potential applications include next generation Wi-Fi 802.11ad/WiGig and 5G technology.

With the request of high frequency and high speed, a better flexible substrate than the one commonly used in 3C electronics is needed. The common substrate adopts polyimide as the dielectric middle layer material, and its high dielectric constant and moisture absorption often cause signal loss under high-frequency and high-speed conditions. Therefore, flexible copper foil suppliers attempt to either modify the polyimide or replace it with a liquid crystal polymer (LCP).

Nevertheless, a standard testing method and wire layout have yet to be established for various materials under high-frequency and high-speed conditions. Considering numerous factors affecting the material performance, we have designed a standard test wire layout and a fabrication procedure to facilitate dependable and precise testing. Testing data in this article indicates that flexible copper foil using LCP as a dielectric substrate has the best high-frequency and high-speed performance, and this performance could even be further elevated by a thicker dielectric layer and a smoother conductor surface.

Introduction
Because of the application requirements for connection speed, time delay, connection density, cover area and power consumption, 5G is used at multiple bandwidths. Thus, a millimeter wave at >30 GHz with a wider frequency and bandwidth are needed for communication. To solve the problem of short transport distance, traditional macro-station disposal tends to combine macro, small, and family station to form a multilayer and the densest pattern for a change. Large-scale antenna technology (Massive MIMO) enhances efficiency and decreases the delay.
Get flex right the first time!

**THE PRINTED CIRCUIT DESIGNER’S GUIDE TO...**

**Flex and Rigid-Flex Fundamentals**

Anaya Vardy and David Lackey
American Standard Circuits

LEARN HOW TO:

- Specify suitable materials
- Identify critical requirements
- Understand the important issues

I-007eBooks.com/flex-rigid-flex
via increasing the number of stations and terminal antennas.

The wireless communication industry has advanced from the first and second generation of voice and text message transport, through the third generation of email and internet transport, to the fourth generation of imaging, online games, and cloud data transport. The current fifth generation is not only capable of the services of previous generations, but also provides data sharing, telemedicine, intellectual family applications, and public safety services in cities, achieving a real communication internet of things (IoT). Ericsson predicts that in 2020, 90% of the population older than age six will use mobile devices, and the forecasted bandwidth will be ten times of that in 2014. Therefore, it is concluded that both the number of users and the needed bandwidth will increase. As the basis for development, the wireless point-to-point digital communication warrants an efficient method for increasing the bandwidth.

According to data from ITU-R and ARIB indicate, 5G will start being used in 2020. To establish a universal frequency standard for millimeter wave, ITU announced after a recent WRC conference that a range of 24-GHz to 86-GHz frequencies could available to the world (Table 1). Shortly after, FCC announced 2015 NPRM on October 21, providing service rules for frequencies at 28, 37, 39, and 64-71 GHz. As a result, the proper frequency choices for 5G becomes clearer: 28, 39, and 60 GHz. Although 5G technology is not perfect, it is certain that millimeter wave is one of its key technologies, and will be implemented very quickly.

The new 5G stations and the latest consumer electronics demand large volumes of high-frequency circuit boards. These circuit boards have stricter technical thresholds and higher profit margins than traditional ones in various products such as smartphones, automobiles, the internet, and artificial intelligence.

PCBs are primarily used as substrates for mounting and connecting various electronic devices. As opposed to a traditional rigid circuit board, FPCs have advantages in their capabilities such as, enhanced trace and space density, flexibility, design freedom, 3D layout configuration, potential for a continuous automation process, the absence of wire connectors, and ease of soldering. Because these advantages help to make lighter, thinner, shorter, and smaller electronic products, the market for FPC is steadily increasing.

