I-Connect007

Quarterly | April 2019

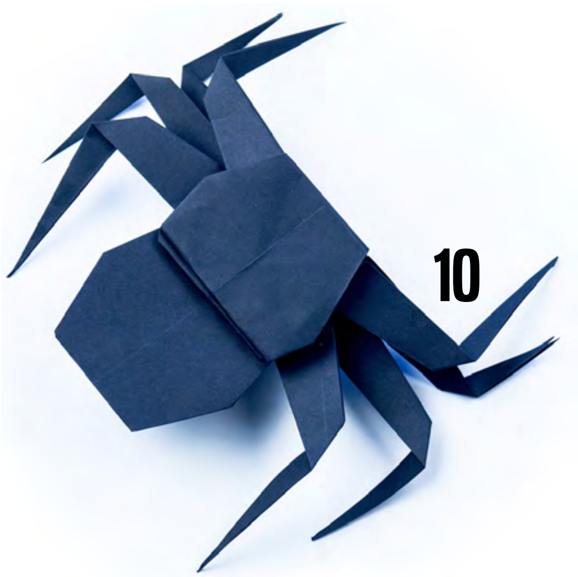
FLEX007 MAGAZINE

flexible thinking

from start to finish

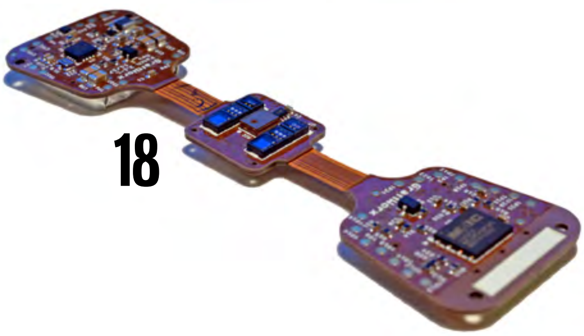

PASSPORT

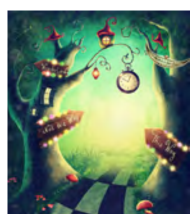
FLEX007 MAGAZINE

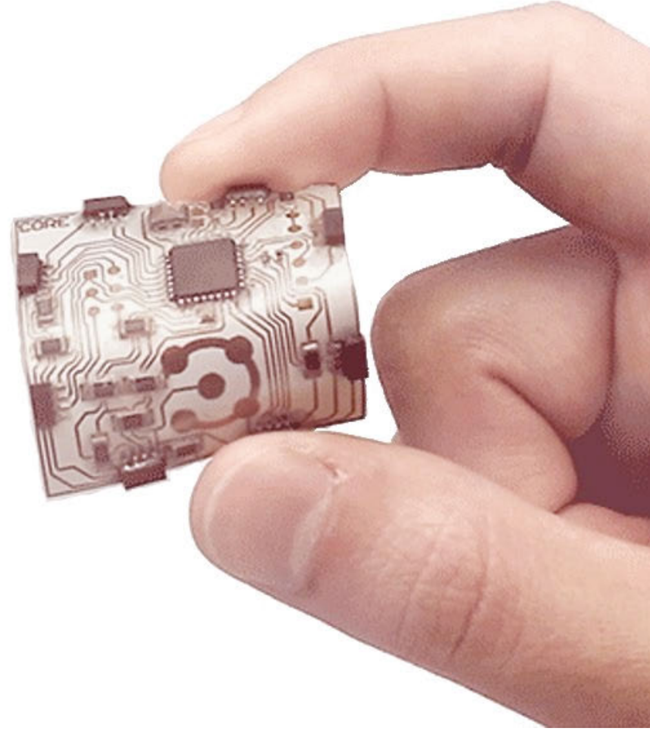


Concept to Completion

How does one get from the concept and design of a flex circuit to the final product, especially when that product is pushing the limits of technology, is an unusual shape, has a short time-to-market, or all of the above? We have articles and columns to help with that, but the main takeaway is: Team up with your supplier and customer and work together for the optimal solution. Plus, in this issue you'll learn more about 3D printing and how it fits with flex.







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FLEX007 MAGAZINE

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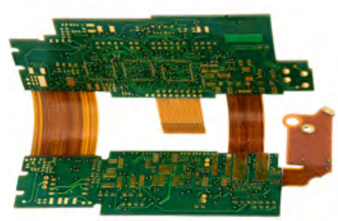


DEPARTMENTS:

From Start to Finish

Patty's Perspective

by Patty Goldman, I-CONNECT007

I could also say, "From Beginning to End," though that is not quite the same meaning. Our topic this month is "From Design Through Final Product" as it pertains to flexible and rigid-flex circuits. Because designing a circuit to fit in the envisioned space and perform as intended can be far from simple or obvious—but you already know that. In fact, not being a designer, I can't imagine designing a simple circuit, let alone one that must bend or fold into a shape and space that may be just an idea in an inventor's mind.

