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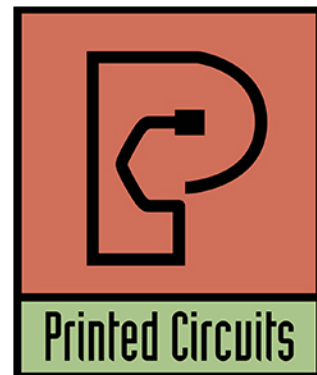
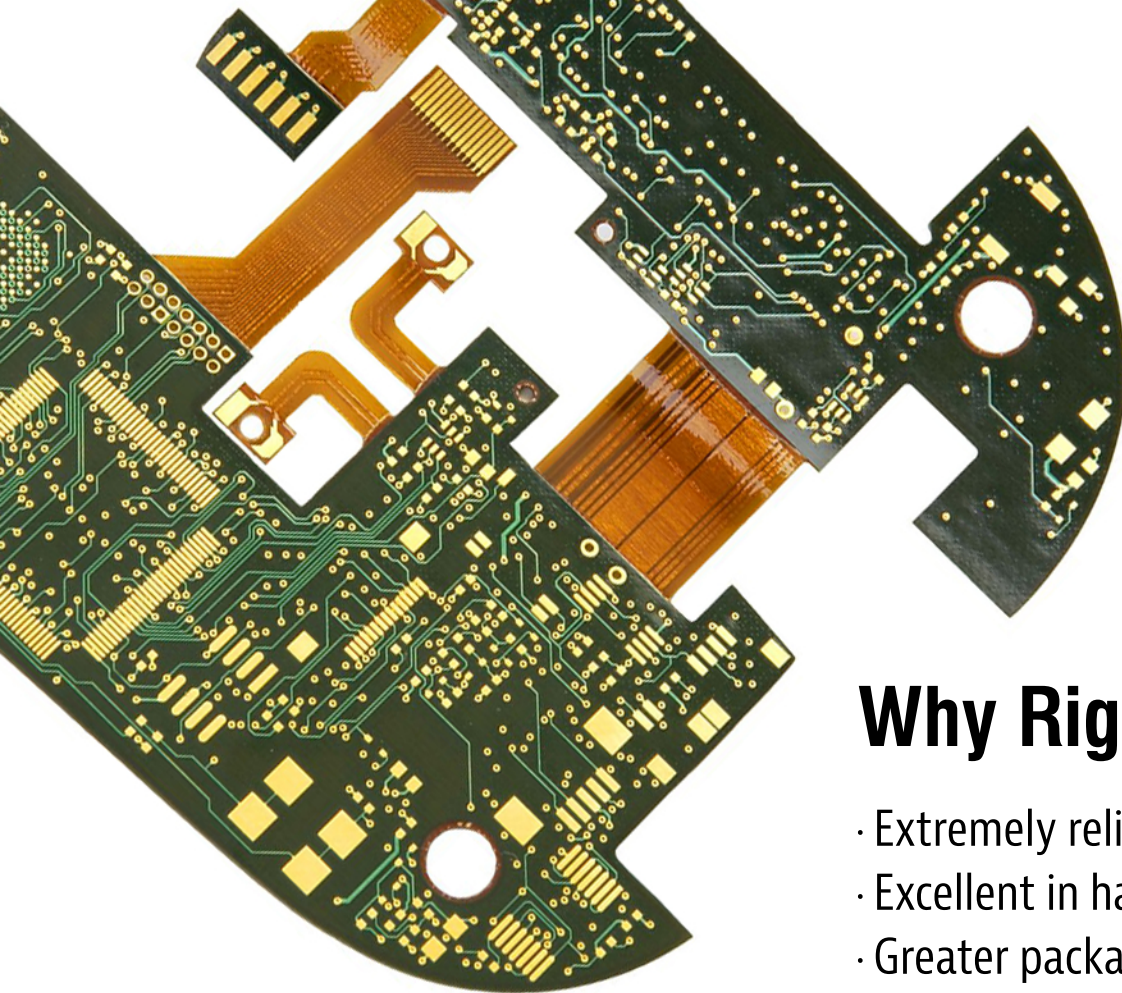
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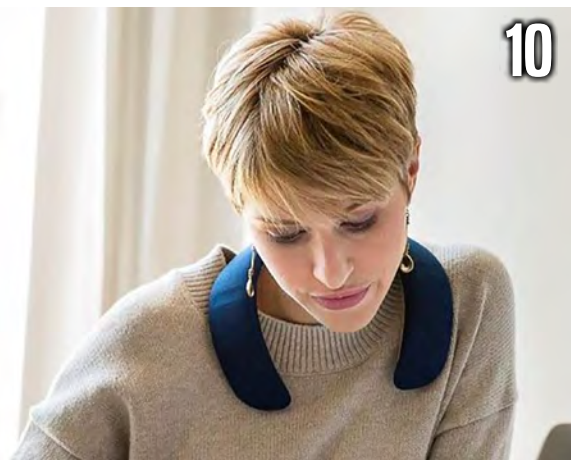
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DIVING INTO FLEX

This month's cover art was inspired by some of the stories we've heard lately about companies that are being forced into using flexible and rigid-flex circuits. This is happening for a variety of reasons: Sometimes rigid boards won't fit the shrinking enclosures anymore, or the company just needs a rugged, reliable circuit.

We have the flex information you need in this sophomore issue of *Flex007 Magazine*, the quarterly magazine dedicated to flex system designers, electrical engineers, flex PCB designers, and anyone responsible for integrating flex into their products at the OEM/CEM level.



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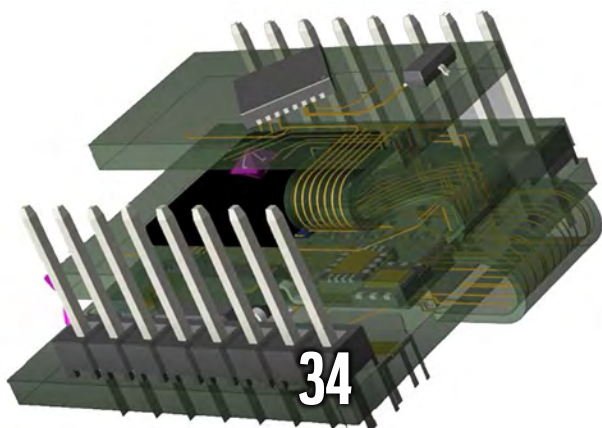
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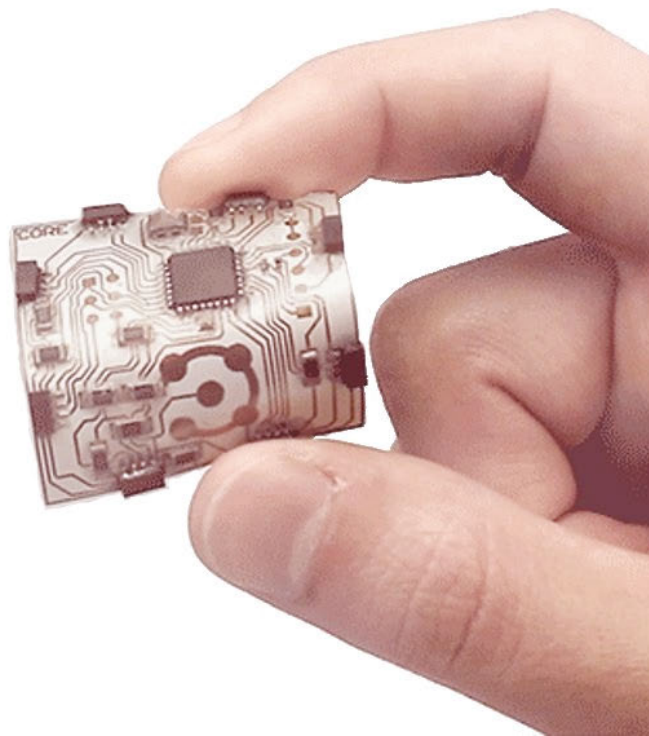
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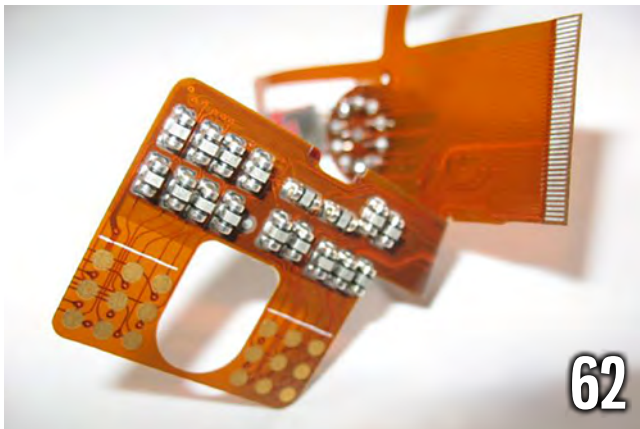


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Diving into Flexible Circuits

ReFLEXions

by Andy Shaughnessy, I-CONNECT007

For some OEMs, it's time to dive right into flex. But don't worry; if your company is considering using flex for the first time, you don't have to go off the deep end, or sink or swim.

This month's cover art was inspired by some of the stories I've heard lately about companies being forced into using flexible and rigid-flex circuits. This is happening for a variety of reasons: Sometimes rigid boards won't fit the shrinking enclosures anymore, or the company

just needs a rugged, reliable circuit. Maybe it's a combination of these reasons.

When no one in your company knows anything about flexible circuits, this move may sound like a daunting proposition, but you don't have to do it alone. As you'll learn in this sophomore issue of *Flex007 Magazine*, your first step should be to contact a flex fabricator and ask for all the help you can get. Your fabricator will be happy to set you up



with guidelines to ensure your first flex job is a successful one.

Designers sometimes think fabricators sound like a broken record by constantly asking for designers to communicate with them early in the cycle, or even to communicate at all. But if you're a rigid board designer doing an OEM's first flex or rigid-flex circuit, you really don't have a choice. You have to communicate with the fab guys. Fortunately, your flex fabricator can tell you exactly what you need to do on the design end. They would love to have a new customer.

First-time flex designers should also take advantage of IPC's flex standards and guidelines. These documents walk you through the process. If you get to a sticking point in your design, the appropriate IPC standard may provide an accepted best practice for solving your problem.

Better yet, get involved with IPC. Attend a committee meeting or join a committee. Attend events like IPC APEX EXPO and soak up every flex class that you can. You have an entire network of flex experts at your fingertips—technologists who have been working with flex for 40 years. Take advantage of their expertise, and then go home and teach your co-workers what you've learned.

As you'll see in this issue, designing flexible circuits isn't that much different than designing rigid PCBs, but there are a few notable differences. You're working in 3D, and it's a moveable type of 3D. You have to worry about things like bend radius. But most experienced rigid designers won't have much trouble transitioning to flex. Today, most EDA tool companies offer some flexible circuit design capabilities, so you're not going to spend much time fighting with your software.

Now, let's do a swan dive into this issue. In our first feature interview, Todd MacFadden of Bose discusses his company's rapid expansion

into the world of flex circuits—from about 90% rigid PCBs four years ago to around 66% flex and rigid-flex today—and how his team managed to get up to speed so quickly. (Hint: They communicated heavily with flex fabricators.) Next, Anaya Vardya and Dave Lackey provide an excerpt of their recent I-Connect007 eBook, *The Printed Circuit Designer's Guide to...Flex and Rigid-Flex Fundamentals*, focusing on some of the mechanical and electrical issues that are peculiar to flex and rigid-flex design.

Then, Jarrod Schulte of Cadwell Industries

explains in an interview what attracted his department to flex: The high level of reliability required by their medical devices. And in an interview with Barry Matties, Prototron Circuits President Dave Ryder and General Manager Kim O'Neil discuss their Tucson facility's recent decision to offer flex and rigid-flex circuits, as well as some of the hurdles they've overcome and what OEMs look for in a flex supplier.

We also have columns by our regular contributors Joe Fjelstad of Verdant Electronics, John Talbot of Tramonto Circuits, Bob Burns of Printed Circuits, and Tara Dunn of Omni PCB. And this month, let's welcome a new columnist—Jahn Stopperan of All Flex, who has taken over the *All About Flex* column with the retirement of his colleague, Dave Becker.

As devices continue to shrink, there's a good chance that designers like you are going to be driven to use flex and rigid-flex circuits. *Flex007 Magazine* will be here with the information you need. **FLEX007**



Andy Shaughnessy is managing editor of *Flex007 Magazine* and *Design007 Magazine*. He has been covering PCB design for 18 years. He can be reached by clicking [here](#).



Bose Ready to Take Flex into the Future

Feature by Andy Shaughnessy
I-CONNECT007

Bose is one of those companies that probably has 100% name recognition among consumers. Their initial fame was for the 901 series speakers that could make sound come from the other side of the room. I still don't understand how that worked; the speakers are here, but the sound is coming from all around the room. Bose audio engineers don't mess around.

Now Bose is really going for it, making wearables and all kinds of cool things that have led the company into using flexible circuits. I spoke with Todd MacFadden, a component reliability engineer at Bose, about the company's experience with flex, as well as some of the advantages and disadvantages of flex, and how to best determine when it's time to switch from rigid to flex.

Andy Shaughnessy: Todd, as a component reliability engineer at Bose, what's your job like, and how does it relate to flex and rigid-flex?

Todd MacFadden: I've been at Bose for 14 years, and in my current role for about five years,

working closely with the design teams at Bose to understand the technology needs on upcoming products, and at the very advanced stages of conception. What choices are they making that are going to drive the PCB design and changes? For example, BGA pitch and array size, that sort of thing. Then, I work on the other side with the PCB and FPC suppliers throughout the world, our supply chain, to make sure they have the capabilities that we need to support those technologies when we need them.

Sometimes that means on-boarding new suppliers or working with existing suppliers to make investments or bring on the engineering resources that they need to optimize their existing equipment. It's pretty exciting, because I work with all of the business units at Bose, which include automotive, professional, consumer electronics and our new wellness division. So this means many diverse form factors, from stadium speakers to wearables. I work with development teams throughout the company on upcoming products, but I also interact with the whole supply chain—materials, fabricators, and assemblers. All of it is related.

The reliability portion of that is making sure the designs are robust enough to survive our



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life cycles and various environments. We do a lot of design for reliability work and modeling. Then we do actual testing. What's interesting is that in the last three years, miniaturization has really forced us into the flex world, which is basically new to us. We've always had the luxury of relatively big boxes and lots of space to accommodate the electronics, but now our products are portable or wearable. It's all about miniaturization, so trying to origami your design into a three-dimensional space has been really interesting and challenging for us.

We're new to this, and we're learning the design rules and the limitations of the supply chain—where we can push the boundaries and where not to—so it's really exciting work.

Shaughnessy: So you were basically forced into flex?

MacFadden: Yes, and we've followed a lot of the industry in this vein. I think a lot of people are just really ramping up with flex, at least in the consumer electronics space, for the same reasons we are. But we've managed to avoid it until this point because of our view that flex was more expensive than just getting a board-to-board connector. What we've learned is that's not always the case. Sometimes it's actually cheaper to make a custom flex circuit that can be integrated into a product in a more elegant way. Not only can you reduce space and even mass, but you can save costs. You don't have to buy board-to-board connectors in all cases.

Shaughnessy: It sounds like you're having to learn the design rules, which are entirely different than rigid.

MacFadden: It is, and you know what's really challenging? We get input from our supply



Todd MacFadden

base of what their capabilities are, and that's really the baseline for our internal design rules at Bose; but every supplier is unique. They have different capabilities. They have different material sets, and different sweet spots, so a design for supplier A may or may not be optimal for supplier B, and because we always try to dual-source just to minimize risk, we really have to optimize that design so that it's robust enough for

both suppliers. Sometimes that means making trade-offs. Maybe we can't make something as small as we want to, or we can't put it as close to the edge as we wanted.

Shaughnessy: In the survey for our inaugural issue, you mentioned that it's important to work with the fabricator and assembly people early on. Do you always know which fabricator you're going to use for every design?

MacFadden: Yes, so we've gotten to know our supply base really well, and we know what their capabilities are now after having a little bit of experience. I generally know what that form factor is going to be and what the technology's going to be on that flex circuit. I know which two or three suppliers I'm going to start engaging, so we'll just bring them into the room or have a call with them even before there's been any pen to paper, when it's just a rough concept.

"We need this sort of layout. It's got to fold up into such and such form factor." Then, we start asking questions. "Is it better to use a stiffener? Is it better to use double-sided? Is it possible to do double-sided surface mount?" We've had that question come up a lot, and it's really key to get those answers at that point of discussion rather than trying to manipulate a design later. As you know, every design iteration becomes more expensive and difficult to change later.

The key point that I've learned is to have a really good relationship with a technical expert from that supplier who can basically be on call for us at that early stage. We've been lucky to find suppliers who had those resources for us, some sharp individuals.

Also, I'm leveraging my engagement and involvement in IPC. There are lots of experts there and on the committees. It's really a good place to learn. It's reassuring to hear that other people are having similar challenges. Recently we've been attending flex workshops, professional development courses, and I'm trying to get some of our designers now to start attending these conferences and seminars, because there's a lot of good learning there. Once designers can start to think in a three-dimensional space and understand some of the limitations of these materials, and the capabilities, it opens a different world.

Shaughnessy: What portion of your products have flex versus rigid? Do you have any idea what the breakdown would be?

MacFadden: I find this to be a really unbelievable change in just the last four years. Four years ago, I would have told you that 90% of our overall spend was rigid, and 10% was flex. Now that has completely changed to the point where rigid-flex and flex each constitute roughly a third of our overall PCB design work and spend. That's happened all within the span of three or four years. We had to come up to speed with the design rules and then an entirely new supply base. It happened quickly. It's been interesting to be at this transition point in the company.

Shaughnessy: Wow. Definitely a sea change. Now, tell me about the flex for wearables that you mentioned. What kind of challenges do you see there?