The applications are increasing in the future with potential FPC applications such as enhanced mobile broadband (eMBB), VR and AR (virtual and augmented reality), smart cities, automobile usage, smart manufacturing, drones, wearable devices, medication, wholesale, and energy. Basically, these applications can be categorized into three classes:

1. Enhanced mobile wide-band communication including wider coverage and hotspot transport. For the former, seamless coverage and higher mobility are the prerequisites. For the latter, the major application is in densely populated areas. It is anticipated that the transport speed increases to 20 Gbit/s from 10 Gbit/s.
2. Large-scale mechanical communication is characterized by a large number of connected devices (approximately one million devices/(km)²), a smaller amount of data transport, and a higher tolerance of data delay.
3. High dependability and low delay communication; the transport requirements of data amount, delay (< 1 millisecond) and dependability (error < 10⁻⁵) are stringent.

The high frequency of data transport often increases the signal decay in the copper con-

<table>
<thead>
<tr>
<th>Possible Frequencies For 5G (24 GHz to 86 GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.25–27.5 GHz</td>
</tr>
<tr>
<td>31.8–33.4 GHz</td>
</tr>
<tr>
<td>37–40.5 GHz</td>
</tr>
<tr>
<td>40.5–42.5 GHz</td>
</tr>
<tr>
<td>45.5–50.2 GHz</td>
</tr>
<tr>
<td>50.4–52.6 GHz</td>
</tr>
<tr>
<td>66–76 GHz</td>
</tr>
<tr>
<td>81–86 GHz</td>
</tr>
</tbody>
</table>

Table 1: Possible frequencies for 5G.
ductor. The insertion loss (IL) of signal transport lines on the flex circuit can be quickly evaluated for various materials under high-frequency conditions. The dielectric layer thickness, dielectric material, and dielectric constant all affect IL. To compare ILs of various materials, we have specified a standard IL testing circuit layout and measurement method.

**Experimental**

Insertion loss is proportional to the dielectric constant (Dk), dielectric loss (Df) and signal frequency. For any material, a higher signal frequency leads to a higher IL. IL is defined as follows:

$$\text{Insertion Loss (dB)} = 10 \log_{10} \frac{P_{\text{in}}}{P_{\text{out}}}$$

where $P_{\text{in}}$ is the input power and $P_{\text{out}}$ the output power.

In addition to its dependence on signal frequency, IL also varies with the dielectric characteristics of the material. The configuration of a double-layer FPC containing a flexible copper-clad laminate (FCCL) and coverlay (CVL) is shown in Figure 1. The FCCL consists of a dielectric layer sandwiched between two copper foils. The copper foils can be classified either as rolled-annealed (RA) or electrodeposited (ED) copper with a normal thickness of 12, 18, or 36 mm. The dielectric layer can be polyimide (PI), modified polyimide, or LCP. The modified polyimide often contains fluorine or PTFE to enhance its properties. The dielectric layer has a normal thickness of 12.5, 25, or 50 mm. The CVL consists of polyimide and epoxy with a normal polyimide thickness of 12.5 or 25 mm, and epoxy thickness of 15 or 25 mm.

During the testing of various FCCLs (including various dielectric materials, thickness, and copper thickness) and various CVLs under high-frequency data transport, we have specified a standard fabrication process and an impedance measurement method to exclude other parameters unrelated to the material. The FPC for IL measurement is fabricated as shown in Figure 2.
It is important to note the following:

1. Drilling: Use a laser to drill round holes for future use. It is not necessary to drill through since conduction is not needed.
2. Image transfer and etching: Use film and UV light to transfer the test circuit to FPC sensitizer film, and form the circuit on copper foil after developing and etching.
3. CVL attachment: Use laser cutting to make a pattern, and attach CVL to the etched FCCL substrate to protect the circuit and insulate.
4. Surface treatment: Plate gold onto connection points via ENIG (electroless nickel/immersion gold) to prevent the copper surface from being oxidized.