But of course, it is done every day by many of our readers. Is it easy for you? Our goal in this issue is to provide insights into how best to accomplish the seemingly daunting task—and with a new and different design each time. A lot of it boils down to one factor: work with your supplier and customer. You are a team, and you need to think and work together as a team with one goal: an elegantly designed product produced in a reasonable time at a reasonable cost (or at least a reasonable future cost).

Interested in some good advice? Read on!

We start with an informative article by Bose's Todd MacFadden, a designer becoming increasingly familiar with flexible circuits. He presents three short case studies of prototype designs that, in his words, "didn't go so well" as lessons for you, dear reader.

Next is a great interview with Anthony Flannery and Amit Rushi of GraftWorx and Lenthor's David Moody and Rich Clemente. They discuss their partnership developing a wearable sensor that required much teamwork and a rigidized flex solution.

Following that is an article by Anthony Flannery explaining their fluid management patch and the story behind it. Needless to say, working closely with Lenthor paid off with an elegant design that was both highly functional and comfortable on the patient's arm.

In his inimitable way, Joe Fjelstad begins his missive with a quote from *Alice's Adventures in Wonderland* by Lewis Carroll to bring awareness to some of the issues to consider when designing flex circuits—a subject he has written about extensively in his free book.

Printed Circuits' Bob Burns follows with some solid advice for non-standard rigid-flex designs, which can present process difficulties, such as asymmetrical layups and pouch constructions, that require extra care for good yields.

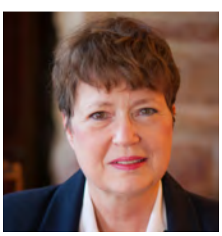
You may have already heard the news that DuPont Electronics and Imaging is investing in their Ohio facility. We interviewed Andy Kannurpatti, the leader of DuPont's Interconnect Solutions in the West, to learn more about this and how they work with both OEMs and circuit fabricators.

The final three articles bring a broader perspective not only to flex circuits but to the electronics industry as a whole. There is no doubt that most of our industry is aware of the difficulty in finding young talent. In an interview with some key people at NextFlex, we learn about their FlexFactor initiative to help high school and college students see a future in electronics manufacturing.

Next, I-Connect007's Technical Editor Pete Starkey reviews a presentation from the AltiumLive summit in Munich by Sini Rytky and Tuomas Heikkilä of TactoTek in Finland. The subject is injection-molded structural electronics (IMSE), a technique for integrating flexible circuits and components into a three-dimensional molded structure.

And lastly, Optomec's Dr. Kurt Christenson discusses their 3D printing technology with I-Connect007 Publisher Barry Matties. This technology eliminates the need for wire bonding by printing interconnects on 3D surfaces—plus, there is the capability to 3D-print electronic components.

That brings us to the end of another *Flex007 Magazine*—one I hope you will enjoy and that will provide you with some valuable tidbits and insights. Our next issue will publish in July, but in the meantime, you can keep up to date with our sister publications *Design007 Magazine*, *PCB007 Magazine*, and *SMT007 Magazine* as well as our daily and weekly newsletters. Register and sign up for any or all of these free publications here to have them delivered right to your inbox. **FLEX007**



Patricia Goldman is managing editor of *Flex007 Magazine*. To contact Goldman, click here.

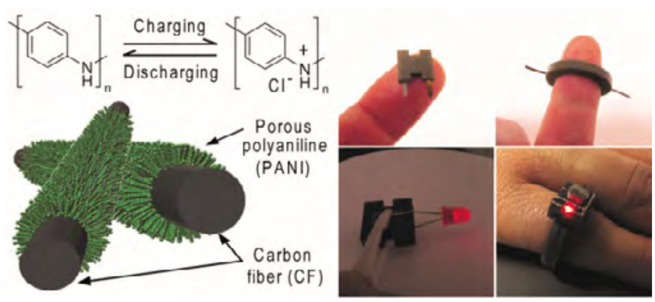
3D Printing Technology Enables Fabrication of Shape-conformable Batteries

Flexible, wireless electronic devices are rapidly emerging and have reached the level of commercialization; nevertheless, most battery shapes are limited to either spherical or rectangular structures, which results in inefficient use of space. Professor Il-Doo Kim's team from the Korea Advanced Institute of Science and Technology (KAIST) has successfully developed a technology to significantly enhance the variability of battery design through collaborative research with Professor Jennifer A. Lewis and her team from Harvard University.

The KAIST-Harvard research collaboration team successfully manufactured various kinds of battery shapes such as a ring-type and H and U shapes using 3D printing technology. Through the research collaboration with Dr. Youngmin Choi at the Korea Research Institute of Chemical Technology (KRICT), 3D-printed batteries were applied to small-scale wearable electronic devices.