MacFadden: Our latest product goes around your neck. It's sort of a collar speaker

that provides a nice sound curtain for the individual. All of these product concepts are based on trying to reduce mass so it's comfortable enough for the wearer, and to put as much functionality as possible into the smallest package possible. The only way to accommodate that has been with flex and rigid-flex to be able to minimize the number of connector headers to be able to fold things up.

It's also really coincided with the chip sets that are available off the shelf, and some of them are very small. They've been customized for the cellphone market, where miniaturization is everything, and the rest of the consumer electronics market is both the beneficiary and also the victim of it. There can be a lot of functionality in a really tight BGA, but it yields a complicated board design. It means higher layer count, more HDI microvias to make these interconnections. At the same time that the form factor requires miniaturization, the functionality is requiring more complicated ICs and off-the-shelf-parts.

In some ways, the off-the-shelf packages also have become more efficient, and we need fewer sub-components to accommodate these designs, so it's a trade-off. It's all about trying to make a wearable that's comfortable and lightweight, that is going to stand up to all of the abuses that you can imagine: drop tests, moisture exposure, leaving it on a dashboard in Phoenix, or leaving it in your car overnight in Minnesota. Sweat is a huge one, and it's obviously a very challenging environment to accommodate. Fortunately, flex materials are chemically robust and thermally robust.

Shaughnessy: It's interesting that you mentioned that sometimes you find flex is cheaper than rigid boards and having to do a whole song and dance to make a rigid board fit in.

MacFadden: Flex materials are vastly more expensive on a per-unit basis compared to rigid materials. But there are cer-



Figure 1: The Bose ProFlight aviation headset features a dynamic slider flexible circuit inside the headband.



Figure 2: Bose discovered that flex is a much better fit than a rigid board for their latest electronic devices.

tain times when you can use flex to, let's say, reduce layer count, or to eliminate connector headers. And if you could incorporate it into the design in such a way that it's serving some other purpose than just connecting board to board, then it makes sense. As an example, we figured out on one of our products that we were just going to use a board-to-board connector, but we realized we could actually get rid of an entire six-layer circuit board by putting LEDs and microphones right on the flex circuit. It was an elegant way to connect two rigid boards and serve an additional SMT function in that case.

That's where I would say it's probably on a one-to-one basis. It may not always be cost-effective, but you have to look at the whole of the design and that's really what I mean when I talk about getting our design team to think about circuit designing a different way. It's not just two-dimensional now. You have three degrees of freedom, which can be thinner and lighter, and how can you leverage those advantages? It's been really great. We often get a lot of iterations within a set. We're seeing more design innovations within the development cycles than I think we ever had. It's partly because people think, "Oh, if I could just tweak this a little bit and move it over it would be more efficient."

Shaughnessy: That's cool. What kind of background do you have?

MacFadden: I studied chemical engineering, and my introduction into the electronics industry was doing work on lead-free electronics for my master's degree. At the time that the industry was transitioning to lead-free solder, so I started at Bose at that early stage to help make

that transition for the company. It was exciting because that, too, was such a transformative event for the industry. It was very exciting to be on the inside, and again, I had to work with people throughout the company from document control to the assembly line and everybody in between about how to make this change.

It was a neat way to start at Bose. I got to know a lot of people. Oh, and we had to give weekly progress status updates to the executives, so at my first job out of grad school I was talking to the president and the whole executive board on a weekly basis. Another one of the great things about Bose is that the executive-level management are all accessible. They're all engineers. They love creative ideas and talking technical with all the engineers at any level of the company. It makes it really exciting.

Shaughnessy: How many PCB designers work at Bose?

MacFadden: First, there's never enough, you know? There's a team of designers, and they work really well together, and it's nice that we have different divisions in the company: automotive, professional, consumer electronics, and then R&D groups, but those board designers work very well cross-divisionally. They share what they've learned. We have common design rules that we all learn from. We're constantly updating our design rules these days, because the technology is changing so fast. At least once a week I get a call from a designer who says, "I know in our design rules we're supposed to have a minimum keep-out of X. Can we just push that a little bit tighter?" So we're having these conversations all the time. Again, this is where getting in front of the board suppliers and their technical requirements is really important at the very beginning.

Shaughnessy: Fabricators often say, "Take advantage of our knowledge. Let us educate you." As you say, you may not know everything about flex.

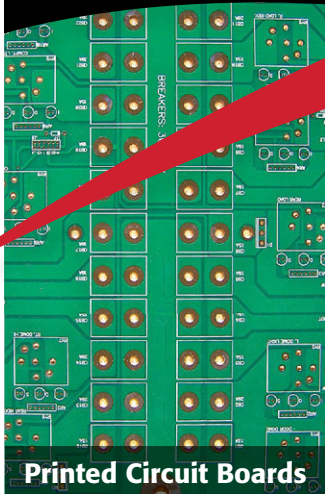
MacFadden: And we don't, and we really have relied on that expertise from the supply base



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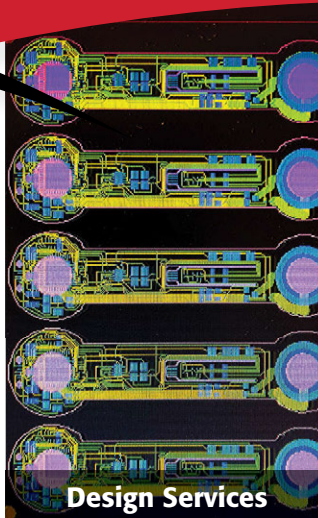
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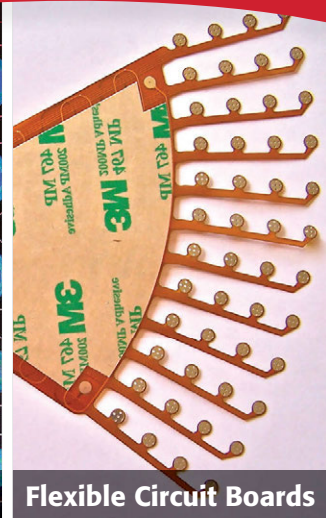
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to help us out, and I'm fortunate. I get to go to these suppliers at least once a year, sometimes multiple times a year, in New England, California or Asia. Getting to see the plants and look at the processes and what's involved in achieving some of these technologies has really been important. A lot of the industry is going to roll-to-roll now to accommodate high volumes, and also some form factors. They can do some really creative and interesting things now on a roll-to-roll format versus panel. You can make it really long. I've seen them—these super-long flex circuits that can be used in ways that people probably never even dreamed of 10–15 years ago.

Our automotive division by necessity tends to be a little more conservative. They have to answer to the OEMs, and in this case, Bose becomes the supplier rather than an OEM, and tends to be a little more cautious. They've been resisting going into the flex world. But we're seeing that flex circuitry really does well in harsh environments.

Shaughnessy: Are you seeing young people coming in at Bose, or in the industry? And how do you think we can attract young people to this industry?

MacFadden: Yes, I've been at Bose for 15 years, and I've watched this transformation. Bose has always been a place where people come to work and stay for their whole careers. We had a lot of people who recently retired after 20, 30, 35 years, so there's a history of longevity here. At the same time, we have a really strong co-op program, and near our office in Framingham, Massachusetts, we're surrounded by great universities. Bose has a very strong relationship with area universities, particularly with MIT, which is where the founder of the company, Dr. Amar Bose, studied and then taught for 40 years.

So we have a lot of co-ops, interns, and new graduates that come through Bose. We've started a new program

recently called the PACE program. It's a way for a junior engineer to enter Bose and do a series of four 6-month rotations, and each rotation is usually in a different division of the company, so that they get a very broad exposure to the kinds of roles and engineering opportunities that there are within the company as well as getting to know people and how things work. Every year we get more and more people in these programs. Sometimes you don't know what you're good at or what you want to do until you start doing it.

Shaughnessy: So what do you think is the biggest challenge, whether for you or just people working with flex in general?

MacFadden: From my perspective, the biggest challenge for me coming from a strictly rigid PCB background was understanding not just the potential of the materials but the limitations. The registrations are different, because the materials are flexible. They're sloppy, and there's just more movement. When you try to sandwich together two flexible materials, they're going to move. We have seen some issues that when the design was not good the materials didn't work as well, and similarly, if we tried to push too hard, we could get into trouble for that. Fortunately we found out a lot early in the design stages partly because of the close relationships we've had with our fabricators. The other thing is that we often can be very successful assembling a flex circuit, or populating it with your SMT components, but assembly into the product can present challenges, particularly where there's a lot of folding and a lot of movement and there are sometimes blind insertions.

In an assembly environment where time is of the essence, there are going to be mistakes on the line, so designs must be robust. People are going to force things that probably shouldn't be forced, and things are going to break. It's



Figure 3: Bose QuietControl noise-cancelling earphones use a combination of rigid-flex and flexible circuits.

not just designing for a robust circuit, but it's robust assembly as well. How is it going to actually go into housing? You could have the most elegant and interesting design in the world, but if you can't make it fit in your housing reliably and repeatedly, you must review that.

Shaughnessy: That is interesting. Twenty years ago, when I started covering this industry, only about 5% of designers had ever done any flex work because it was just so expensive and completely different.

MacFadden: Yes, it's the 3D aspect that's challenging for a lot of us older engineers who are so used to two-dimensional. New design tools have made it easy now to visualize three dimensions, but to visualize it is one thing; trying to incorporate these things into a housing can be a challenge. Recently we had LED components on a surface that were meant to be inserted into a product housing and behind a molded light pipe fixture, and there was always one of a series getting damaged. We just needed to move one support rib maybe one millimeter, and it made the problem go away. No one could have anticipated that this was going to be a problem until assembly.

Another one was one time we tried to cheat a little bit on the recommended bend radius. I won't recommend that, not without at least first trying it. We did have some issues with cracked fingers. I will say that on a ZIF connector, that's become a problem for some people, but had we just given ourselves a little more bend radii step that probably wouldn't have existed. Eventually we did manage to fix it. Fortunately it was before product launch.

Shaughnessy: You mentioned the design tools. Have EDA tools caught up with flex design? I know not very long ago they weren't set up for flex.

MacFadden: No. There's been a lag in the tools in terms of what they can do. I mean, a lot of the first flex designs that we made were just by brute force, manual manipulation of the tool to make it do what you needed to do. But I know some of the latest versions have incorporated a



Figure 4: The Bose SoundWear Companion speaker uses a multilayer flexible printed circuit for board interconnects, and for mounting components such as LEDs, tactile switches, and microphones.

lot of these changes that we were hoping to see. Like automatically calculating the bend radius based on your inputs and helping you create a curved line instead of having to do hand drawing. Some of our designers were actually doing this. It seemed like madness.

Rigid-flex can be complicated with the transition zones between the rigid and the flex areas. You want to make sure that your keep-outs are well defined, so you don't have too much adhesive squeezed out onto the flex portion so that it limits your bend radius. The updated design tools have really helped the engineers understand what those boundaries and limitations are.

Shaughnessy: Is there anything you would like to add? Any advice?

MacFadden: I think my number one piece of advice would be to interact early and often with the technical reps from your respective suppliers, because they have a lot of information that they could share with you before you make expensive mistakes. It's really just talking about ideas. Then, I guess the other piece is be prepared to iterate. It's even becoming easier now with laser cutting and models using actual material sets that are representative of what you're going to get.

Shaughnessy: I appreciate your insight, Todd. Thanks for your time.

MacFadden: Thank you. I enjoyed it. **FLEX007**



EXCERPT:

The Printed Circuit Designer's Guide to... Flex and Rigid-Flex Fundamentals

Feature by Dave Lackey and Anaya Vardya
AMERICAN STANDARD CIRCUITS

Designing Flex Circuits for First-Pass Success, Part 2

Circuit Layup Symmetry

It is a long-standing practice to design multilayer circuit structures with special attention given to the symmetry of the layers in the circuit. That is, the construction should be balanced from center to surface on both sides of the circuit board, whether rigid or flex. This is most easily accomplished by choosing core materials that feature two metal layers. It's more difficult to control this balance when using core materials with an odd number of metal layers.

The symmetry requirement applies to the layer count as well as the overall copper area of the different layers. In this regard, the retention of maximum copper in the circuit pattern

is beneficial to manufacturing, because copper is a dimensionally stable element of the construction. The base polymer is by its very nature flexible, and not intrinsically dimensionally stable.

Designing for Bending: Understanding the Important Issues

Bending and flexing are hallmark functions of a flex circuit, whether the circuit is bent once or flexed millions of times. Understanding specific design rules for flex circuits is crucial for success in the field.

The first thing to keep in mind is perhaps the most obvious: The thicker the cross-section of the material stack in the bend area, the less flexible it will be. It is important to keep the area where bending or flexing is to occur as thin as possible. Ideally it should be a single metal layer, if possible. This is especially true for dynamic flex circuit applications.

In other applications where simple bending to shape is required, thickness is less impor-

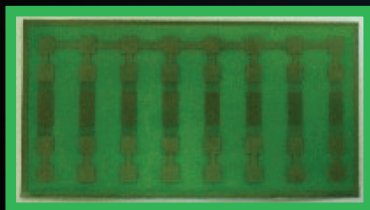
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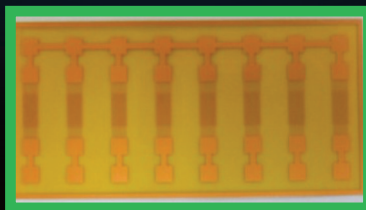
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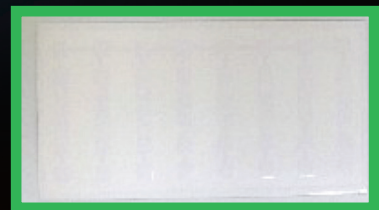
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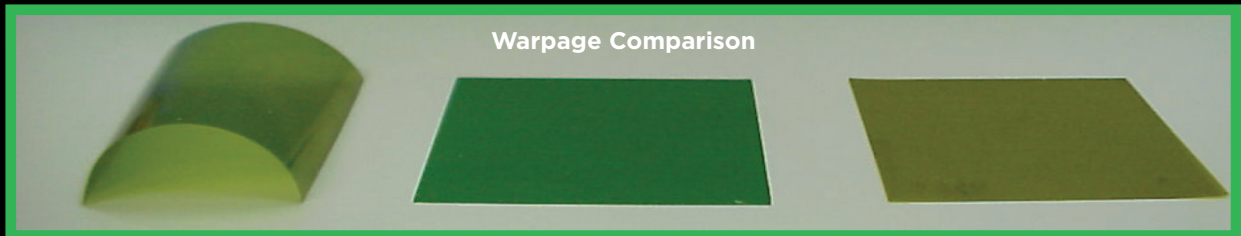
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tant, up to a point. There is a minimum optimal bend radius which is largely a function of the properties of the copper foil. The less ductile the copper, the larger the bend radius should be. However, there are some long established rules to keep in mind:

- For a single metal layer, the minimum bend radius should be on the order of 3–6 times the thickness of the circuit.
- For two metal layers, the minimum should be 7–10 times the thickness of the circuit.
- For multilayer flex, the minimum bend radius should be 15–20 times the thickness or more. If the multilayer sections are unbonded in the bend area, this rule might be relaxed.
- For dynamic flexing applications in which high-flex-cycle life is required, again the design should be limited to a single metal layer and the bend radius made as large as possible (20–40 times thickness or more).

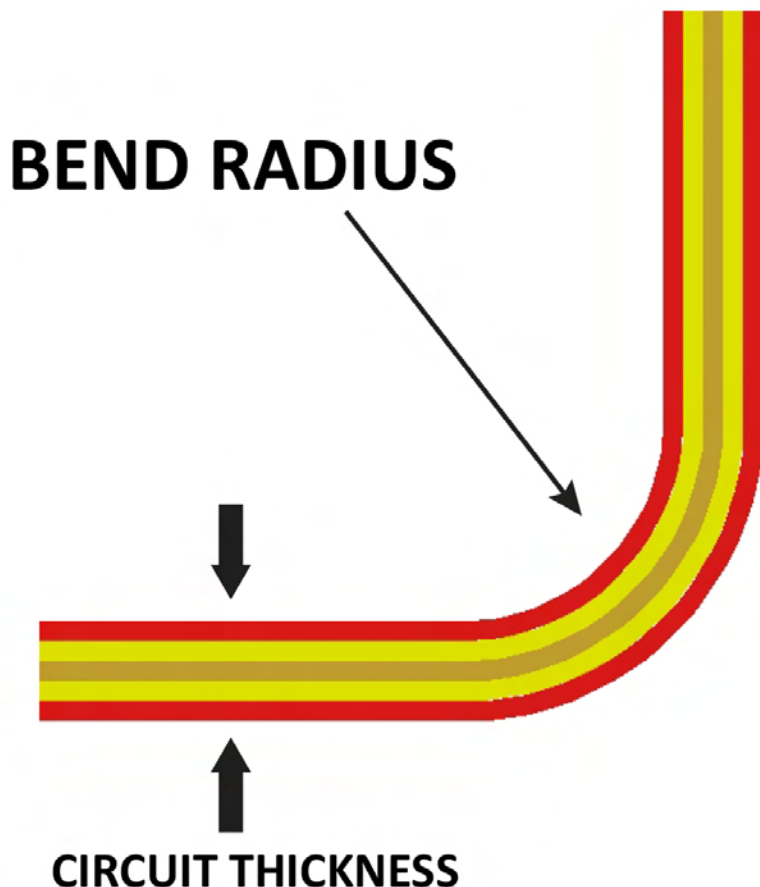


Figure 1: Bend radius.

Always choose materials, copper metal foils, and thicknesses that will accommodate the proper bend radius (Figure 1).

Finite element modeling can be very useful in determining the bend limits of a particular structure. It is recommended that the designer check with his vendor for recommendations based on their past experiences. It is normally much less expensive and more expedient to “go to school” on the lessons learned over time by others.

Dealing with Controlled Impedance Designs

With the increase in higher-frequency circuits, the control of electrical properties in key circuit routes in a design is becoming more critical. Flexible circuits are well suited to the challenge due the nature of the base materials, which are nominally homogeneous polymers of relatively low dielectric constant, as opposed to the heterogeneous epoxy glass composite materials used for rigid circuits, which tend towards higher Dk values and less suitable dissipation factors.