Signal IL depends on the impedance of the signal leading trace, and this impedance varies with the line thickness, width, and pitch, as well as the material and thickness of the dielectric layer. To compare the loss performance of various materials under high frequency, we designed a standard test circuit layout which has the same impedance for all materials. Therefore, all parameters unrelated to the material are excluded and IL will be dependent only on the material. The IL test circuit layout is designed as follows:

Use differential microstrip to configure as in Figure 3. As opposed to a single signal line, the differential signal line has better resistance to noise and suppression of electromagnetic interference and increases the precision of IL measurement. D1 and D2 are a pair of differential signal test circuit traces or lines with the same width (W) and thickness (T), and length.
PCB BUYERS - compare nearly 1900 manufacturers now at The PCB List.

Quick Search

Advanced Search

The best way to find a PCB fabricator, anywhere.
each wire on the working panel, only IL data with corresponding impedance falling in the range of 100 ± 10 ohm are viewed as valid.

An Agilent Vector Network Analyzer, with a measurement bandwidth of 25 GHz was used to measure the ILs of dielectric material in various FCCLs. All three dielectric materials have the same dielectric thickness of 50 mm, copper thickness of 12 mm, and CVL thickness of 50 mm with a total thickness of 174 mm (Figure 6). For FCCL measured under 10 GHz, LCP has a Dk value of 3 and Df value of 0.0016, modified PI has a Dk value of 3.2 and a Df value of 0.003, and traditional PI has a Dk value of 3.5 and a Df value of 0.005 (Figure 7). Compared to the traditional polyimide dielectric material, modified PI and liquid crystal polymer are better suited as the dielectric material for making FCCL.

The effect of dielectric thickness on IL has been studied for each dielectric material. The test was conducted under a constant copper thickness of 12 mm and CVL thickness of 50 mm for three dielectric thicknesses of 25, 38, and 50 mm, resulting in a total FPC thickness of 149, 162, and 174 mm, respectively (Figure 8). The data in Figure 9 indicates that a thicker dielectric leads to a lower insertion loss.

Our trace layout and measurement method were also used to compare RA and ED copper foils based on their effect on IL of FCCL. Because the skin effect at the surface is more pronounced at a higher frequency, surface roughness will significantly affect IL. Therefore, the surface roughness of RA and ED copper foils are measured before the FCCL fabrication. Using the same dielectric material with equal dielectric thickness, copper thickness,
and CVL thickness, RA copper foil has a lower surface roughness (Rz = 1.3) than ED copper foil (Rz = 2.7). IL measurements are shown in Figure 10. RA copper foil has a lower IL owing to its lower surface roughness.

**Conclusion**

Due to the dielectric characteristics, test traces with the same line widths and pitches have different impedances on different substrate materials. This would increase the IL measurement error. Described in this article is a standardized differential microstrip that enables us to achieve equal impedances for all materials by adjusting line width and pitch, and thus excludes parameters unrelated to materials for the IL measurement.

Our measurement data clearly indicates that using an LCP as a dielectric leads to the lowest insertion loss. Modified PI (doped with other species) also leads to a lower IL than traditional PI. For each dielectric, a thicker dielectric layer produces a lower IL. Furthermore, RA copper foil having a lower surface roughness provides a lower IL because of the skin effect at its surface.

---

**Paper Sensors Remove the Sting of Diabetic Testing**

A technique that enables biologically active enzymes to survive the rigors of inkjet printing presents a promising alternative to routine blood screening exams faced by diabetic patients. The KAUST-led team used this approach to make disposable devices that can measure glucose concentrations in human saliva.

Researchers are now working to create paper sensors that quickly indicate disease biomarkers. The key to this approach is replacing traditional electronic circuitry in the sensors with low-cost plastics that can be manufactured quickly and in large quantities.

The team used inkjet technology to produce sensors sensitive to small sugar concentrations in biofluids. Utilizing a commercial ink made from conducting polymers, the team printed microscale electrode patterns onto glossy paper sheets. Next, they printed a sensing layer containing an enzyme, glucose oxidase, on top of the tiny electrodes. The biochemical reaction between available glucose and the enzyme creates electrical signals easily correlated to blood sugar levels.