The research group has adopted environmentally friendly aqueous zinc ion batteries to make customized battery packs. This system, which uses $Zn2+$ instead of $Li+$ as charge carriers, is much safer compared with the conventional lithium rechargeable batteries that use highly flammable organic electrolytes. The aqueous Zn-ion batteries are stable upon contact with atmospheric moisture and oxygen, can be fabricated in ambient air, and have advantages in packaging since plastic does not dissolve in water.

The cathode, based on conductive polyaniline consisting of a 3D structure, exhibits very fast charging speeds (50% of the charge in two minutes) and can be fabricated without the detachment of active cathode materials, so various battery forms with high mechanical stability can be manufactured. (Source: KAIST)



Learning to Be More Flexible: Case Studies on Improving FPC Design

Feature by Todd MacFadden
BOSE CORPORATION

Like most kids, I spent my childhood dreaming that someday when I grew up I would get to optimize the design and manufacturability of flexible printed circuits. I envisioned the fantastical circuit outlines that would look like a squashed tarantula in 2D, but would origami intricately and elegantly into impossibly small 3D spaces. And, like other kids, I imagined the rigorous training I would receive in school and on the job to teach me exactly what materials to select and what parameters to use to achieve magnificent, robust bends that would (obviously) conform generously to IPC bend radius guidelines.

OK, not really. As a child, I dreamed of being a famous musician, until I learned more about the supply and demand curves for mediocrity. And, as many of us who have done this know, there is no formal training and often no right answer or perfect solution for FPC design. The IPC design standards—such as IPC-2223: Sectional Design Standard for Flexible/Rigid-Flexible Printed Circuits and IPC-6013: Qualification and Performance Specification for Flexible/Rigid-Flexible Printed Boards—provide indispensable guidance and are justifiably the go-to starting place. But the authors of these standards are careful to distinguish between requirements and guidelines, and they acknowledge that the standards cannot possibly encompass all use cases.

This is increasingly true as miniaturization requirements force us to pack more functionality into ever-smaller packages, and it becomes more difficult to conform to IPC construction recommendations. Achieving robust FPCs requires frequent, iterative interaction internally among the mechanical, electrical, and PCB design teams, as well as with the fabricators and assemblers. The sooner in the design cycle we can engage the supplier and assembler, the better.

This article will present three case studies of early prototype designs that didn't go so well, and the lessons learned from each to highlight

some of the challenges we faced and the steps we took to overcome them.

Note: no tarantulas were harmed during the writing of this article or in the design of any circuits.

1. Bend Radius Recommendations—You're Joking, Right?

The bend radius recommendations from IPC-2223 (Table 1) provide a valiant starting place. But, increasingly, we are so far from these guidelines that design teams ask if we're joking when we suggest them. It is now more common than not for us to exceed them, and over time, we have learned to accommodate much tighter bends than what IPC recommends. But there have been painful lessons along the way; these recommendations exist for a reason.

Flex Circuit Construction		IPC-2223 Minimum Bend Radius Recommendations
Bend to Install (Static Bend)	1 Layer	10x circuit thickness
	2 Layer	10x circuit thickness
	Multilayer	20x circuit thickness
Dynamic Bend	1 Layer	100x circuit thickness
	2 Layer	150x circuit thickness
	>2 Layer	Not Recommended

Table 1: Bend radius recommendations from IPC-2223 Sectional Design Standard for Flexible/Rigid-Flexible Printed Circuits.

Figure 1 illustrates one particularly cringe-worthy example. This is a 3-layer circuit (for simplicity, only Layer 2 is shown in the graphic) that is reduced to two layers in the bend regions. The conductors in the bend region were cracking at high rates during assembly. In hindsight, the design mistakes are glaring:

- **The tight bend radii are uncontrolled:** The two bends are respectively 1.0x and 1.5x the circuit thickness or about 10 times tighter than IPC guidelines. These are effectively creases. It is possible to crease 2-layer flexes, but the creasing operation must be well-controlled and only occur one time—creased circuits must never be reopened. Such care was not taken during this assembly process
- **The bends begin right at the stiffened region:** This is not recommended because it concentrates stress on the conductors. Ideally, there should be 0.5–1.0 mm of length after the stiffened region before a bend
- **Solder mask in the bend region:** The solder mask (3) extends beyond the stiffener (1) and into the flex region to accommodate a trace on Layer 1 (not shown in this graphic). Solder mask should always be supported by a stiffener with at least a