Several factors need to be addressed to get the right characteristic impedance values from a design: trace width, dielectric location, and the thickness of the dielectric between ground and traces. The properties of the dielectric are also of importance. In the design process, it is best to provide nominal values for the controlled impedance trace widths and then let the vendor adapt the process to deliver the right product. To determine the feature size requirements, the designer can use one of several impedance solvers available on the market (Figure 2).

In general, tighter tolerances for etched features are possible with flex circuits because of the lower profile adhesion treatment or “tooth” of the copper. When the design allows, the use of thicker flexible dielectric substrates can ease the etching challenge because thicker substrates allow for

Job Name: **Vega**

Customer Required Finished Thickness **95.00 (± 9.50) mils**

Customer: **CUSTOMER NOT DEFINED**

Estimated Finished Thickness **47.25 (Over mask on plated copper)**

Estimated Over Lam Thickness **45.25**

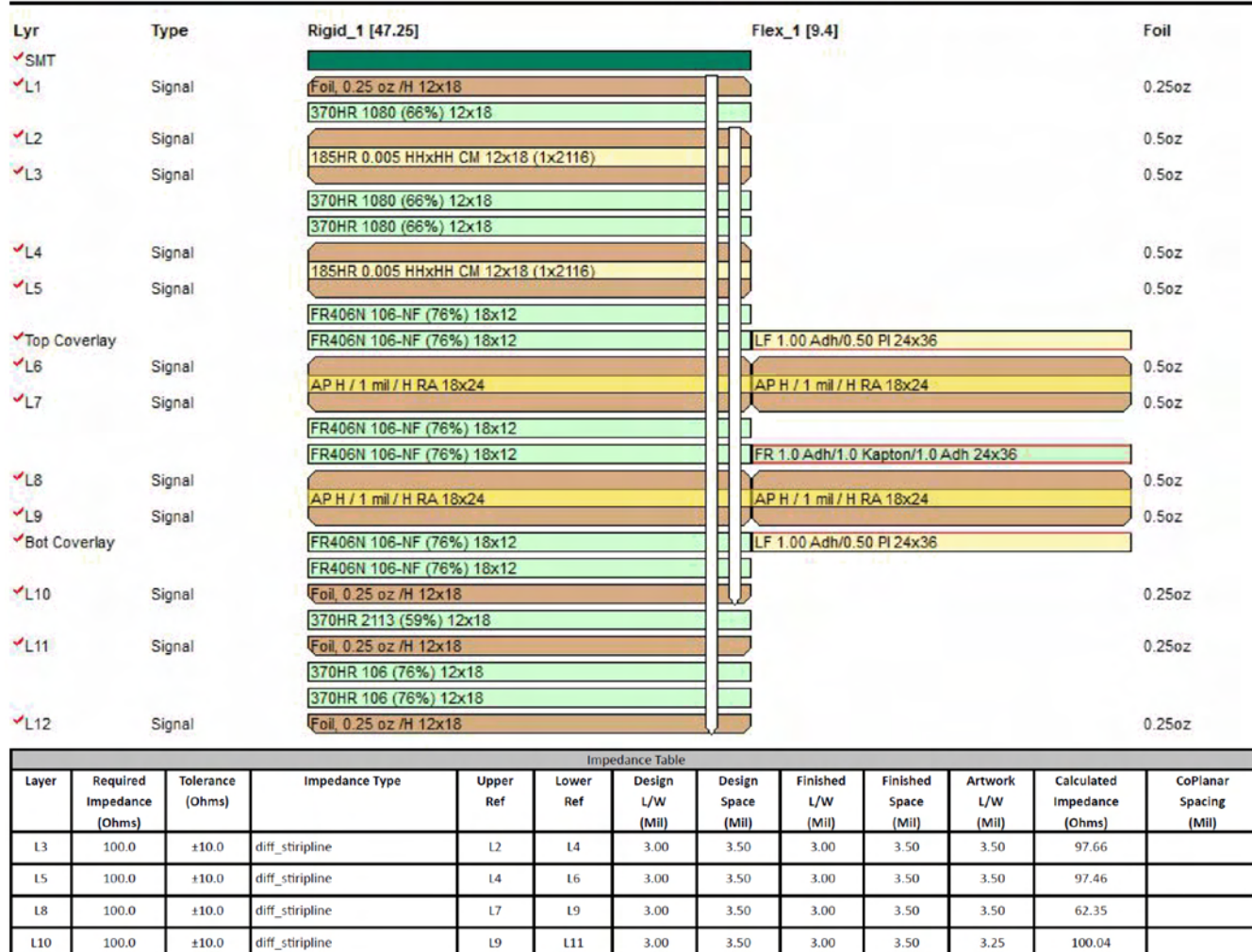


Figure 2: Stack-up and controlled impedance model.

wider signal lines. The wider circuit trace can be more easily fabricated to meet the tight tolerances needed for controlled impedance circuits.

To achieve greatest flexibility, the ground plane can be hatched. Improving flexibility by cross-hatching the plane layers in the flex portion instead of increasing thickness is helpful. Remember that hatching will have an effect on the impedance value. Most fabricators have the modeling tools necessary to determine if cross-hatching (the preferred design) is feasible and will allow for the needed impedance callout (Figure 3).

In terms of impedance structures, there are several different constructions possible using flexible circuits.

The first and simplest is the co-planar strip-line construction. The circuit is produced with just one metal layer, alternating single and ground features. These constructions are well-suited to higher characteristic impedance designs. A drawback of these designs is that they are susceptible to EMI noise.

The second type is the microstrip circuit, a two-layer flex construction with one metal layer devoted to ground. These circuits, nomi-

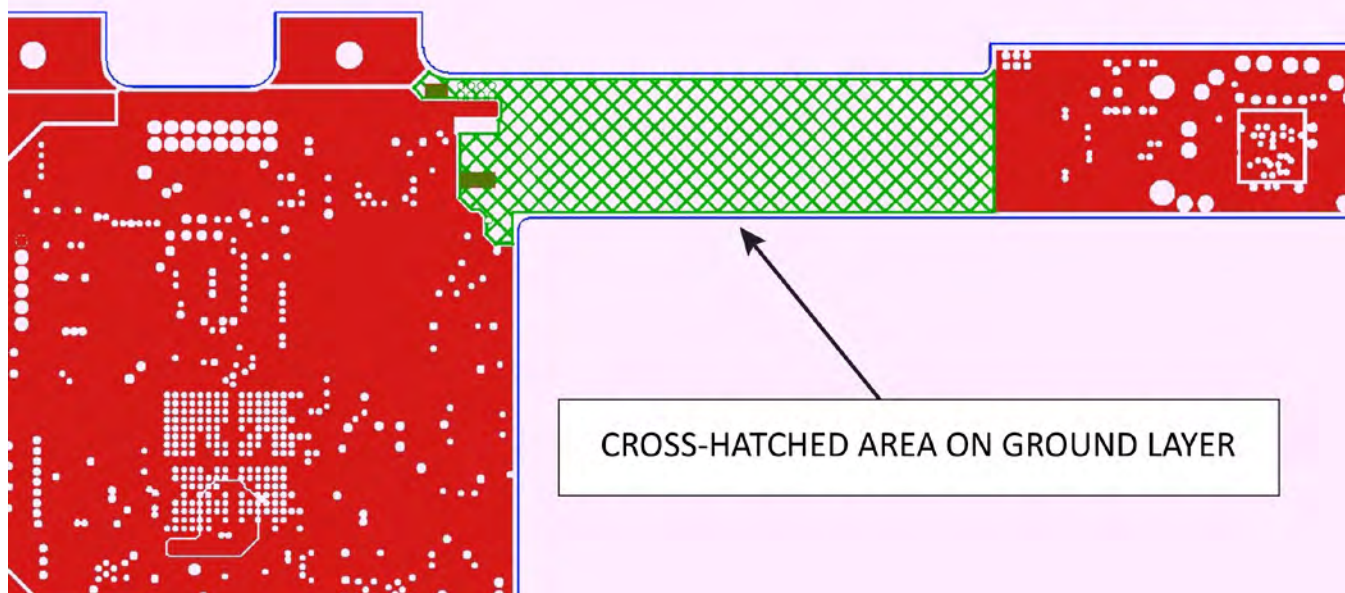


Figure 3: Cross-hatched ground layer.

nally targeted at 50 ohms, have been successfully employed in transmission line applications, and are often used for single-ended interconnections. Higher characteristic impedance designs can be built with microstrip construction, but flexibility normally suffers.

Stripline circuits are the third basic type of controlled impedance construction. These circuits feature three metal layers with ground layers on both sides. Excellent signal integrity can be achieved with this construction; however, they do not tend to be very flexible due to the extra dielectric and metal foil used. Stripline circuits are often designed to 100 ohms and are frequently used for differential pair interconnections.

There is also a stripline construction in which ground lines surround the signal lines to approximate coaxial cable constructions. These structures are of greatest interest where crosstalk is a concern and where maximum signal integrity is required. To improve performance, some designers stitch the top and bottom grounds together through the ground traces with plated through-holes, but this can be a costly process.

Important Mechanical Design Concerns

Flexible circuits are much thinner and generally less mechanically robust than their rigid counterparts. Therefore there are some important issues related to the mechanical requirements in flex circuit design.

First is the matter of the plated through-hole. Through-hole reliability is critical to the electrical performance of a flexible circuit. While there are no hard rules relative to plating thickness in the through-hole, a higher nominal value is generally going to provide better long-term performance and greater resistance to barrel cracking and other thermal and stress-induced failures.

With respect to positioning of holes in the body of the flex circuit, there should ideally be a minimum of 50 mils of clearance between the edge of any such hole and the edge of the circuit or transition areas between rigid and flex. Placing vias closer to the flex and rigid interface can cause issues with possible chemistry leaking under the rigid portion and causing shorts or contamination.

In rigid-flex circuits, it is recommended that some strain relief be provided at the interface

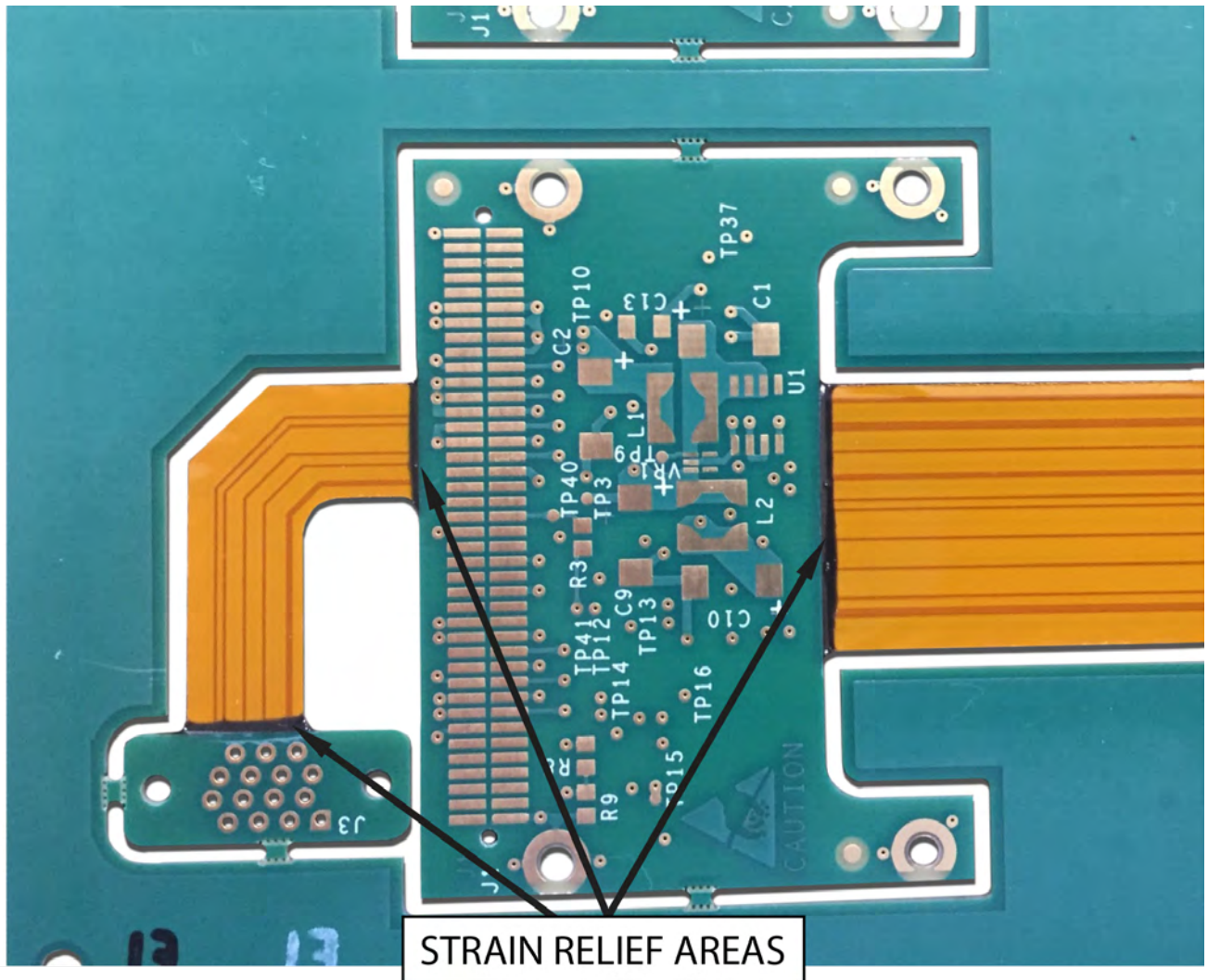


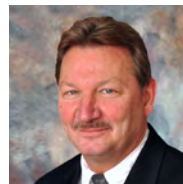
Figure 4: Epoxy strain relief.

between the rigid and flexible areas of the design. The transition area is highly vulnerable to failure at the interface due to the naturally occurring stress concentrations which manifest there. The simplest solution is to provide a bead of polymer at the interface to move the stress point back from the edge (Figure 4).

In the next, and final, installment of our series, “Designing Flex Circuits for First-Pass Success,” we will wrap things up by addressing a multitude of general concerns about flex and flex design. **FLEX007**

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

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



Anaya Vardya is CEO of American Standard Circuits.

For Cadwell, Flex is the Right Prescription



Feature by Andy Shaughnessy
I-CONNECT007

Increasingly, companies are moving to flexible circuits for a variety of reasons. Medical device company Cadwell Industries is ramping up their use of flex circuits for their added reliability. I asked Jarrod Schulte, an engineering support specialist at Cadwell, to discuss the ins and outs of designing flex for medical equipment, the importance of communicating with fabricators early in the design process, and some of the differences and similarities between rigid and flex design techniques.

Andy Shaughnessy: Jarrod, tell us about your job at Cadwell Industries and your work with flex circuits.

Jarrod Schulte: I started with Cadwell as a service technician and was doing that for almost four years. Then the engineering department had an open position for a PCB designer, which at the time I had zero experience as; however, I knew all about our product catalog, so I had a leg up there.

I got my foot in the door and started learning the trade from a guy by the name of Shawn Windom, our senior PCB designer. He has been designing boards since the days of tape on mylar. He was and continues to be an awesome teacher and he pushed for me to go for CID training with IPC. Once I got settled into the engineering department, I just started diving into anything I could get my hands on. I built a 3D printer kit at home, enjoyed it a great deal and I'm now our 3D printing guru. I design the flex boards, do a bunch of rigid design, and I've dipped my toes into the process of injection molding. Basically, if there's anything that needs to be done, I just try to do it.

Shaughnessy: You're their utility player.

Schulte: That's me.

Shaughnessy: How did Cadwell first get involved with flex?

Schulte: Well, it's actually a pretty recent addition to our toolkit. We had done some flex boards quite a while ago, before I was with the



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engineering department, in the early 2000s, I believe. They weren't having great luck with a lot of them at that time and so, until recently, we had been doing rigid, 90-degree interconnects between our patient connector boards and the amplifier or stimulator boards we were building.

As of late, we've been trying to design to a high level of ruggedization. We drop test everything far beyond the requirements, and we were breaking those rigid 90-degree connectors off pretty easily. Shawn and I brought up flex as a possible solution. Since they flex, you get the robustness of the connection, but it's a dynamic thing; the boards can move independently of one another when you drop it. We went that route and it's been working well for us. We've done three flex designs this year. All of them are some sort of interface from two perpendicular boards and we've reused a couple in new projects.

Shaughnessy: So it's similar to rigid-flex, but not quite.

Schulte: Yes, we just design the flex and rigid portions independently. We've been doing rigid boards for most designs and if we're concerned about durability then we'll do a flex interconnect cable, if you will, where each end has a snap fit connector on it. It's a lot cheaper than doing a rigid-flex design and it adds a bit of modularity to the designs; if a flex portion of the circuit fails you can just replace that bit instead of an entire expensive rigid-flex design.

Shaughnessy: You're just using flex as a cable, basically.

Schulte: Yes. We're just cabling over from some sort of patient input or output connector board into the amplifier or a recorder or whatever device it is. The rigid-flex stuff is complicated and expensive to build, so we tend to stay away from that. If we can get away with doing designs without blind or buried vias or other things that add a level of complexity to the manufacturing, then we will. We try to keep it simple, and we only go to those complicated



Figure 1: Jarrod (right) and his brother Brandon Schulte relax after completing a 10-mile Tough Mudder endurance competition. He and his brother both played football at the University of Idaho.

measures if the product size or something else of that nature is a driving factor. If it's really got to be small, we can do that. We also service all our products here in the same building, and so we try to design in a way that you can repair or replace just the board that's misbehaving instead of having to throw out a big, electro-mechanical assembly. You can just replace the particular board as needed, which keeps repair costs lower for the customer.

Shaughnessy: What are some typical devices that you are building that use flex circuits?