Experiments showed the top coating gave the sensor an unprecedented shelf life; the enzyme could be kept alive and active for a month if stored in a sealed bag. These results are encouraging the team to expand the capabilities of this approach by incorporating different enzymes into the sensing layer.

(Source: KAUST)
As the reader has likely already determined, flexible circuits are an excellent technology for making electronic products that are bendable, shapeable, lighter, and smaller than those made using rigid materials. However, flexible circuit materials also tend to be a bit more costly than rigid materials. To save money on the product, it is necessary to conserve material in design. In this regard, the flex circuit designer is arguably the most important person in the entire flex circuit manufacturing process in meeting this objective.

The decisions made by the flex circuit designer are going to carry over to every other part of the process and can have a significant impact on the ultimate or overall cost of the assembly.

To that end, it is essential that the flex circuit designer be attentive to any features that are likely to impact the cost. One should aim to reduce overall material use, which can help keep manufacturing costs down. Good enough, but what can the designer do specifically?

One of the first things the flex circuit designer can do is to design circuits that can be closely spaced on the processing panel. While panelization is not something the circuit designer is normally tasked with, the choices the designer makes will have a definite effect on how closely the circuits can be spaced relative to one another on the panel. Close spacing and maximum utilization of the material is accomplished by carefully arranging the circuit on the panel to ensure the greatest use of material.

This important technique of optimizing the number of circuits per panel is called nesting. While it is a goal to use the maximum material, there are other forces in play. Sometimes,
it is more important to optimize the layout rather than maximize material use to meet critical engineering needs that might affect performance or reliability. For example, when laying out a flex circuit, one must know the end use.

In some cases, the circuit may be called upon to serve a dynamic interconnection circuit. In such circumstances, there may (or should) be a demand that portions of the flex circuit be properly oriented relative to the grain direction of the foil—such as is required for dynamic flexing. When addressing this need, the result may be that there is a less than maximum material use for circuit construction. However, when this concern is absent, the opportunity to lay out the circuit to get the most out of the material should not be missed.

Proper circuit nesting can greatly improve panel yield and lower overall cost. If folding can be tolerated as an assembly operation, yield can be maximized. For dynamic flex circuit designs, the grain direction requirement may impact layout.

In summary, the decisions made by the flex circuit designer when laying out a flex circuit will have an impact that lasts the entire process. By considering how the circuit might fit onto a panel before submitting the design to a manufacturer, it may be possible to save a considerable amount of material and money. Not all designs will allow such freedom, but it is worth keeping in mind for those applications where the benefit can be secured.

Further Reading

For more detailed discussions on this and other flex circuit topics, download your free copy of Flexible Circuit Technology, 4th Edition here.

Joe Fjelstad is founder and CEO of Verdant Electronics and an international authority and innovator in the field of electronic interconnection and packaging technologies with more than 150 patents issued or pending. To read past columns or contact Fjelstad, click here.
**TOP 10**

Articles and Columns from Flex007.com

1. **Increasing Productivity for Flex Fabricators**
   Barry Matties and Nolan Johnson of I-Connect007 met with Shane Noel and industry veteran Mike Jennings of ESI to discuss the introduction of their CapStone laser tool, a product aimed at doubling their flex circuit fabricators’ throughput. Mike also shares advice for fabricators who are looking to move into the ever-growing flex market.

2. **EPTE Newsletter: Exotic Materials for Flexible Circuits**
   Wearable technology is common in the electronics industry and is expected to be a profitable category for the next generation of electronics. Flexible circuits are the most significant packaging materials for wearable devices including medical and healthcare devices.

3. **Standard of Excellence: Preparing Your Vendors for the Future**
   Now, it’s time to talk about the future with your PCB vendors. Referring to our previous columns, if you’ve done everything right so far, you will now have a strong working relationship with your PCB supplier. They understand all they need to know to fabricate perfect boards for you at this time. With trust and respect between you, you’ve truly formed a strong partnership going into the future.