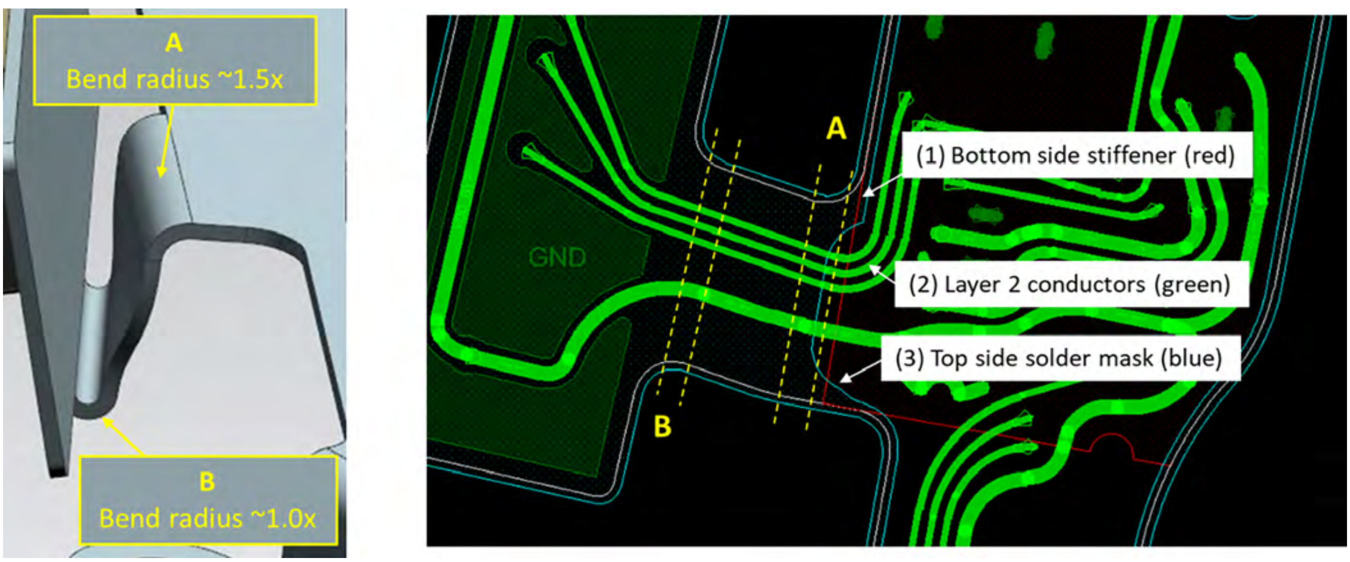


Figure 1: Design renderings of a recent FPC failure due to cracked traces, including a 3D illustration of the tight bends (L), and a snapshot of the Layer 2 routing (R), showing some of the features that contributed to the failure.

0.2-mm overlap to accommodate registration tolerance of both solder mask image and stiffener location. While the solder mask formulations used by most FPC fabricators are referred to as "flexible," they are not in fact designed to bend, particularly not this sharp. Having solder mask in the bend area increased circuit stiffness precisely where the bend began

Fortunately, these failures occurred during an early prototype run, so there was time to respond. The circuit was redesigned to address each of these issues; no subsequent failures were encountered. Figure 2 shows the revised design in which bend areas are relocated far from stiffened zones with SMT components. Moreover, modifications were made to the housing to relax the required bend radii. The revised design performed flawlessly.

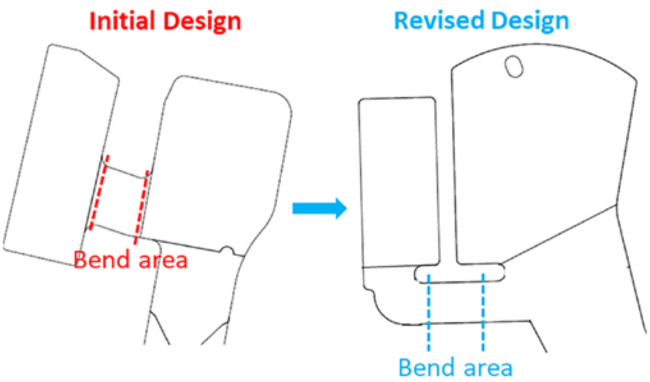


Figure 2: Outline of the circuit from Figure 1 comparing the original design that failed (L), and the modified version (R), which did not fail.