Schulte: We're in the neuro diagnostics field. We design tools for electromyography (EMG) and nerve conduction velocity (NCV) studies. We design electroencephalogram (EEG) amplifiers with channel counts starting at 32, we're actually working on a new product right now that's going to have 512 channels available. We've got some new sleep study or polysomnography (PSG) products coming down the pipe.

We also do interoperative neuro monitoring equipment (IONM), which monitors your neural pathways, both motor and sensory, while you're in surgery, to help guide the surgeon during a procedure. This reduces the risk of a patient suffering from some sort of neurological deficit after a procedure. The IONM world is fascinating, my description just scratches the surface of what our equipment is capable of. For example, when I was in the service department, I was doing phone support as well as repairing and testing equipment, so occasionally you'd get a call with people who were in the OR and something was wrong with their equipment. You have to get it back up and running while they're monitoring an active surgery. It's no joke, but it's good stuff. It made me feel like I was sitting in the OR as part of the surgical team.

Shaughnessy: With these devices, reliability is your number one watchword, right?

Schulte: Yeah, reliability is very high on our list of priorities when we're building products, especially anything that will be near the OR. We want to build things that you can depend on not to fail while in the middle of a procedure.

Shaughnessy: Do ever have to use HDI, any of the real cutting-edge technologies?

Schulte: We're starting to push the size of our products smaller and smaller. We are just starting to dip our toes into the high-density and BGA design. If we can avoid it, we will for now. Conventional densities are easier to fabricate and assemble so there is less fallout during production. It makes troubleshooting designs during R&D a lot easier and it's a more reliable if you can use bigger parts, so we lean that way if we can. We've got some products coming down the pipeline right now that really pushed our abilities. We are cramming components on, adding layers and just trying to keep it as dense as possible.



Figure 2: Jarrod is a woodworker in his spare time.

Shaughnessy: Do you know generally where your flex or rigid boards are going to be fabricated and assembled every time?

Schulte: Our volumes are low enough that we tend to stick to one or two fab shops. We have a pretty intimate relationship with the people who are building our devices. That's one of the ways that we can keep our reliability high—by working with people we can trust. So, I have confidence that if we make a mistake, they're going to catch it.

Shaughnessy: That's one of the things fabricators always say. "We wish the designers would talk to us early in the design."

Schulte: Here at Cadwell, the designers and engineers are the ones who are ordering the assembly, or ordering the boards, and so we get to make that call on who's building what, and who is assembling what. It's more engineering-driven rather than from up on high saying, "We've got keep the costs of these boards down, send them to China." That's not really a driving factor around here. It's actually a small enough company that I can walk downstairs and talk to the CEO if I want to.

Shaughnessy: I know a lot of fabricators are considering getting into flex because it's more profitable.

Schulte: It's only in the last year or so that I've started building flex designs, so I can't really speak to that directly. It seems to me they're pretty simple, really, at least in my recent designs. Especially when compared to a multilayer rigid design. The flex designs are mostly just a couple of connectors, some copper, adhesive and polyimide tape. There aren't any components other than connectors on the designs that I've done lately. But it has allowed us to tighten up the dimensions of the housing that we're wrapping around

these boards and the reliability of our products has gone up as well.

Shaughnessy: What do you think are the biggest challenges for anyone designing flex circuits?

Schulte: Well, for me it was the initial investment in time spent reading up on flex design. I started contacting flex manufacturers and asked them if they had any design guides. Almost every one of them sent me a design guide saying, “If you design to these specifications, that’s really going to help us,” and they gave us tips on making them reliable and more flexible.

Once I found a shop that I liked talking to and that was responsive, then I could get a little more specific with my questions as the designs got more refined. But the biggest challenge was just getting up to speed with the terminology needed to use for designing flex. It’s not a whole lot different than doing a simple rigid board. You just have to keep a different rule set in mind when you’re doing flex.

Shaughnessy: What do you think about the EDA tools’ ability to do flex? Do you think EDA has caught up with flex?

Schulte: Well, with Cadstar, it’s not ideal. It’s definitely geared more for rigid designs, and it does a great job with rigid. However, there’s really no tools that I’m aware of in our package that are geared for doing flex boards. We recently made a switch to Altium, I’m looking forward to learning the flex specific tools that are associated with their package.

We use SOLIDWORKS for all our mechanical design, Altium will also plug right into that. You can design the flex in that environment and push it to the mechanical engineer, who can then put it into his assembly and make sure that everything fits prior to ordering product.

On the subject of challenges, that’s something that’s actually been surprisingly difficult. It seemed like it would be pretty simple to figure out how long a flex board should be, but when you design things in a 2D space that are going to live and move in a 3D world, sometimes it’s tough to figure out exactly where

those bends are going to happen, and what forces that might put on the connectors once it’s plugged in. That’s been the only modification that would have had to happen to any of the boards, either adding a little or take a little length out of them. Other than that, the fab shop does a good job of answering questions and making sure that I can get them a design that’s buildable and reliable.

Shaughnessy: Do you do paper dolls every time?

Schulte: Well, not every time. In fact, in one instance that I am thinking of, all the boards, even the rigid boards, were all in the process of being manufactured for the first time, so we didn’t have anything physical that we could put our hands on to see where these were going to line up. It was all conceptual models and our best guess was to draw curves into the models and say, “It looks like it’ll probably go right about there.”

We didn’t have anything that we could put a paper doll up against to see if it was going to fit. But once we get stuff in hand, that’s actually how I would nail down the length. Just draw up a paper doll, cut it out, and compare it to what we’ve got, and we can adjust accordingly if needed.

Shaughnessy: What do you think about the IPC flex standards?

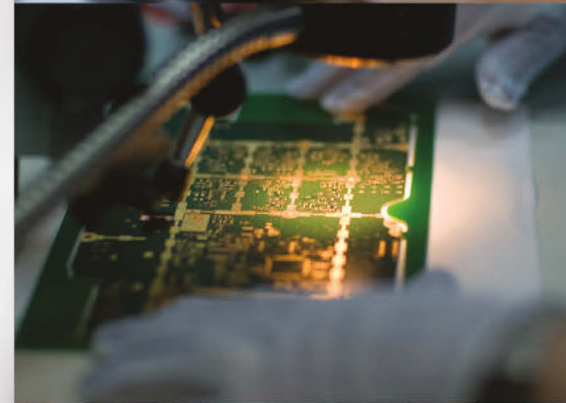
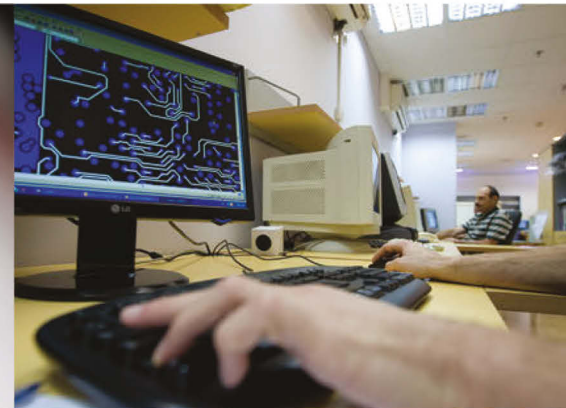
Schulte: I read through them to see if there’s anything pertinent to what I’m doing. The main use I get out of them is to make sure that I can call out all the UL ratings that I need. The flammability standards are a little different with bend materials than it is for rigid materials. I had to pull that out of IPC-2223, I believe.

A lot of the design guides that I got from the fab shops were regurgitating a lot of that same IPC information, but boiled down and condensed into a quickly-readable package. I like to look up the standards whenever I can. If I’ve got a question on how big a hole should be or if I can do something in particular, my first go-to is to try to find the IPC standard that

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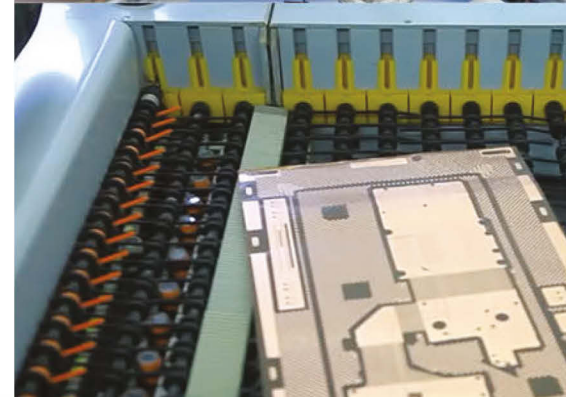
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applies and see if they have a well-accepted practice for whatever I'm trying to do.

Shaughnessy: Sure. People criticize the standards process and say that by the time a standard comes out it's kind of out of date, but at least you know that it's buildable anywhere.

Schulte: I'm with you there. You can push and do things that the standards say you shouldn't. We've worked with fab shops and assembly shops where we'd send a design, and their initial thought is, "I don't know if we can build that." We'll work with them a little bit and we usually can get it to where it's buildable and reliable.

Shaughnessy: You medical folks have to deal with FDA regulations, right?

Schulte: Yes, the FDA and ISO 60601 guidelines. That's the most influential standard that we're designing to. Any time we do a new product, it goes through a very rigorous testing and certification process to meet all those FDA and ISO standards. We also pursue the CE mark for all of our products. That's another set of standards that we have to hit, and it seems like every country has their own regulatory system we must comply with, and that's a lot of work. Hats off to our regulatory department.

Shaughnessy: Right. How many PCB designers and EEs do you have?

Schulte: There are two PCB designers including myself. For the longest time, Shawn was the only designer at Cadwell, but he was starting to get overloaded as we were pushing to keep releasing products, and so they brought me up and trained me, and so now we split those designs up between the two of us.

For EEs, it's a pretty lean crew. I think we're running with seven people who are design engineers of different capacities. We have four

dedicated circuit design engineers, two guys who do firmware, and then another guy who bounces around in between all of that. We shift around to whatever project needs the most attention at the time or whatever the biggest priority is. So many engineers will get locked in on a project and they stay on that. I personally bounce between stuff constantly and just try to keep things moving and do whatever the engineers need to progress.



Jarrod Schulte

Shaughnessy: Well, it sounds like a cool place to work. Your headquarters are in Washington?

Schulte: Yes, we're in Kennewick, Washington and we do the design, manufacture, service and all the support out of the same building there.

Shaughnessy: When you say manufacture, are you talking about assembly?

Schulte: Yeah, assembly. We order all the complicated bits, the PCB assemblies and any injection molded parts and things like that. We'll have those sent to us. But for the overall assembly, we have a full-time production staff and we build all of our equipment. We test our boards and test our equipment and build it up here in our facility.

Shaughnessy: The only thing you send out is the fab then?

Schulte: Yeah, the fab is the only part that's not happening in our building. Whenever we can, we try to use local sources. We use an injection molding shop here in town that does a great job. Most of our PCBs come out of Westak in Forest Grove, Oregon. They're a great shop to work with, they have great feedback from their engineering staff and they're only a three-hour drive from here, so if there is ever an issue we can drive over there. It's a lot easier to build things when you speak the same language and

are geographically close to the people who are building the stuff.

Shaughnessy: So, do you have any advice for anyone just getting into flex, any hurdles they should avoid?

Schulte: Do your homework upfront. If you're familiar with rigid designs, you'll find that flex is just a couple of tweaks from what you have been designing. My biggest advice would be to talk to the people who have to build the stuff. When I have toured facilities, both for assembly and fab, they echo what we've been talking about here, "It sure would be nice if everybody would come and talk to us like you guys do."

Shaughnessy: Well, most designers either have never been in a board shop or they haven't been in 25 years, because they're all wearing three hats at work.

Schulte: That's incredible to me. I've only been doing this for going on five years now, and I was dumbfounded by how much goes into building a rigid board or a flex circuit. I haven't toured a flex facility yet, but I'm trying to get my foot in the door somewhere. When I started designing, Shawn and I went to our rigid facility and assembler. I asked Shawn, "Can't we do the fab and the assembly shop in the same day?" He laughed and said, "You're not going to want to do that."

Sure enough, I was a little glassy-eyed by the time we left the PCB shop. There was so much information. It's an incredibly complex process. It's cool, and I feel like designers should be visiting the places that are building their stuff. If you understand that process, you can more confidently move through a design knowing that you're not going to have to come back and make changes.

Shaughnessy: Right. Did you say that you do some printed electronics work?

Schulte: Not printed electronics, necessarily, but the FDM type of printing in plastics. I'm an

enthusiast. I've built a couple of kits myself. I started diving into it here at work too and then we hired another mechanical engineer who was into 3D printing, and between the two of us we were able to get ourselves a new printer. That thing is running constantly now. I've started doing a lot of my test fixture design in 3D printed parts. Before, I had to draw up the fixture carrier boards in 2D ACAD and send files out to be routed out of bare FR4 and I'd often have some manual assembly to do once I got boards back. If something was wrong, you'd have to repeat the process. Now I can design something in SOLIDWORKS, print one out and verify its form, fit and function before I make only the amount needed all in the same day.

Shaughnessy: It's just crazy how the 3D printing has just taken off. Now you can just use that instead of having to basically build a circuit board.

Schulte: If it was up to me, we'd have a bunch more printers and I'd be printing all sorts of stuff.

Shaughnessy: Well, it's good to be a hobbyist.

Schulte: That's what got me interested in electronics in the first place: playing with car stereos and computers.

Shaughnessy: Are you noticing an influx of younger people? We see a lot of gray-beards retiring, and a few people coming in, but not many.

Schulte: I would say half of our engineering staff is probably within 10 years from retiring. Five years is probably not out of the question either. We've been expanding the engineering staff for the last couple of years, and so I've been seeing younger people under 40. We're getting some younger talent in the doors here, but we are fortunate to have a bunch of experienced engineers, some of whom have been here for 30, 35 years, and are a great resource to lean on. They've been there, done that. When you have questions, they've got a good answer for you or can point you in the direction of somebody who might have a good answer.

It's a good thing to have both of those generations working together. You see the new guys come in and bring their new skills to the table and the legacy guys keep you grounded, moving in the right direction and offer incredible advice to those who listen.

Shaughnessy: Is there anything we haven't covered that you want to mention?

Schulte: It's cool to have this opportunity to talk to you. I enjoy this field of work and designing circuit boards has become a passion of mine. It's something I didn't know I would ever be doing and I feel pretty fortunate to have stumbled into it. It's a great career and I wish there was a more formal path for people to see this skillset and learn this skillset than on the job, because you look around and you don't really see any design certifications out there. Besides the IPC CID and CID + certs, there isn't much training out there. I haven't seen any tech schools offering PCB design courses or certificates or anything. You really just have to get your hands on it and do it a lot.

Shaughnessy: There are classes at PCB West, IPC APEX EXPO and DesignCon, but colleges don't offer much PCB design education.

Schulte: Yes, and that's surprising to me. If you look at job postings, a lot of times you see companies who want the engineer to do the layout, which I feel is asking an awful lot. It's one thing to know your particular design, your general circuit design stuff, and be good at that, but it's a whole different ball game to come in and design a PCB. It's really two separate fields of study.

Shaughnessy: PCB design is still not as simple as pushing a button, even though some engineering managers may think so.

Schulte: You know, we joke around here that you just load up a schematic, press "Enter, enter" and out comes a PCB. That was the shortcut to launch the autorouter. But they always give you a garbage result, so you have to spend as much time setting up the autorouter design constraints as you would to just route the damn thing.

Shaughnessy: It's been great talking with you, Jarrod. Thanks for your time.

Schulte: Thank you for the opportunity. FLEX007

FLEX SURVEY: DESIGN ISSUES

In a recent survey, I-Connect007 asked readers who work with flexible circuits to list their biggest problems related to flex design. Here are a few of the replies, edited slightly for clarity.



What are your three biggest problems related to flex design?

Chris Richardson, Navico:

1. Price
2. Profile/cut accuracy (volume)
3. Fixtures/SMT processing

Lee Siknee, Syntex Technology:

1. Printing inconsistencies
2. Conformal coating often uneven
3. Reflow challenges due to heat transfer

Roman Pesikov, JRPT Design:

1. Signal integrity of paths through flex and rigid parts of PCBs
2. Minimal bending radius for installing dynamic flex PCBs
3. Find good, inexpensive raw materials, MCAD and PCB CAD collaboration, etc.



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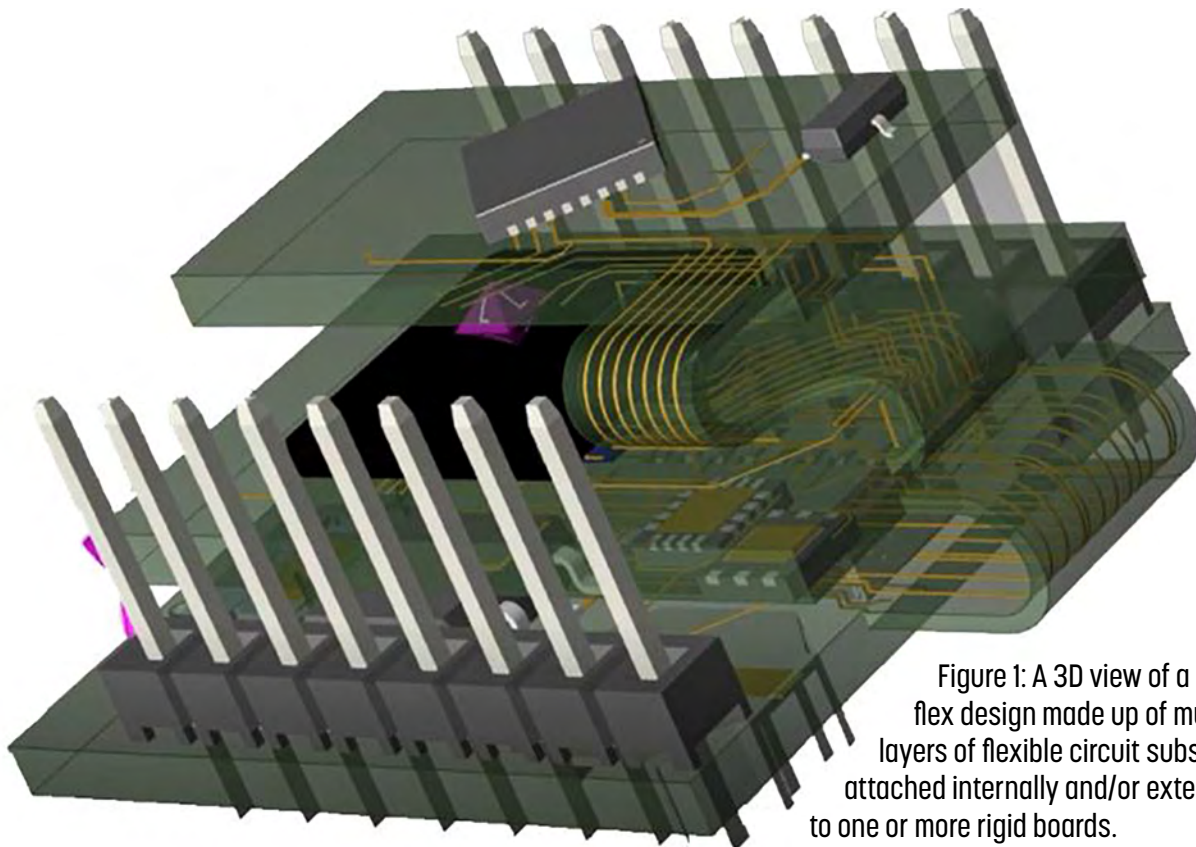


Figure 1: A 3D view of a rigid-flex design made up of multiple layers of flexible circuit substrates, attached internally and/or externally to one or more rigid boards.