4. **Substrates for Advanced PCB Technologies: What Will the Future Hold?**
   The UK chapter of the global IMAPS community of electronics and microelectronic packaging engineers shared a wealth of knowledge and wisdom about PCB substrate technology trends, developments, and future requirements in a webinar on the first of November.
EPTE Newsletter: Sputtering or Chemical Plating?

More than 20 years ago, material manufacturers competed with each other to develop adhesiveless copper-clad laminates for the next generation of flexible circuits. These technologies were categorized into two types: a casting and laminating process, and the metallization of polyimide films.

It’s Only Common Sense: Tips for Attending Trade Shows

As we near 2019 and the upcoming trade show season, Dan Beaulieu discusses some of the best ways to get the most use from your hard-earned trade show spending.

Punching Out! Creating PCB Industry Giants and Mid-majors Through Acquisitions

Summit Interconnect announced the acquisition of Streamline Circuits. Summit itself was created in 2016 through the merger of KCA and Marcel, and is backed by a private equity firm. In the PCB and PCBA industry, TTM Technologies is the giant King Kong of acquisitions, growing from just $80 million in revenues 20 years ago to over $3 billion today.

Powerful Prototypes: The Future of PCB Designs

I designed my first PCB using tape and etch-resist pens from RadioShack. I penciled the schematic on graph paper, drew the layout directly onto the single-sided copper-plated board, and then etched it in my parents’ garage.

150+ Years of Experience: Reflections with Three Industry Icons

You would be hard-pressed to find a more knowledgeable and experienced group than that of Gary Ferrari, Gene Weiner, and Happy Holden. In a brief interview with Barry Matties, these three industry icons consider the past, present, and future state of electronics manufacturing while also offering advice to the newest generation of manufacturers.

Stephen Chavez: Breaking the Design Data Bottleneck

In this interview, PCB designer and EPTAC design instructor Steph Chavez explains some of the biggest issues related to good design data hand-off, and he offers some ways forward.

For the Latest Flex News and Information, Visit: Flex007
Events Calendar

IPC APEX EXPO Conference and Exhibition ►
January 26–31, 2019
San Diego, California, USA

DesignCon 2019 ►
January 29–31, 2019
Santa Clara, California, USA

MD&M West 2019 ►
February 5–7, 2019
Anaheim, California, USA

EIPC 2019 Winter Conference ►
February 14–15, 2019
Milan, Italy

FLEX 2019 and MSTC Conference and Exhibition ►
February 18–21, 2019
Monterey, California, USA

China International PCB and Assembly Show (CPCA) ►
March 19–21, 2019
Shanghai, China

MicroTech 2019 ►
April 4, 2019
Granta Park, Abington, UK

KPCA Show 2019 ►
April 24–26, 2018
Kintex, South Korea

IPC Automotive Electronics High Reliability Forum ►
May 6–7, 2019
Nuremberg, Germany

Medical Electronics Symposium 2019 ►
May 21–22, 2019
Elyria, Ohio, USA

IPC IMPACT Washington 2019 ►
May 21, 2019
Washington, DC, USA

JPCA Show 2019 ►
June 5–7, 2019
Tokyo, Japan

Additional Event Calendars
ADVERTISER INDEX

All Flex................................................................. 3
Alpha Assembly Solutions................................. 11
American Standard Circuits.............................. 43
Candor Industries................................................. 7
Cicor..................................................................... 15
ESI........................................................................ 57
I-Connect007......................................................... 61
I-Connect007 eBooks........................................... 2, 81
Insulectro............................................................... 5
IPC......................................................................... 31, 77
Lenthor Engineering............................................ 47
MacDermid Alpha Electronics Solutions......... 27
Miraco................................................................. 23
PCB007 China Magazine...................................... 71
Printed Circuits Inc............................................... 73
Prototron Circuits................................................ 37
The PCB List......................................................... 85
SMTA..................................................................... 67
Taiyo...................................................................... 19
Tramonto Circuits................................................ 33

When you register at my I-Connect007, be sure to subscribe to our monthly magazines.