2. Everything Is Easy Until the First Unit Is Built

A flex circuit in a 3D CAD model looks predictable and well-behaved (Figure 3). Everything nests well, there is no mechanical interference, and the allotted tolerances seem generous. Of course, the reality can be quite different. Mechanical fixtures may, for example, be less precise than anticipated, operator access to housing recesses may be restricted, dispensing equipment may be obstructed, etc. Add to this the inconsistency and variability of human operators and the flex circuit can be exercised

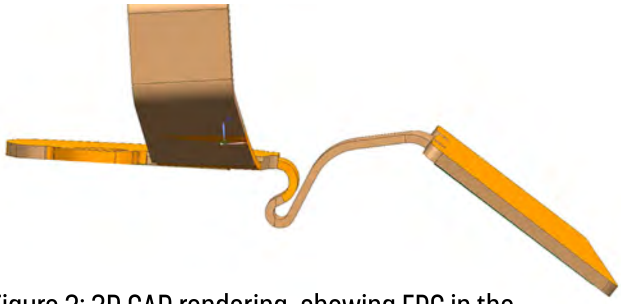


Figure 3: 3D CAD rendering, showing FPC in the installed position. The designed bends shown in this graphic are substantially different than the actual bends required during assembly.

in vastly different ways than expected.

Figure 4 shows the actual circuit from Figure 3 after it cracked during assembly, which required the FPC to be threaded through a cavity during insertion. The CAD model didn't predict this because of a complicated layering of operations that wasn't apparent until the first assembly. Due to a tight bend radius, a pre-bend of the FPC was required, but the assembly process essentially meant inverting the pre-bend and then re-bending, which was apparently enough to break the circuit.

Fortunately, this occurred early in development, allowing enough time to react. Modifications to the housing greatly improved accessibility and reduced the bend requirements. Working with the FPC fabricator, we changed the material stackup, which greatly increased the flexibility of the circuit.

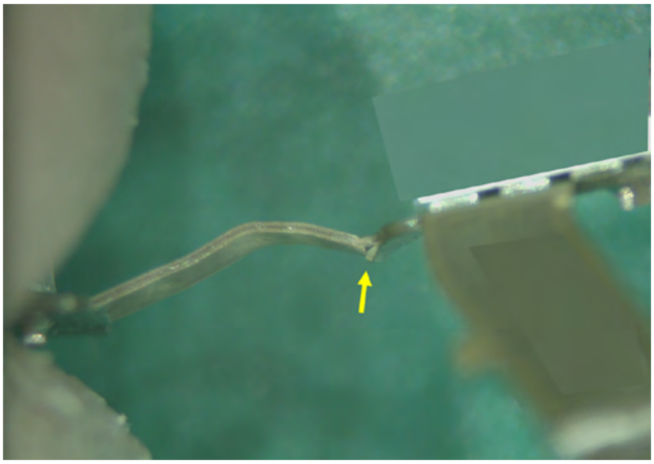


Figure 4: Yellow arrow points to a fracture in the circuit that occurred during assembly due to unanticipated bending and re-bending.

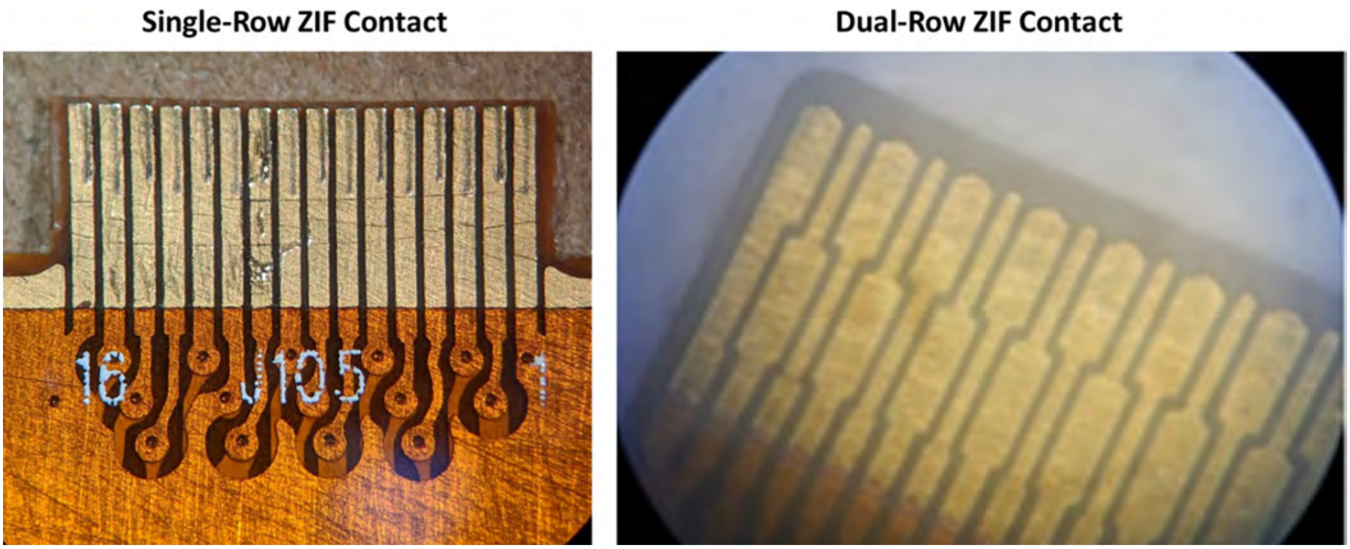


Figure 5: ZIF connectors are a popular method to terminate FPCs for interconnection with other circuits. The traditional single-row style (L) is increasingly being supplanted by dual-row versions (R), which can greatly reduce the connector footprint.