Managing the Challenges of Flex and Rigid-Flex Design

Feature by Dave Wiens
MENTOR, A SIEMENS BUSINESS

PCB designers working with flex or rigid-flex technology face many potential risks that can derail a project and cause costly design failures. As the name implies, flex and rigid-flex designs comprise a combination of rigid and flexible board technologies made up of multiple layers of flexible circuit substrates, attached internally and/or externally to one or more rigid boards. These combinations provide flexibility for the PCB designer working on dense designs that require a specific form factor. Rigid-flex allows the PCB design team to cost-efficiently apply greater functionality to a smaller volume of space, while providing the mechanical stability required by most applications.

Rigid-flex technology is usually applied when a product needs to be compact, lightweight and/or flexible. Examples of end prod-

ucts where flex and rigid-flex systems are found include smartphones, modern televisions, digital cameras and laptops. As flex and rigid-flex boards are becoming more complex, modern design tools must be able to understand the unique design constructs and rules that surround these designs.

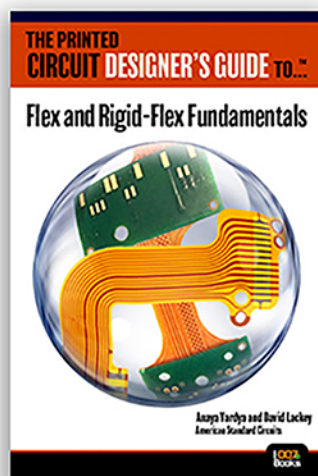
The Key Benefits of Flex and Rigid Flex

The major benefits of rigid-flex technology implementation and why design teams need to adopt this methodology include:

- Reduced cost and increased reliability by eliminating physical connectors used in the traditional “design-separately-then-assemble” approach to systems design
- Improved signal integrity through the removal of cross-sectional changes to the conductors (eliminating physical connectors and their associated solder connections)



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- Physical space requirement reduction since parts can be placed, and traces can be routed, in three dimensions
- Improved electromechanical functionality including dynamic bending, vibration and shock tolerance, heat resistance, and weight reduction

Flex and Rigid-Flex Design Challenges

In addition to the usual PCB design challenges, flex and flex-rigid PCB designers are faced with a long list of unique challenges that, unless properly managed, can lead to design failures, re-spins, and long-term reliability issues. Let's take a look at the key challenges:

- Multiple board outlines, each with separate layer stackups, require proper configuration throughout the design process in collaboration with both mechanical and electrical domains.
- Special layer stackup constructs for flex and rigid-flex designs vary, requiring the designer to efficiently manage them to ensure they are conveyed for proper fabrication.
- Bending and the 3D aspect of the folded assembly has its own set of requirements to maximize design reliability, including the need to route along curving boards without causing reliability issues due to metal stress.
- 3D rigid-flex-aware design rule checking (DRC) that understands specific flex-rigid rules including verification to identify potential design issues and space optimization.
- Signal and power integrity (SI and PI) of a multi stackup board requires an analysis tool to recognize flex-specific layers and local stackups.
- Flex fabrication output that safely conveys design intent to the fabricator is critical so feedback on material, stackup, bend requirements, stiffeners, keep-out regions, etc. is critical for high-reliability fabrication.

These are the constructs and requirements that must be met to deliver a design to the fab-

ricator and get a working board in return.

Traditionally, a designer would use his/her experience to navigate around these problems and apply workarounds as their PCB CAD tools failed to understand what was being designed. Many advanced designs were created using this method, but the chances for a successful design depended entirely on the skills and experience of the designer. No critical items can be overlooked which can easily lead to human-error, especially when under a tight deadline.

With designs becoming more and more complex, and an increasing demand for ever-shorter design times, designers are stretched too thin. Adding design support that understands the specifics around flex and rigid-flex, and guides the designer towards a correct design, becomes critical for success. However, the rigid-flex technology challenges themselves can be further exasperated if the electronic CAD tools utilized by the design team do not facilitate and ensure process compliance.

Best Practices and Guidelines

Today, education on terminology, requirements, processes and best practices are all critical to mitigate the challenges associated with rigid and rigid-flex design. For the PCB designer who must deal with rigid-flex designs requirements, here are guidelines and best practices for success:

- Be sure that the trace width and trace spacing are both as large as possible.
- Round corners should be used to route traces, and 90-degree corners should be avoided. The designer should make sure that the round corners are true arcs; segmented arcs will create stress fractures. In most cases, the trace contour should mimic the flex board outline contour. An ECAD tool that provides automatic trace routing to follow the board outline contour will save the designer a tremendous amount of time.
- If the design requires routing on more than one layer, be sure to stagger the traces for adjacent conductors.

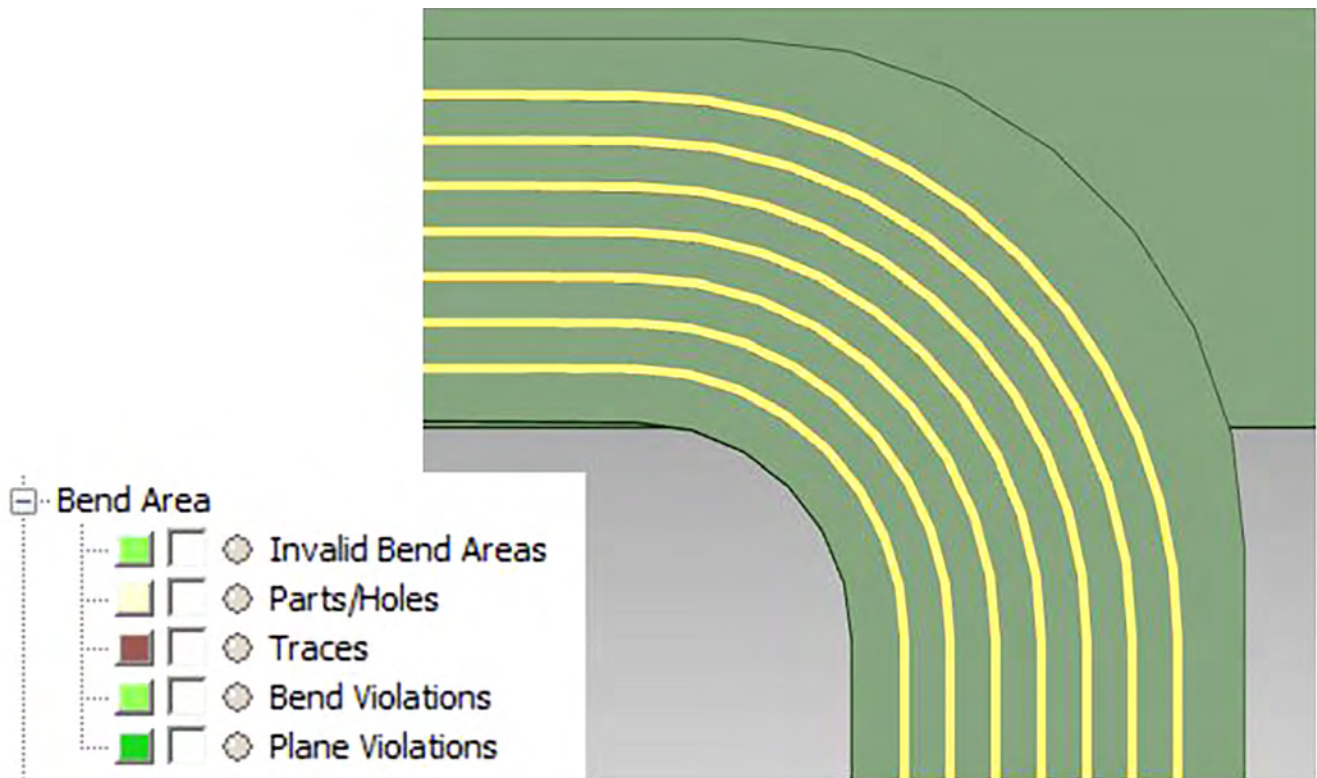


Figure 2: Rigid-flex bend area DRCs can help ensure process compliance.

- Cross-hatch power/ground planes as permitted by electrical requirements. Cross-hatching a plane has significant impact on the impedance of any conductor using it as a return path.
- If any portion of any flex requires a part such as a flex connector, plug, or jack, use stiffeners.
- For the flex bend region (the area of the flex that will bend or twist), which has its own set of fundamental best practices and guidelines, the designer can consider these best practices maximize reliability:
 - Never change the width of the traces within the region.
 - Be sure to distribute traces evenly.
 - Route traces perpendicular to the bend direction because any lack of symmetry will increase the chance of stress buildup.
 - Vias are not permitted within the region.
 - Hatched power/ground planes should be parallel with the region. Cross-hatched power/ground planes are preferred, however the cross-hatch pattern should be at a 45-degree angle in relation to the bend line. Using an ECAD tool that can calculate the cross-hatch angle in relation to the bend line (when creating the plane fill) can save time, particularly for designs with odd angle bend lines.
- It's critical to note that the bend radius calculation is likely the greatest challenge associated with the bend region, thus requiring close collaboration with the fabricator. Based on the application, the bend-radius requirements will vary. The flex will either be static (bend once during installation) or dynamic (bending can occur numerous times throughout the products lifespan).
- Static flexes will require a tighter bend radius than dynamic flexes. The bend radius is critical in order to avoid compression (area inside of the bend) or tension reliability issues.

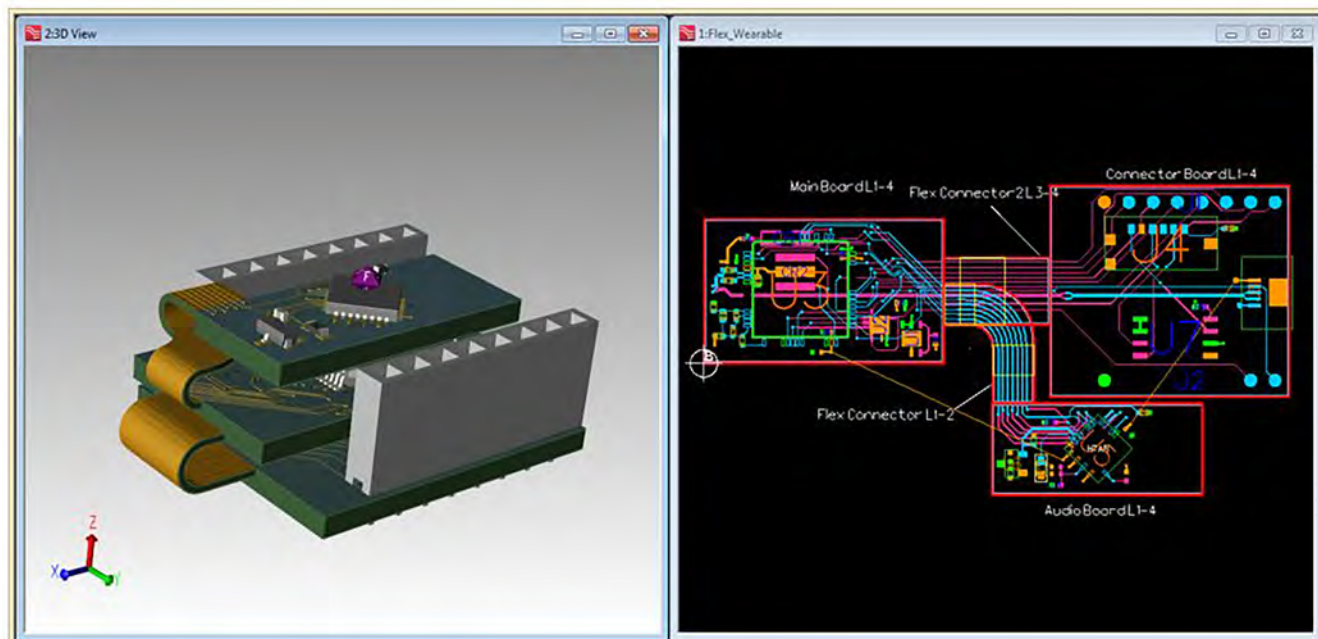


Figure 3: With the increasing complexity of today's flex circuits advanced design tools, such as Xpedition from Mentor, designers can increase user productivity and reduce development costs to ensure correct-by-construction design intent.

While these guidelines and best practices are not fully inclusive, they serve to help the designer who is new to managing flex and rigid-flex implementation. These tips will help the PCB designer better understand the unique qualities of flex and rigid-flex technology, which is useful for anyone how must manage even the simplest rigid-flex design. The PCB designer should also consider several aspects of flex technology with the fabricator, such as: impedance control, hole-to-interface distance (where the flex interfaces with the rigid), construction options, laminates and bonding materials, surface finish, and cover layer design. These were not covered in this article but should be researched for future reference.

ECAD Design Tools for Flex and Rigid-Flex Design

As the more traditional “design separately, then assemble” approach moves to current generation rigid-flex design, product development teams should explore using advanced ECAD design tools for flex and rigid-flex designs. Today's robust electronic design tools, such as the Xpedition and PADS Professional

flows from Mentor, can improve productivity by making it easy to set up flex and rigid-flex designs, implementing changes to stackup and outlines. By supporting true 3D design and verification, not just 3D viewing, such ECAD tools can help users deliver robust, non-ambiguous fabrication outlook. To ensure first-time production success, validation can be performed considering rigid-flex-specific constructs that impact signal/power/thermal integrity and manufacturability. This results in improved productivity and reduced development costs to ensure correct-by-construction design intent. **FLEX007**



Dave Wiens is Xpedition product marketing manager for the Board Systems Division of Mentor, a Siemens Business. Over the past 30 years, he has held various engineering, marketing and management positions within the EDA industry.

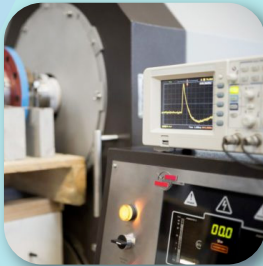


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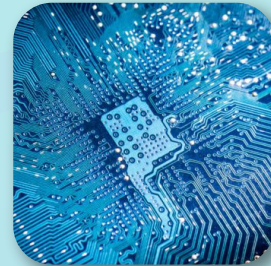
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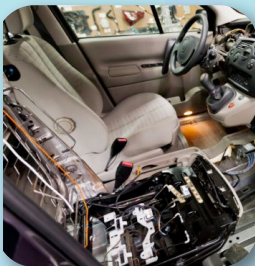
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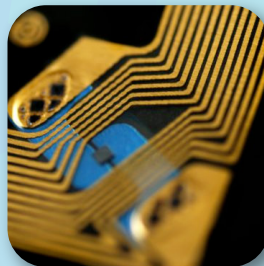
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Prototron Stretches into the Flex Arena

Interview by Barry Matties
I-CONNECT007

Barry Matties recently spoke with Prototron President Dave Ryder and General Manager Kim O'Neil about their Tucson, Arizona, shop's transition to flex and rigid-flex boards. They discussed the process that this move has entailed, what services OEMs are seeking in a flex manufacturer, and some of the biggest challenges and successes they've seen so far with flex circuits.

Barry Matties: Kim, tell us a little about your background.

Kim O'Neil: This is my 40th year in printed circuits. I started out at Sperry Flight Systems as a laminator and a plater. I moved to Digital Equipment Corporation in the Tempe, Arizona area when they bought a facility there, and I was a part of the startup team for that. Then I had a short time at a shop in Stockton, California. From there, I went to work at Continental Circuits Corporation (C3) in Tempe. It was a great experience participating as that company grew.

After 12 years, I went to Teradyne in San Diego, where they were starting up a back-panel shop. I thought we were going to stay there, but unfortunately in 2001, the crunch came, and they closed the shop. In 2003, I got a call from Jim Simpson, the GM at Prototron, and he offered me this position. I've been here for 15 years.

Matties: Please tell us a little bit about Prototron Tucson.

O'Neil: Prototron Circuits in Tucson has been open since 1999. One of our niches is that about 30% of our orders are on specialty material in the RF microwave world. We've run polyimide almost every day, and we thought that flex and rigid-flex would be a natural evolution for us. It turns out they were, and we've had some great success.

Matties: What are the challenges that you've bumped into regarding producing flex?

O'Neil: I think it's just working with these thinner materials. We had to adapt some of our equipment to work with the thinner materials,

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and to get the press cycles correct. We had the Schmoll representative here to help us with the drilling. We had some issues with registration in the beginning, and we took care of that with the operators and how they were laying up the flex.

Matties: So you're selling flex now?

O'Neil: Yes. We've done up to eight layers of regular flex, and single- and double-sided, so we're anticipating selling rigid-flex here really quickly. In fact, we are quoting an order today.

Matties: From a customer's point of view, what is it that they're looking for from a flex supplier?