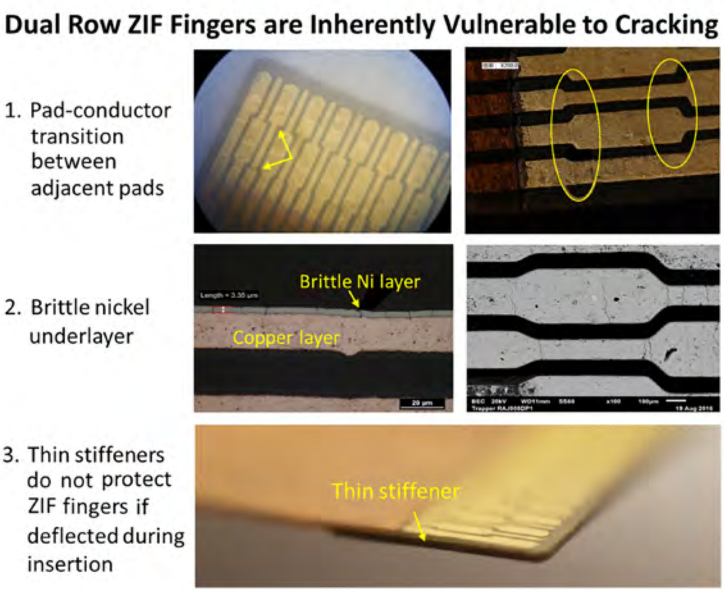


Figure 6: The design and construction of dual-row ZIF connectors makes them vulnerable to cracking.

3. Beware of the Dual-row ZIF Connector

Fine-pitch, dual-row zero insertion force (ZIF) connectors are becoming increasingly common because they greatly reduce the footprint area of an interconnection compared with single-row ZIF connectors (Figure 5). However, several inherent characteristics of dual-row ZIF fingers make them vulnerable to fracturing (Figure 6):

- **Pad-conductor transition:** The transition point where the pad narrows down to pass between adjacent pads is vulnerable to cracking
- **Brittle nickel underlayer:** The standard surface finish for ZIF contacts is electroless nickel immersion gold (ENIG), but nickel underplate is brittle, and cracks on this surface can translate through the copper underneath
- **Thin stiffeners:** In the quest to miniaturize, connector suppliers have responded by reducing the standoff height of the connector receptacle; therefore, the "stiffeners" on the opposite side of ZIF fingers are now so thin they act more like shims than stiffeners, offering little support

The consequence of these factors is that any misalignment during insertion that causes the end to fold or deflect, even moderately, can crack the fingers. In some cases, cracks in the copper conductors can be small, resulting in partial or intermittent connections that may not be detected during electrical test—the worst case of a walking wounded.

Because these are inherent characteristics of the ZIF contacts established by the ZIF con-

nector suppliers, they are not possible or practical to modify. Therefore, the end user must take steps in the design of the FPC and the housing to ensure the ZIF fingers are well-protected during assembly and in the field. Figure 7 highlights the key elements of a recent ZIF contact failure on early prototypes of a rigid-flex circuit:

- **A—Blind insertion:** This image shows the rigid-flex installed in position. The assembly process was challenging and required the operator to insert the ZIF end of the rigid-flex board (R) blindly into the ZIF receptacle under the PCB (L). After locking the ZIF receptacle, the operator would manually bend the rigid-flex into shape
- **B—Solid ground plane:** For signal integrity reasons, electrical designers called for a solid ground plane in the bottom side of the flex layer. But this made the flex region extremely stiff and put great strain on the locked ZIF fingers because of the manual bend
- **C—Vias in the bend region:** It is a big no-no to place plated vias of any kind in bend regions because they concentrate stress, and the vias here added even more stiffness to this flex area
- **D—Cracked finger:** This cross-section clearly shows a full crack through the nickel and copper layers. There were several failures during this build cycle, all with the same failure mode

Fortunately, as with the previous case studies, these ZIF failures occurred early in development, so there was time to react. By the following revision, each problem area had been addressed:

- The solid ground plane was hatched after the electrical team determined an appropriate pattern to preserve signal integrity