Kim O'Neil

O'Neil: They're looking for quality and time. Our standard lead time is five days for non-flex work. Customers know when they come to Prototron that they can depend on us to deliver on time. Our on-time matrix is extremely important to everyone within Prototron. As we continue to expand

into flex, short lead times will be just as important as they are with our rigid products.

Matties: Right now, you said you're doing flex and you're just starting the rigid-flex. What's that process been like for you?

O'Neil: I've been very fortunate to have an engineer who just happened to show up one day, and he's really been spearheading this move to flex. He's been hand-walking things through and also teaching the operators the ins and outs of manufacturing with flex. He's had extensive experience in flex, and he was a really good find for us.

Matties: What I'm hearing is, it's material handling and operator training?

O'Neil: Exactly. That's the key.

Matties: And in terms of the training, what sort have you had to focus on?

O'Neil: We've focused in on lamination and imaging. Like I said, we had a little issue with drilling that really took some care. For etching, we do two-core and three-core FR-4. Much of the RF/microwave materials we work with can act almost like rubber, and handling can be an issue with those, too. Plating and etching weren't a problem; it was mainly lamination and imaging. We're focusing more on using coverlays instead of the solder mask. The solder masking cycle time is longer, and although we do it, we prefer using coverlay vs. solder mask.

Matties: In your 40 years, have there been any moments that really stick out as highlights or surprises along the way?

O'Neil: One or two. When I was at C3, surface mount was making its way into the market, and the company got into that business early. That market grew quite a bit during those times. It was a great opportunity to work the challenges of technology and production. Also, that was my first exposure to quick turns. We had an individual group within the company that would run a prototype for a customer and then follow up with the production. That was kind of a novel concept back then. Not so novel these days, of course. Coming to work at Prototron and learning about materials has been a nice highlight. Before I came here I was strictly working with FR-4. I had read about microwave materials and processing, but I'd never been involved in any manufacturing. It was a great opportunity to learn manufacturing with these types of materials. Those two phases would stick out for me. It's nice when you're a bit senior in the industry and you get an opportunity to learn something new and challenging.

Obviously being exposed to really quick turns is completely different. I told Dave Ryder that when I was working in production we would have eight-week lead times or longer. When I first looked at the WIP here, there were just two days filled up and there wasn't anything

behind that. That was a little bit scary. But it just fills up. You just have to do it that way and get used to that. That's a wonderful thing that you can offer customers, the ability to be on time. Not just saying you're doing it but actually doing it.

Matties: Dave, from a business strategy point of view, what's the drive here?

Dave Ryder: Well, for the last couple of years we've had a number of customers just start throwing us the RFQs regarding flex and rigid-flex products, and we really weren't able to do too much with that. We built some thin-core stuff as far as bendable boards, but not true flex. I would say about a year ago, the guys down in Tucson took it upon themselves to start playing around with some single- and double-sided flex at that point, and customers seemed to be responsive to that and we've seen a number of RFQs. We were doing some of that through an offshore partner, and so the timing is just right for the rigid-flex product as well as the flex. So I think that it's going to be well-received by the customers.

Matties: That's one of the largest growing areas of the board industry. Are there any specific markets that you're targeting?

O'Neil: Not at this time. We are qualified to MIL-PRF-31032. It's not that difficult to expand your slash sheets. We will be looking to expand there. That is one particular market to look at. Also with our certification to AS9100 a year ago, Aerospace is another market segment we are interested in. Close to 70% of our customers in Tucson are from those two market segments.

Matties: So from a buyer's point of view, are you seeing any of the "wait and see" attitude before a customer starts buying flex from a company that's just starting off in flex?

O'Neil: That is a concern, but several of the customers whom we are already doing business with are beginning to find out that we can do

flex. That is a product that they need. There may be some hesitation at first, but I believe the reputation Prototron has for quality, on-time delivery and customer service have taken that out of the equation. So yes, maybe a little bit, but with their past experience with Prototron I believe they're actually enthused that we can step into another market.

Matties: And how many years have you been in business, Dave?

Ryder: I've been doing this for 31 years.

Matties: You have 31 years of reputation to back you up, so it's not like they're just going to a new facility.

Ryder: No. These will be the same customers we've been doing business with for years, and in some cases, decades. And so I don't think it'll be a big leap as long as we deliver the goods. At the end of the day, that's really what they're looking for. We're already on the AVL with these customers, so it's not a big leap for them in most cases. Certainly they'll keep an eye on us, which they should.



Dave Ryder

Matties: And as your reputation as a top-level flex producer reaches into the marketplace, obviously your customer base will grow.

Ryder: That should go hand in hand.

O'Neil: Absolutely.

Matties: Thank you both very much for your time.

O'Neil: Thank you.

Ryder: Thanks. I appreciate it. FLEX007

How Flex Can Help Circuits Keep a Low Profile

Flexible Thinking

by Joe Fjelstad, VERDANT ELECTRONICS

Flexible circuits have played an invaluable role in the world of electronics design since they were introduced, typically to make dynamic interconnections between rigid islands of electronic circuits. However, one of the benefits of flexible circuits most recently taken advantage of on a regular basis is as preferred medium for making electronic products thinner. And electronic products of many different types have benefited. Perhaps the greatest users and beneficiaries of flexible circuits' low profile have been the now ubiquitous smartphones that both enable and often dominate many aspects of our lives.

This trend towards making products smaller has been going on for years and is unlikely to abate any time soon. They have arguably created a whole new meaning to the term "Keeping a low profile."

While flex circuits have played—and will continue to play—an important role in keeping things thin, they will need some help from the other elements of the electronic interconnection hierarchy to continue the drive to make products ever thinner and smaller. A key technological partner in that drive is the semiconductor industry. Today, semiconductor wafers are being thinned down to 25 μm and in some cases, even thinner. Interestingly, the limits of feature size reduction, once deemed hard stops, continue to be passed through due to the efforts of creative semiconductor engineers.

These had been concerns owing to the fact that thinned wafers tend to warp and can even





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roll up like a newspaper due to the structural differences of the opposing sides. IC packages, including wafer level packages, have helped to hold the thickness reduction gains with minimal increases in overall thickness. Moreover, wafer stacking has redefined the possible as 3D assemblies become a more prominent solution to the density challenge.

Another element in the effort is passive device technology. Embedded passive technology has long been a partner in the creation of lower-profile assemblies, though it was not the original intent. Embedded passives were originally seen as a way to free up circuit real estate on the surface of PCBs. They have proven especially attractive in applications such as analog circuit applications that are often populated with myriad discrete devices. The problem is exacerbated by the fact that the “bleeding edge” devices have become so small as to be virtually indistinguishable from “fly specks.” This makes assembly a challenge, relative to both pick-and-place and soldering.

Still, discrete devices have an attractive feature that exceeds the limits of most of their embedded brethren alternatives. Specifically, they can be built to better tolerance and are less prone to drift over time. The result is that there have been a number of efforts to embed discrete passive devices into the circuit board. To date, all known efforts have focused on use of standard devices with traditional planar orientations which increase the need for more exacting placement accuracy and more expensive placement equipment, leaving the door open to improvements.

One attractive alternative is to create discrete devices, both passive and active, which are thin and have a vertical orientation for connection by design. The concept of

a vertical orientation for an embedded resistor was envisioned and had been implemented, however a structural variation described in U.S. Patent No. 7,049,929 is arguably more practical. However, an interesting alternative concept involves the creation of vertically-oriented discrete components. These prospective alternative devices offer the combined benefits of discrete devices along with the surface space savings and a higher degree of flexibility for the design of dense circuit assemblies.

Low Profile Discrete Device Assembly

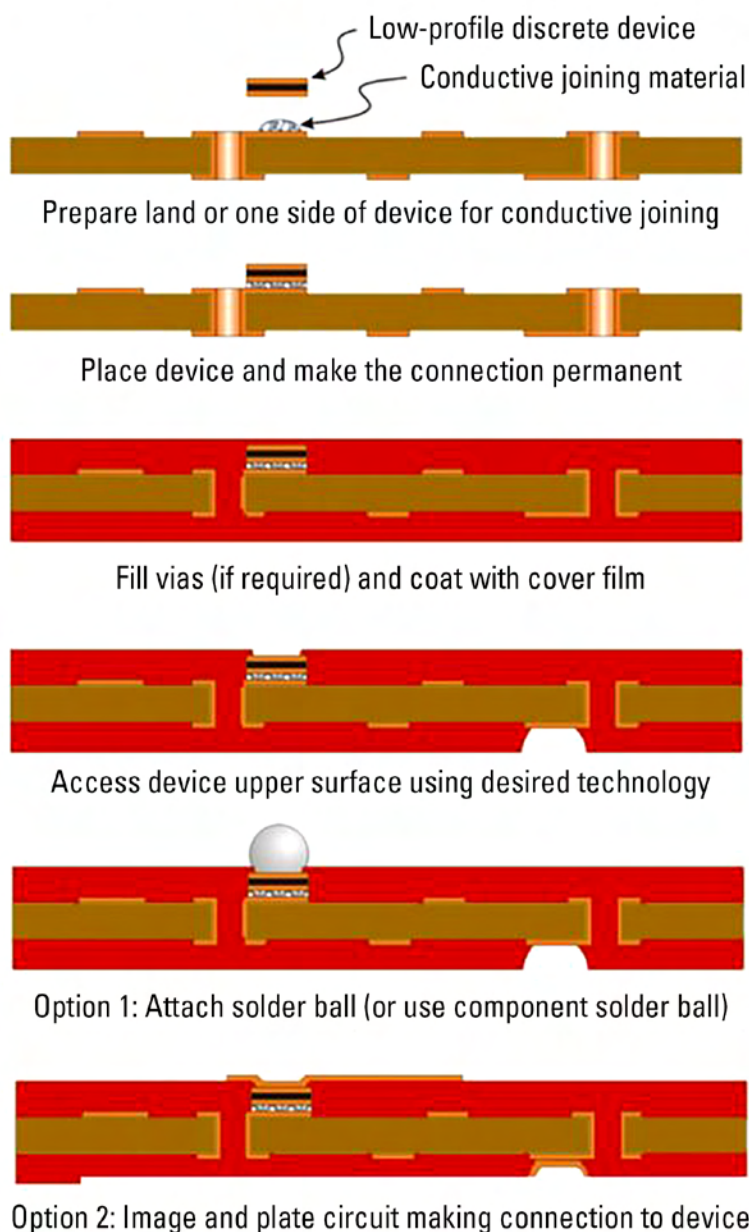


Figure 1: Examples of low-profile flex construction and assembly.

With continuing advances in materials sciences and especially with what has been developing with nanotechnology, it becomes possible to create devices that have a range of resistive and capacitive values that should meet a broad range of design needs. For example, materials with dielectric constants such as $\text{MgNbO}_3 + \text{PbTiO}_3$ claim values of about 22,600. Thus small, thin devices could provide substantial capacitance. It could also ease the dependence on large-sheet distributed capacitor technologies first implemented in the 1970s. Resistor technology, especially, those of low value and precision, and having minimal tolerance concerns are also good candidates for such design. However, one can be reasonably confident that greater precision and tolerance devices should become increasingly available over time.

Vertically-oriented discrete devices suited for embedment into circuits as anticipated here will require some modest changes in the circuit manufacturing process, but there exists capital equipment presently capable to handle the task. Moreover, concerns over rotation and accuracy should be reduced. An example of prospective constructions and a process for assembly can be seen in Figure 1.

In summary, the desire for ever-thinner electronics will continue on into the future and lower limits will continue to be found. It is likely that the solutions described, along with those processes that eschew the use of solder, a significant contributor to overall assembly height, will find important roles in helping electronic products keep a low profile in the years ahead. **FLEX007**



Joe Fjelstad, a founder of Verdant Electronics, is an international authority and innovator in the field of electronic interconnection and packaging technologies with more than 150 U.S. patents issued or

pending. He is the author of *Flexible Circuit Technology* and author, co-author or editor of several other books including *Chip Scale Packaging for Modern Electronics*.

The Future of Electronics is Chemical

Molecular electronics, which aims to use molecules to build electronic devices, could be the answer. But until now, scientists haven't been able to make a stable device platform for these molecules to sit inside which could reliably connect with the molecules, exploit their ability to respond to a current, and be easily mass-produced.

An international team of researchers, including Macquarie University's Associate Professor Koushik Venkatesan, have developed a proof of concept device which they say addresses all these issues. The team exploited the fact that metallic nanoparticles can provide reliable electrical contacts to individual molecules, allowing them to transport charge through a circuit.

"Imagine a miniaturised transistor made up of several single molecules," says Koushik. "That's the promise of molecular electronics—devices that are smaller, faster, have more memory and are cheaper to make."

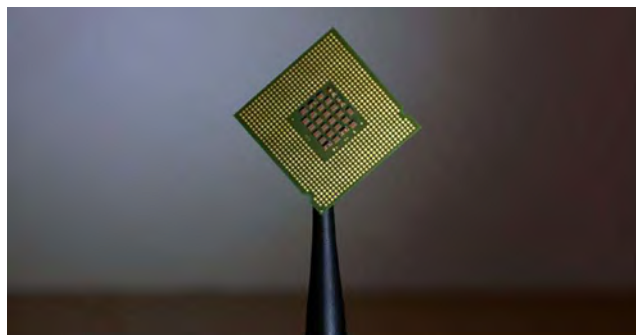
Koushik is confident their research will open up the bottleneck for this molecular-based technology to move forward.

"This fundamental research is extremely exciting as it points the way to practically 'wiring molecules' by exploiting the fact that Koushik and his colleagues have made a metallic nanoparticle provide a reliable electrical contact to individual molecules," says Professor Alison Rodger, Head of the Department of Molecular Sciences at Macquarie University.

"It is amazing to think that this work leads the way to true molecular-sized electronic circuits."

The paper was co-authored by researchers from Macquarie University, IBM Research - Zurich, the University of Basel, the University of Zurich, Karlsruhe Institute of Technology and Sun Yat-Sen University.

Source: Macquarie University.



Acrylic vs. Epoxy Adhesives for Flexible Circuits

Consider This

by John Talbot, TRAMONTO CIRCUITS

Once only suited for specialty applications, flexible circuits are found in many household electronic products today. Product developers worldwide have designed flexible circuits into some of the newest products, as well as improved versions of existing products. In some cases, the flexible circuits replace the traditional printed circuit boards that have dominated our electronics for decades.

Many times, flexible circuits are chosen instead of traditional rigid boards to make a product smaller or lighter, or both. A common statement from a PCB designer using a flexible circuit for the first time is, “We know nothing about flexible circuit design or materials. Can you help us define the stackup?” Often, that first design and stackup is used as a standard for their designs moving forward. And it makes sense because that’s what we’ve been doing for traditional PCBs for a very long time.

However, the flexible circuit is a different product. There are options when choosing the correct materials for the application. It is valuable to know these options as well as their advantages or disadvantages.

In this column, we’ll discuss one of the most misunderstood materials in flexible circuit fabrication: the adhesive system used to laminate the layers together. Since flexible circuits go through several lamination processes, it’s important to know the options and where best to use them in your electronic products.

Identify the Application: Dynamic or Static

Two of the most common applications for flexible circuits are static and dynamic. A static scenario is one where the flexible circuit is put into place, even if it has to flex to get there, and then remains static throughout the lifetime of the product. A dynamic application is one where the flexible circuit is in motion





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during the lifetime of the product. Think of a flip phone, a printer, or an MRI machine. A flexible circuit used in a static operation can be thought of as a derivative of the traditional PCB, albeit lighter and more malleable. However, in a dynamic application the circuit must be, not only flexible, but robustly so. We must be able to exploit all of the inherent advantages of the materials to their fullest extent. In either of these cases the adhesive plays an important role. Let's review another factor that affects the choice of adhesive.

Identify the Environment

The environment where the product will reside during the majority of its lifecycle also enters into the adhesive choice. Will the environment be excessively hot or cold? Will the circuit be immersed in water or chemicals? Does the circuit need to be flame retardant or not? These are all questions that may make a difference in the adhesive system chosen

**These are all questions
that may make a difference
in the adhesive system
chosen for the circuit.**

for the circuit. For instance, if the circuit will or can be immersed in water, we'll want to choose an adhesive system that is the least absorptive. If the circuit will be used in an application that will see it covered in chemicals or biological fluids, we'll want the most chemical-resistant system. If the circuit will see higher than ambient temperatures, we'll want an adhesive that performs well at those temperatures without any degradation of the lamination. Does the circuit need to perform to UL94 V.0? That is, must the circuit be flame retardant as in automotive or aerospace applications? All of these concerns must be addressed when choosing the adhesive system for your flexible circuit.

Design Matters

Surprisingly, the design of the circuit matters as well when choosing an adhesive system. If the circuit will be single-sided (one layer of copper) or double-sided (two layers of copper), then either adhesive system will perform equally well, all other criteria being equal. However, if the design will be a multilayered circuit, then the characteristics of the adhesive have a significant effect. Small plated through-holes less than 8 mils in diameter may also have an effect on the performance of the circuit if the wrong adhesive is chosen.

As you can see, there is a lot to consider when deciding on an adhesive-based system for your flexible circuit. Now, let's discuss some of the properties for both types of systems and see how they relate to the discussion above.

Acrylic Adhesive: Pros and Cons

Acrylic adhesive is the best choice for dynamic applications because it stays malleable after it is cured. That is its most valuable characteristic. That is, unless, it must be flame retardant. In order for acrylic adhesive to comply with UL94 V.0, brominated flame retardants must be added which reduces the reliability for dynamic flexing. It reduces the thermal stability as well. Acrylics do not perform well at higher temperatures either. The material starts to soften in the 180–200°C range, which can cause delamination of the insulating layers as well as the copper traces. Acrylic doesn't perform well for wire bond designs either. The softer adhesive tends to absorb the ultrasonic wire bonding energy causing difficulties in the assembly process. And finally, it has a higher coefficient of expansion. This causes movement in the Z-axis which means that it is not a good choice for multilayer circuits because of the damage that could be done to plated through-holes.

Epoxy Adhesive: Pros and Cons

Epoxy adhesive, on the other hand, is not a good choice for dynamic operations because it cures hard. However, that makes it a better choice for a lot of other applications. For instance, it has the best bond strength at high

temperatures and has a low coefficient of expansion, making it a great choice for multilayer designs and circuits that will reside in higher temperatures. It is also very good for wire bond designs because it cures hard and doesn't absorb the ultrasonic energy the way acrylic adhesives do. Epoxy-based adhesives have great chemical resistance and better moisture absorption rates making it a good choice for medical applications and moisture sensors of all kinds.

Using Acrylic and Epoxy in the Same Design

In the case of a multilayer rigid-flex hybrid circuit, both adhesives may be used in the same circuit. For instance, the flexible portion of the circuit may use acrylic adhesive for flexibility and the multilayer rigid section may use epoxy adhesive because of its increased stability.

Reliability of Acrylic vs. Epoxy

Clearly, both types of adhesive systems have their ideal uses. Both are reliable and perform

well as long as the applications they're used in are considered carefully. Both adhesives are used frequently to manufacture flexible circuits. Some designers insist on acrylic adhesives because the first vendor they worked with called it out on their design.

However, it's prudent to consider the application and the specifications seriously before you decide on an adhesive system for your flexible circuit application. There are times when either system will work equally well and times when the decision means the difference between a robust circuit or one that performs poorly without an obvious cause. Consider this the next time you design a flexible circuit. **FLEX007**



John Talbot is president and owner of Tramonto Circuits.

A Step Closer to Single-Atom Data Storage

As our data-storage needs are increasing at a rate of almost 15 million gigabytes per day, scientists are turning to alternative storage devices. In a new study published in *Physical Review Letters*, physicists at EPFL's Institute of Physics have used Scanning Tunneling Microscopy to demonstrate the stability of a magnet consisting of a single atom of holmium, an element they have been working with for years.

"Single-atom magnets offer an interesting perspective because quantum mechanics may offer shortcuts across

their stability barriers that we could exploit in the future," says EPFL's Fabian Natterer who is the paper's first author. "This would be the last piece of the puzzle to atomic data recording."

Using a scanning tunneling microscope, which can "see" atoms on surfaces, the scientists found that the holmium atoms could retain their magnetization in a magnetic field exceeding 8 Tesla, which is around the strength of magnets used in the Large Hadron Collider. The authors describe this as "record-breaking coercivity," a term that describes the ability of a magnet to withstand an external magnetic field without becoming demagnetized.

"Research in the miniaturization of magnetic bits has focused heavily on magnetic bistability," says Natterer. "We have demonstrated that the smallest bits can indeed be extremely stable, but next we need to learn how to write information to those bits more effectively to overcome the magnetic 'trilemma' of magnetic recording: stability, writability, and signal-to-noise ratio."

Source: EPFL News.



When is Rigid-Flex the Best Solution?

Flex Time

by Bob Burns, PRINTED CIRCUITS

We started this series with a [column](#) that addressed why rigid-flex boards cost more than hard boards and flex boards. It may seem like an odd place to start, but it is the predominant question we are asked when working with OEMs.

As a board designer, you know that there are times when rigid boards are the perfect solution, and there are times when a flex circuit is ideal. But there are also times when a rigid-flex board will give you a performance advantage that more than offsets the additional cost. This column will cover the most common applications where rigid-flex boards outperform other packaging solutions.



Photo Credit: U.S. Air Force, Tech. Sgt. Gregory Brook.



Photo Credit: US Army, 3rd SFG (A) Combat Camera.

Advantages of Rigid-Flex

If rigid-flex boards cost more, why should you ever consider using them as your packaging method?

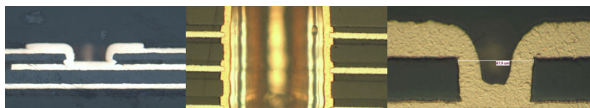
There are five reasons that we get a call to work on a project: high-shock applications, high-vibration environments, high-density packaging, space and weight savings, and designs that must connect four or more rigid sections into a continuous unit.

Rigid-flex packaging originally developed as a solution for high-shock environments. Military and space applications needed systems that could survive extremely high g-forces, and rigid-flex provides that kind of survivabil-

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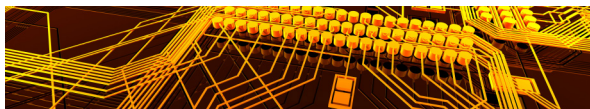
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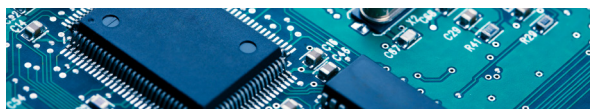
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ity. It was initially used on weapons guidance systems, military avionics, missiles, satellites, detonation hardware and other applications where the electronics must survive extreme shock—sometimes tens of thousands of g’s—and not fail. Traditional connectors and flex cables just can’t do that.

Because the flex part of the board extends all the way through the rigid sections of the board, rigid-flex boards can take enormous punishment and still remain functional. It is

Because the flex part of the board extends all the way through the rigid sections of the board, rigid-flex boards can take enormous punishment and still remain functional.

the preferred packaging method for missiles, jet fighters, ruggedized military cameras, and all method of weapons systems, including optics for conventional rifles and mortar launchers. More recently, rigid-flex is being applied to unmanned vehicles/war fighters, drones, underwater vehicles, remote/unattended ground sensors dropped from aircraft, and other creative uses.

It’s easy to overlook rigid-flex if you don’t think your product is subjected to high g-forces. But everyday items can have pretty tough duty cycles as well. We had a commercial application a few years ago for a camera module—a very simple rigid-flex

board. One of the customer’s key test vehicles operated akin to tumbling the device in a clothes dryer until it failed. The rigid-flex boards never failed, but the traditional connectors with flex cables eventually did. The difference was significant enough that the mean time between failure on their products had a dramatic reduction, saving the company much more than the initial outlay for the rigid-flex boards.

High-vibration environments also prove the worth of rigid-flex packaging, again finding wide use in missiles, space systems, and weapons that have to endure high shock and high vibration. But they have also been commonly used in electronics for helicopters, aircraft anti-lock brake systems, ruggedized cameras/infrared cameras, displays, aircraft autopilots, avionics and other electronics. Some of the more unusual applications we have worked on include a dog collar, a bicycle computer, a ruggedized solid-state hard drive, and a very thin, lightweight 12-layer board for a robot that climbs into volcanoes and reports until it expires.

Rigid-flex for high-density applications fall into two general categories. The first is when there simply is no more room for connectors, and when every precious square inch is necessary for components. We see this a lot in implantable pacemakers/defibrillators, diabetes pumps, hearing aids, cameras, video cameras, military heads-up displays, goggles and vision systems. One of

the more creative uses of rigid-flex boards is the Medtronic Pill Cam, a camera that is swallowed like a pill to allow physicians to diagnose Crohn’s disease and other intestinal ailments.

The second use of rigid-flex in high-density applications occurs when there still may be enough room for connectors and flex cables, but the designer is trying to get the



Figure 1: Rigid-flex boards allow the electronics to fit to the form of the device.



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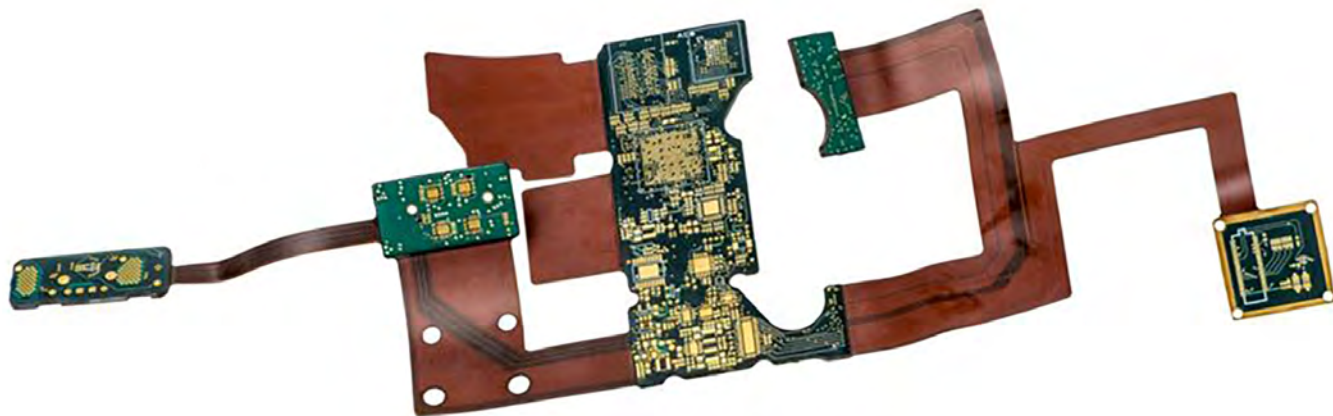


Figure 2: Rigid-flex is ideal for applications with four or more rigid boards and usually can reduce the cost of these designs.

electronics to fit into a certain form. This is pretty common in handheld medical devices, robotics, unmanned vehicles, “pigs” that are designed to inspect pipelines for weak points, and wearable electronics. Figure 1 is one example of a motherboard, with plenty of room for components, but the electronics needed to fit within a specific form factor.

One of the most often overlooked aspects of rigid-flex is that it often can cost a lot less than traditional packaging methods. Whenever you are considering a design with four or more rigid boards, it would be wise to at least consider rigid-flex packaging. It offers all of the advantages listed earlier for extreme high-reliability electronic packaging, and rigid-flex can also save money if you consider the total cost of packaging.

When you have four or more hard boards connected with flex cables and connectors, or wire harnesses, or standoff connectors, the cost of the other packaging components begins to add up. At a certain point a rigid-flex design with the same capabilities will reach a tipping point where it is cheaper to build with rigid-flex than to build the fully assembled equivalent using conventional packaging. It also is much easier and faster to assemble. Rigid-flex boards are often provided in a rigid array that holds the board stable during assembly, which is then removed after assembly. It is very fast, very efficient, and doesn’t require subsequent hand assembly. We see this frequently in cameras, robotic applications, insulin pumps, and other

electronics where the designer needs to connect more than just a few rigid boards together.

Some other advantages to using rigid-flex that are often forgotten are space and weight savings. Rigid-flex boards can be made very thin, often under .020”, providing you with high-density connectivity at the lowest possible weight. This makes it ideal for drones, avionics, and space flight applications. There is also an electrical advantage to using rigid-flex: As clock speeds get faster and faster, rigid-flex, with its integrated interconnect between rigid layers and flex, reduces noise loss (attenuation) by eliminating connectors, where much of the loss can occur.

Designers have found rigid-flex packaging to be the right solution for ruggedized laptop computers, servers that require hot swappable daughter cards without shutting down, automotive LED electronics, and all manner of ruggedized industrial applications such as bar code scanners.

Rigid-flex designs give the electronics design engineer a unique method of packaging, which is ideal in those applications where hardboards, flex circuits and their interconnections are not enough, and a greater reliability is required.

FLEX007



Bob Burns is national sales and marketing manager for Printed Circuits.

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The Learning Curve: Your First Flex Circuit

Flex Talk

by Tara Dunn, OMNI PCB

Can you relate to this? You are tackling your first flexible circuit design. It is a simple circuit, with just two layers. Lines and space are generous, the hole size isn't pushing any limits, and this seems like a perfect design to cut your teeth on.

You do your research, complete the layout, send the design package in for a quotation and then place the order, confident in the process. There are a few engineering questions related to materials, and you make a note for future applications: Be more specific about the coverlay requirements and whether flexible solder mask or film-based coverlay is needed.

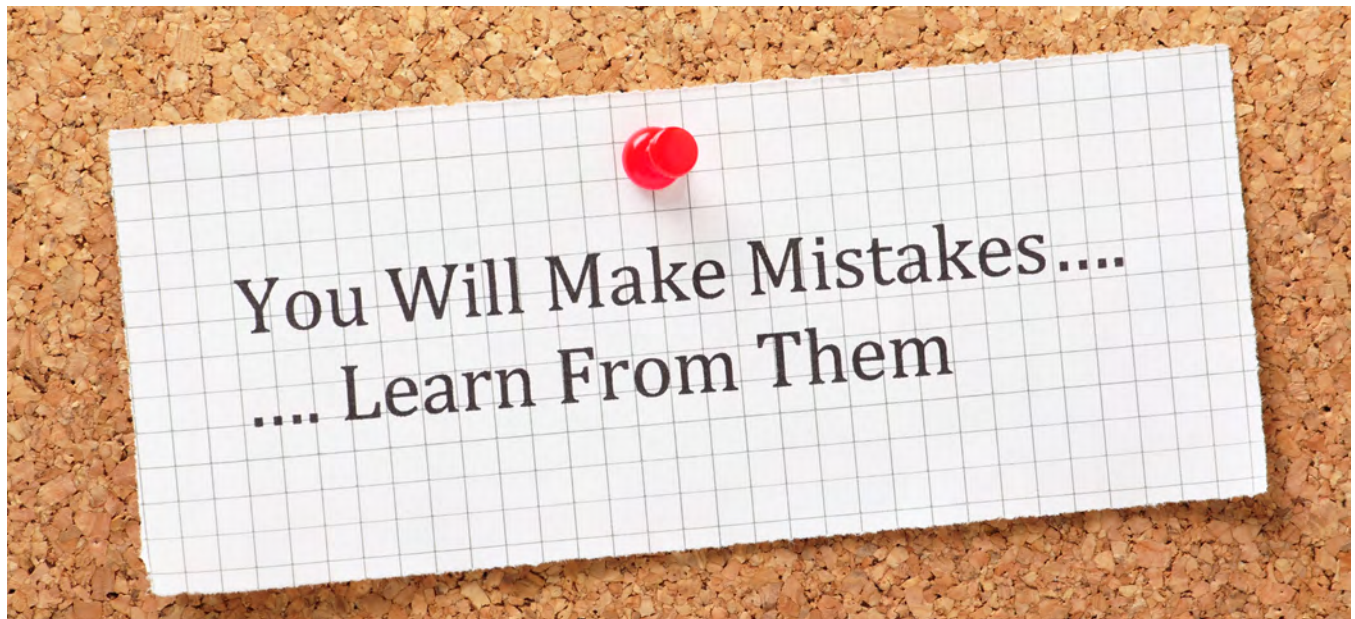
Things are going smoothly. The circuits are delivered, assembled, installed right on schedule. But something isn't working. Now the fun begins—troubleshooting. Where do you start? After the painful process is complete, you discover that one of the components was too heavy and bulky for the flexible circuit to

support without reinforcement and traces had been broken during installation. A quick redesign adds a rigidized stiffener, the circuits are ordered again, and the project moves forward. In my experience through the years, when first working with flexible circuits or rigid-flex circuits, this is a learning curve that everyone goes through.

With this learning curve in mind, I reached out to customers and industry friends to ask them to share some of their first experiences with flex, “gotcha” moments and advice for those new to flexible circuit design. A few common themes stood out.

Materials

Material selection is critical in some designs, especially dynamically flexing applications, and anecdotal information tells the story that the options available are more complicated than one would anticipate when first work-





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ing with flex. Several decisions must be made: RA or ED copper, adhesive-based materials, or adhesiveless materials, copper thickness, dielectric thickness, coverlay or flexible solder mask, what type of stiffener, polyimide or FR-4? Skill and knowledge is required to balance those decisions with the end use of the circuit, available materials, and cost.

There were a few stories about “the flex that didn’t flex” when a multilayer stack-up became so thick there was no way to bend the circuit without cracking the copper. This seems to be a common occurrence—it has happened to me in the past! As a side note, most were resolved using unbonded layers in the stack-up.

There were a few stories about “the flex that didn’t flex” when a multilayer stack-up became so thick there was no way to bend the circuit without cracking the copper.

Another common message was that material lead time seems to be longer than expected, with more questions about the stack-up than anticipated. It is true there are a lot of variables in inventory, preferences, and capabilities between fabricators. The piece of advice given most often was, “Work with your fabricator during the design and to understand their capabilities.” Great advice.

Conductor Routing

Conductor routing practices was another category that stood out in the conversations about lessons learned. Nearly everyone has a story about cracked traces and the learning curve they went through to be confident in the flex design and performance. A flexible circuit is a hybrid of mechanical and electrical design. This introduces a lot of variables.

I’ll share one story that stood out. The application required a double-sided circuit that was expected to be flexed during installation and test, but not over the life of the product. The first design used solid copper for shielding and was manufactured with adhesive-based materials. It cracked in the bend area during installation.

Several new ideas were implemented for the second revision. The traces were rerouted perpendicular to the bend area, materials were changed to adhesiveless, and cross-hatch shielding was added. These are all great options for improving flexibility. The second revision cracked in the same location.

For the third revision, traces were routed to just one side of the bend area, and all copper was removed in that area. In addition, polyimide stiffeners were added to help more specifically direct where the bend was occurring. Even though all the best practices were employed in this design, the third revision cracked also. The problem was resolved when they realized that the circuit was not just absorbing the stress from the known bend area, but as the unit was working stress was being applied in another axis. A slight redesign of the unit eliminated the cracking. This had to be a painful and frustrating experience for all involved, but it also was a good lesson in ways to improve the flexibility in any design.

I received a lot of real-world advice for conductor routing. A few of the key items included: avoid abrupt changes in conductor size and direction, route conductors uniformly and perpendicular to the bend area, add radius to all inside corners, make pad patterns bigger to add stress relief, and add anchoring tie points to the solder pads to reduce the opportunity for pad lifting during assembly.

Improving Flexibility

Another common topic of discussion was the learning curve for options to improve flexibility. The previous example provides many tips and tricks pertaining to conductor routing. Wisdom was shared for additional options to consider, especially relevant for dynamically flexing and applications and when tighter than

recommended bend radiuses are required. To share a few key pieces of advice, consider removing material in the bend area; this could be cut-outs in the circuit or removing coverlay and adhesive to provide a thinner package. Eliminate the ED copper in a design by requesting button plating for your design and adding copper only to the plated through-holes, not the rest of the panel. Add stiffeners to move stress points to other areas in the package that may be better able to withstand the stress.