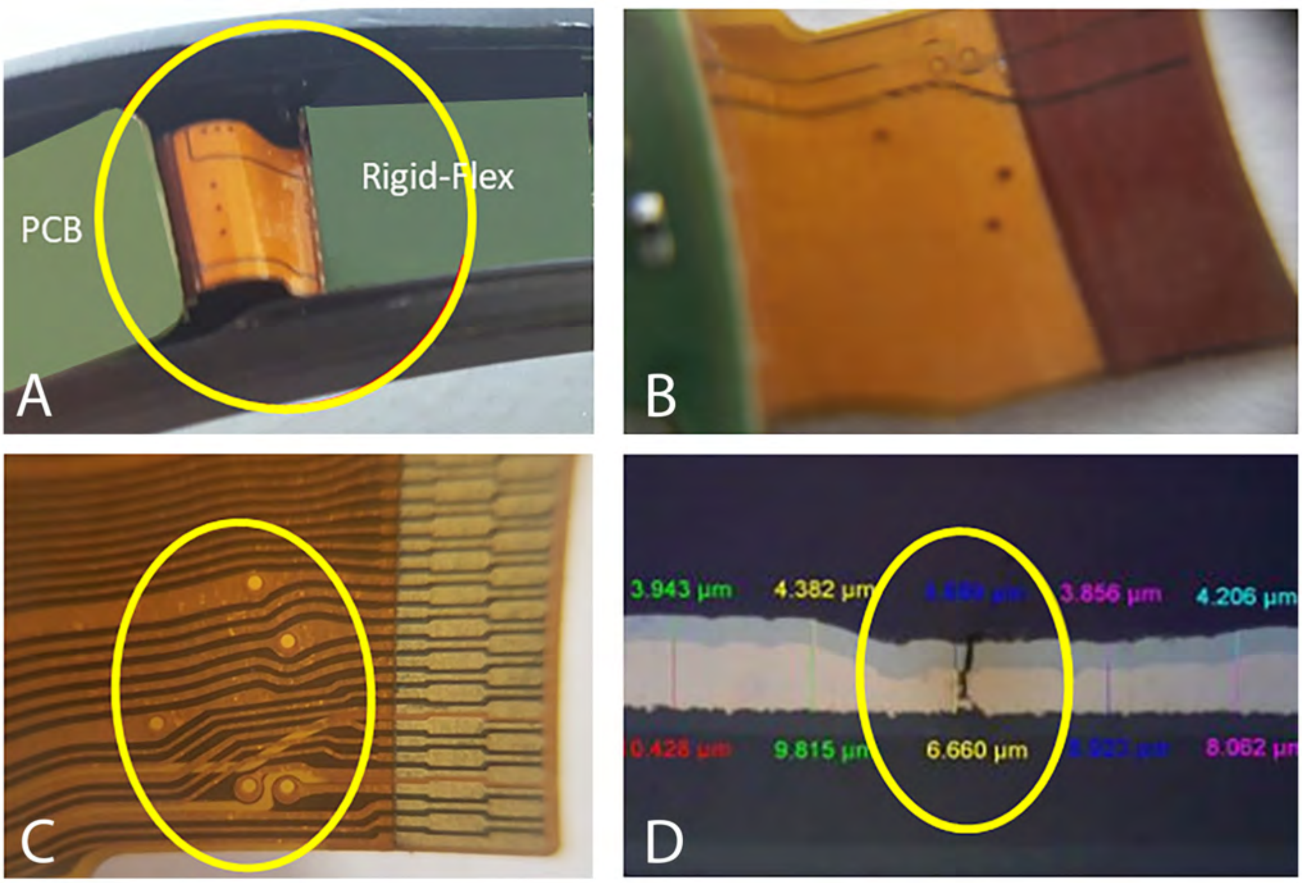


Figure 7: These images highlight the construction and configuration of a rigid-flex circuit with a ZIF termination (A, B, and C), and a cross-section of a ZIF finger that cracked after assembly (D).