This process was certainly interesting. Everyone seems to have a favorite story of lessons learned when starting to work with flexible circuits. Most are told with a slightly humorous spin after the fact, but I am certain it felt anything but funny at the time. Flexible circuits are a growing portion of the PCB market and more and more applications are expected to require flexible circuits.

For those new to flex, or anyone considering using a flexible circuit in their next design, there was one piece of advice that was repeated by nearly everyone I spoke to: Work with your fabricator early in the design. I couldn't agree more with that advice. Not only will this help avoid material availability issues, your fabricators work with flexible circuit designs day after day and are happy to share their experience to help ensure the product works as you intend it. Take advantage of the expertise! **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 to contact Dunn, [click here](#).

NASA, Partners, Advance In-Space Assembly Robotics

A robotic arm moving a solar array up and down along a space structure sounds like a scene from a science fiction movie, but it's just another day in the office for NASA engineers. This week marked the last in a series of ground tests demonstrating the capabilities of the Tendon Actuated Lightweight In-Space MANipulator (TALISMAN) robotic arm; the Strut Assembly, Manufacturing, Utility & Robotic Aid (SAMURAI); and the NASA INtelligent Jigging and Assembly Robot (NINJAR) components of the Commercial Infrastructure for Robotic Assembly and Services (CIRAS) project.

Earlier this year, the team of engineers manipulated the newer, longer arm back and forth from folded to extended positions to demonstrate that it is fully operational, then they showed it could pull a truss out from being stowed in a compartment. In this demonstration, the TALISMAN arm was used to move a solar array from one truss section to another and to install the array.

SAMURAI, the robotic hand that passes truss parts, and NINJAR, the jigging robot that holds the pieces in place while they are fastened, have similarly been put to the test this year. The team first used a remote control to operate

the two robots and assemble truss segments. This most recent test accomplished an autonomous truss build, using only code and no remote control.

CIRAS is a part of the In-Space Robotic Manufacturing and Assembly (IRMA) project portfolio, managed by NASA's Technology Demonstration Missions Program and sponsored by NASA's Space Technology Mission Directorate.

Source: Nasa.gov.



Flex Circuits: More Than Just a PCB

All About Flex

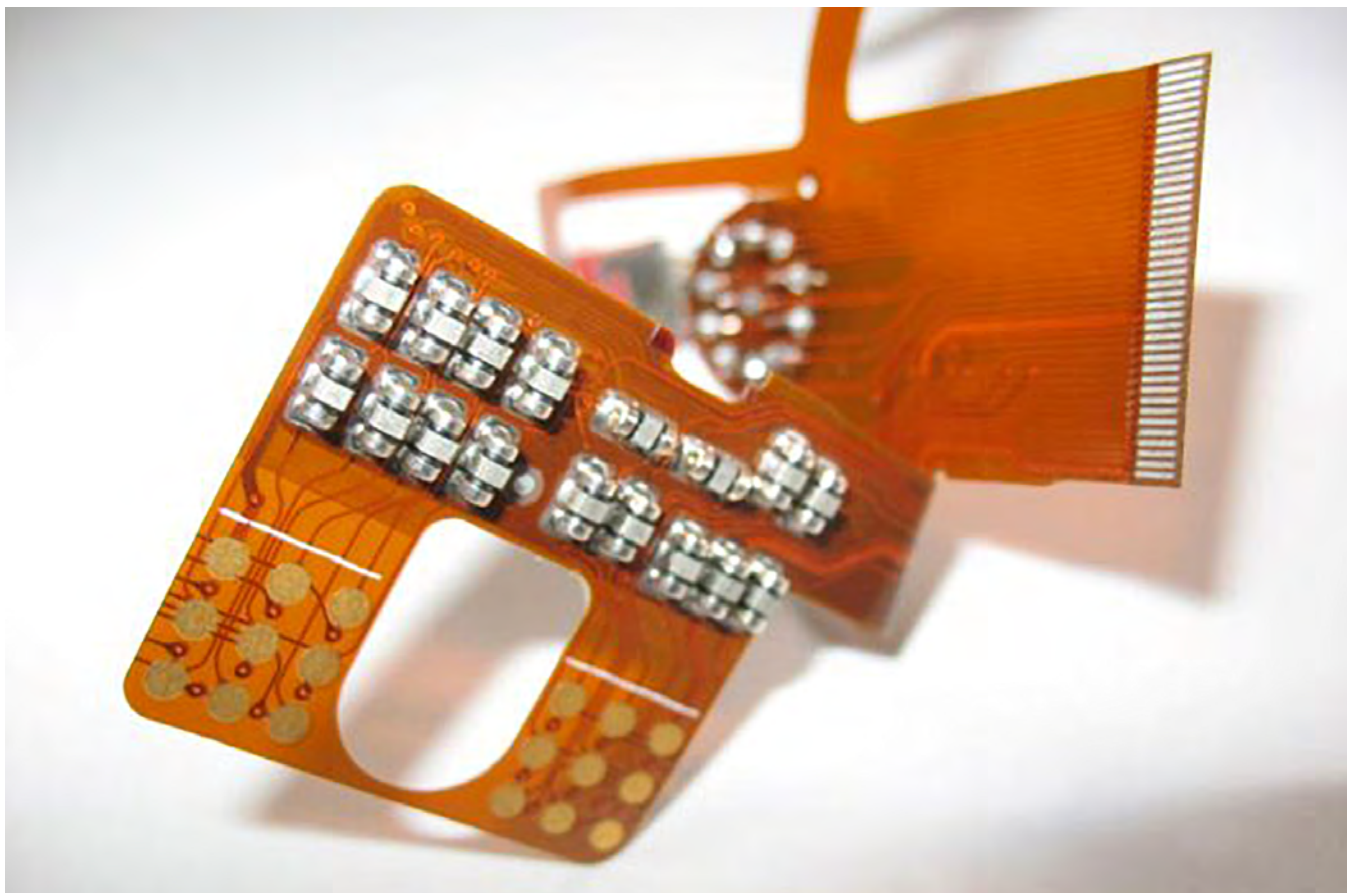
by Jahn Stopperan, ALL FLEX

Approaching 20 years ago, the PCB industry endured a major shift from domestic sourcing to offshore fabrication. Yet since then, the flexible circuit sourcing map has remained fairly constant. Why is that?

The primary reason is that flexible circuits are more than just PCBs. Yes, a flexible circuit performs the function of an interconnect and active substrate for control logic and signal distribution like a PCB does. But a flex performs a significant mechanical function on top of its PCB function. Even to be economically feasible, a flexible circuit needs to bring more to the

game than a rigid PCB. It needs to eliminate connectors, fit into small spaces, weigh less, withstand high temperatures, perform in harsh environmental conditions, handle flexing/movement, dissipate heat, survive in unusual chemistries or gasses, and provide increased reliability by eliminating connection points. Without one or more of these additional functional requirements, a flex is more expensive.

But what does this have to do with the flex industry remaining entrenched in the USA? The answer is that in order for flexible circuits to perform these other mechanical duties, they



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In addition to the technical education and networking on **September 13**, **IPC E-Textiles 2018** will also be host to an open-forum **IPC E-Textiles Committee Meeting on September 12**. Plan to arrive a day early to meet with others from your field to brainstorm standards and test methods needs and learn how to influence industry standards being developed by the IPC E-Textiles Committee.

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Flexible circuits will incorporate different:
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• Foil types
• Base film types
• Base film thicknesses
• Interlayer bonding adhesives and bonding methods (adhesiveless for example)
• Mounting adhesives
• Mechanical support materials and rigidizing methods

Table 1: Flex circuits are similar to rigid PCBs, with these important exceptions.

typically incorporate a wide range of material options. There are hundreds of different flexible circuit constructions that all fit under the general category of a “flexible circuit.” Each flexible circuit is customized not only in shape and electrical interconnect design; it is also customized with the materials that meet the supplemental specific application requirements of the OEM, many of which were mentioned earlier.

In addition to these material selection options, there is also a long list of design-related features that are incorporated into the conductive pattern. These look to address potential reliability issues that may surface due to the environmental and mechanical forces the flex is subjected to.

For instance, a very specific material may be needed for the flexible circuit to withstand exposure to a unique chemical within an application. However, that material may have thermal expansion characteristics that can impact plated through-hole integrity. Another example may be a flex circuit design that requires dynamic flexing, but the layout has sharp corners or plated through-holes in the flex zone that can introduce reliability problems.

Unfortunately for the OEM, this wide combination of material options and reliable design knowledge for the application-specific solution is something that only an experienced flex circuit manufacturer with high material science expertise can address.

Furthermore, individual designers and engineers at OEMs are not in a position to be knowledgeable about the ever-changing material solutions and the unique flex circuit design considerations compared to the flex manufacturer. The OEM designer may be involved in a flex circuit design once every two years, likely designing significantly more rigid PCBs for his company’s product development work. Such infrequency does not enable the designer

to become an expert in flex circuits and all of their options to solve different problems that arise. He has no choice but to rely on the flexible circuit manufacturer for this expertise and guidance.

With rigid PCBs, the OEMs don’t have to worry about the supplemental mechanical elements woven into a flexible circuit application. The rigid PCB industry is nearly identical from one manufacturer to another; once the PCB is completed, it can be shopped around to the cheapest source. In addition, the board itself remains identical in construction no matter who builds it so the risk of introducing a problem by selecting an alternative supplier to the PCB is low.

But with flex, the unique characteristics of the flexible circuit created by the material choices and design factors can change even with minor or unpredictable differences from one flex manufacturer to another. For instance, one flexible circuit manufacturer may standardize on one type of bond ply that is ‘equivalent’ to another according to the manufacturer of the bond ply. Yet, unknowingly, the two have different behaviors when subjected to the OEM’s specific application and one fails. This is a risk an OEM can’t afford to take by changing from one flex supplier to another. The original flexible circuit has proven to meet the challenges of the application through the OEM’s testing protocol and making a switch to another vendor could introduce something

disastrous. Even the electrical properties can be impacted.

A third factor is the speed of new product development taking place in the market. The life cycle and product life of almost all devices and new products has condensed dramatically in the last several decades. OEMs expect delivery windows of their vendors to be in alignment with the speed of their own development work, which is faster than ever. This introduces hurdles for off-shore suppliers in becoming the chosen flexible circuit supplier early in the design phases such as responsiveness, time zone differences, communication obstacles, and delivery. Once the flexible circuit engineering and customization has been solved and is successfully tested even within the prototype phase, OEMs have difficulty rationalizing the potential cost savings of changing to an offshore supplier vs. the economic impact of a significant problem that may be introduced due to the change.

As discussed, the flex industry is strong in the U.S., not because of one single factor, but as a result of a combination of items: the flexible circuit addressing key mechanical functions, the OEMs' need to utilize the knowledge and expertise of the flex supplier to solve the mechanical functions, the potential hidden risk of mechanical issues surfaces when changing vendors, and the speed of OEM product development cycles. For OEMs, understanding that a flex circuit is more than a PCB is an important ingredient in the sourcing equation. In addition and particularly for flex circuit applications that have non-traditional functions and application areas, OEMs should also recognize the critical factor of working with a flex supplier that is an expert in material sciences. **FLEX007**



Jahn Stopperan is a marketing executive for All Flex Flexible Circuits. He is taking over this column following the retirement of his colleague Dave Becker.

The Pros and Cons of Artificial Intelligence

AI is set to trigger a major transformation in society. A new study on the opportunities and risks of AI is now being conducted on behalf of TA-Swiss.

Artificial intelligence (AI) is not just about the irritatingly charming face of a humanoid robot gazing inquisitively at us. In stark contrast to the talking, humanoid machine Sophia, which is capable of learning and was introduced to the world by a Hong Kong company last year, we encounter AI every single day in a form that cannot be pinpointed physically, such as when our actions on the internet generate data, from which companies draw their conclusions.

However, AI also begs questions of social relevance that go way beyond data protection. What if algorithms replace human decisions, trade on the stock exchange or influence voter habits? That's why the Swiss Center for Technological Assessment (TA-Swiss) recently commissioned three research institutes to study the new challenges. Until 2019 a team at Empa is compiling specific action recommendations for Swiss politics and industry in this extremely dynamic field.

"We are currently examining the opportunities and risks for innovations, research and education that are associated with AI," says Clemens Mader from Empa's Technology and Society lab in St. Gallen.

One of the tasks facing the scientists is now to study possible applications of AI in scientific research and as a driver for innovation. "The use of learning algorithms should be discussed where large data quantities accumulate and the analysis of complex correlations is promising, for instance," says the researcher.

Source: Science and Technology Research News.





Flex007 Highlights



Flex Talk: E-Textiles—The Wild Frontier ►

Tara Dunn recently sat down with Connie Huffa, textile engineer and principal of Fab-designs. Her current work is focused on photovoltaic, conductive and smart fabrications. Connie shared some thought-provoking e-textile applications and her experience in this developing market.

EIPC 50th Anniversary Conference Day 2: The Past, the Present and the Future, Pt. 1 ►

Speaker Micha Perlman of Orbotech predicted that automotive electronics would place new demands on the PCB industry: HDI was predicted to grow from zero to over 15% of the total HDI market by 2020, high-power systems would require heavy copper, and flex and flex-rigid harnesses would replace conventional wiring.

Flexible Substrates Market Worth \$775.8 Million by 2023 ►

The flexible substrates market is projected to grow from \$402.9 million in 2018 to \$775.8 million by 2023, at a CAGR of 14% from 2018 to 2023. The growth of the flexible substrates market can be attributed to the rising demand for flexible displays from the electronics industry.

Flex Time: Why is Rigid-Flex So Expensive? ►

One question that I hear fairly often, particularly after an initial quotation, is “Why is rigid-flex so expensive?” In this article, I’ll share with you the cost drivers in rigid-flex relative to standard rigid boards and flex circuits with stiffeners. A typical rigid-flex PWB will cost about seven times the cost of the same design on a hard board. Why?

All Flex Introduces Thermal Controller ►

The AFTC-5000 utilizes a single-button interface providing both OEMs and end-users with the ability to easily adjust the thermal settings. The controller provides six temperature setting increments that are pre-programmed by All Flex per the customer’s specific requirements.

Atotech Introduces Cupracid Flex and InPro Flex ►

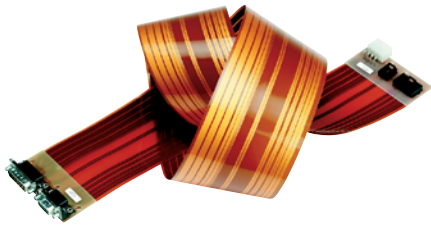
Atotech has developed two new acid copper processes—InPro Flex and Cupracid Flex—to serve the flexible printed circuit board market and support its customers to overcome the current technical barriers in FPCB manufacturing. The two simple additive processes can be analyzed by standard CVS methods.

RMAs: Negative Experience or Valuable Opportunity? ►

In the flexible circuit industry (and any other industry, for that matter), there are times when all the material delivered to the customer fails to meet the specifications. Non-conforming material that is sent back by the customer can easily be interpreted as a negative experience. However, if it is perceived as an opportunity to learn and support the customer it becomes a much more pleasant and satisfying endeavor.

Printed Circuits Upgrades Photo Department ►

“We purchased a 16-watt laser direct imager a few years back and needed to add capacity, particularly for inner and outer layer photoimaging,” said Matt Tannehill, executive vice president at Printed Circuits. “The new LDI uses LSO, or large scan optics, for very high throughput with excellent quality at the same time, which is critical for our customers’ success.”



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Events Calendar

IEEE Int'l Flexible Electronics Technology Conference ▶

August 7–9, 2018
Ottawa, Ontario, Canada

PCB West 2018 ▶

September 11–13, 2018
Santa Clara, California, USA

IPC E-Textiles 2018 Workshop ▶

September 13, 2018
Des Plaines, Illinois, USA

electronica India & productronica India ▶

September 26–28, 2018
Bengaluru, India

electronicAsia 2018 ▶

October 13–16, 2018
Hong Kong

SMTA International ▶

October 16–17, 2018
Rosemont, Illinois, USA

TPCA Show 2018 ▶

October 24–26, 2018
Taipei, Taiwan

electronica 2018 ▶

November 13–16, 2018
Munich, Germany

IDTechEx Show ▶

November 14–15, 2018
Santa Clara, California, USA

HKPCA/IPC International Printed Circuit & South China Fair ▶

December 5–7, 2018
Shenzhen, China

48th NEPCON JAPAN ▶

January 16–18, 2019
Tokyo Big Sight, Japan

IPC APEX EXPO Conference and Exhibition ▶

January 26–31, 2019
San Diego, California, USA

Additional Event Calendars



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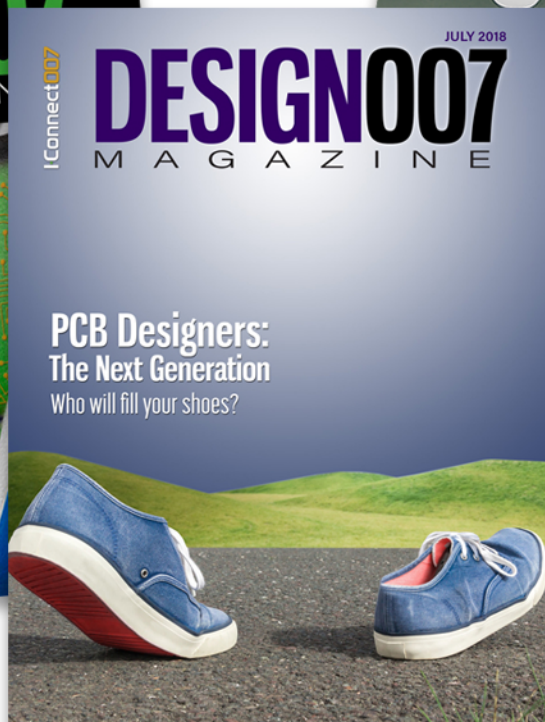


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