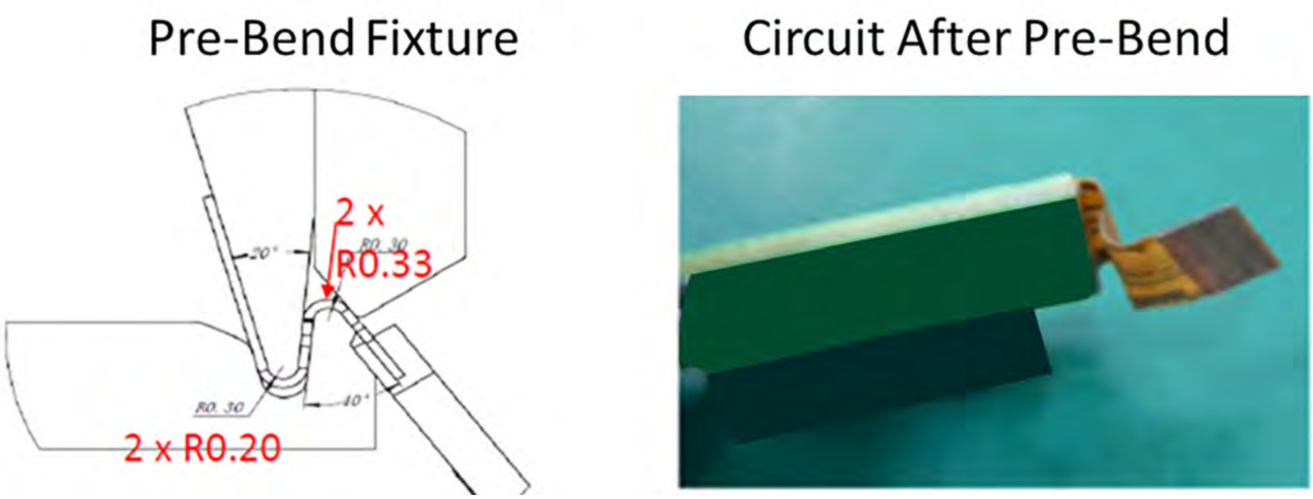


Figure 8: A pre-bend fixture was developed and implemented to ensure predictable and repeatable bend of the flex tail with the ZIF fingers (L), and the rigid-flex circuit after pre-bend (R).

- The layout of the rigid-flex board was reconfigured to accommodate moving the plated vias into the rigid areas
- The assembly process was modified to avoid requiring blind insertion of the ZIF into the receptacle on the PCB side
- The team developed a pre-bend fixture, providing a consistent, repeatable alternative to manual bending (Figure 8)

After these changes were implemented, no subsequent failures were encountered.

Conclusion

The three case studies presented here provide an opportunity to share lessons learned by highlighting some of the common failure modes of flexible printed circuits and illustrating several key concepts and best practices to ensure robust, reliable FPCs. Key takeaways include:

1. IPC-2223 bend recommendations provide a good starting place for FPC design, but they are often too conservative for many applications.
2. It is possible to exceed the bend radius recommendations, but extreme care must be taken with (a) material selection, (b) conductor design and the layout of supporting structures, and (c) the assembly process to ensure controlled and predictable bends during assembly and in the field.
3. Flexible solder mask is not intended to bend and should be well supported by stiffeners or isolated from the system.
4. The bend configurations conceived and represented by engineering design tools are idealized; the actual bends a circuit sees during assembly and application may be far different and more severe.
5. Dual-row ZIF connectors are inherently vulnerable to cracking, so it is important to protect the ZIF fingers by ensuring they are isolated from sources of strain during assembly and use.

As described in this article, there are often no right answers or perfect solutions for a given FPC design challenge. Ensuring robust, reliable FPC designs requires close cross-functional collaboration with internal electrical, mechanical, and PCB design teams as well as with the FPC fabricator and the assembly partner. Achieving success often requires some iteration, so it's best to engage with internal and external partners as early as possible in the development cycle. **FLEX007**

Todd MacFadden is a PCB technology engineer at Bose Corporation.

Amit Rushi, GraftWorx

Collaboratively Creating Wearable Medical Products

Feature Interview by the I-Connect007 Editorial Team

Patty Goldman, Barry Matties, and Happy Holden recently spoke with David Moody and Rich Clemente of Lenthor Engineering along with Anthony Flattery and Amit Rushi—their customers at GraftWorx. They discussed a recent project and how they worked together to solve a difficult problem by designing a rigidized flex circuit for their product.

Patty Goldman: Tony and Amit, thanks so much for joining us today to talk about your project with Lenthor.

Anthony Flannery: We had a number of different challenges that were unique to our product. It was fantastic working with Lenthor. We're very happy with how the final product came out.

Barry Matties: Let's start with some information on your company for our readers. What does your company make?

Amit Rushi: I lead business development product and marketing at GraftWorx, and I've been here for about two years. At GraftWorx, we build an end-to-end remote monitoring solution to target fluid management issues in chronic condition patient populations. We realized that a big gap in solving for that was the lack of a continuous-sensing technology that generates clinically actionable cardiovascular metrics, specifically hemodynamic metrics.

We took on this endeavor of creating an end-to-end platform, including making a new, continuous-sensing solution. In our vernacular, we refer to it as a SmartPatch. That journey has gone through its own gyrations to determine the adequate number of sensors, the desired flexibility of the circuit board, and how can we make it truly forgettable in the mind of the patient from a wearable perspective.

We started with the architecture of an end-to-end remote mounting platform but needed to solve for the gap of this continuous-sensing SmartPatch. The first market we're targeting is dialysis—a patient population that, unfortunately, has a lot of rigor to living their life

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on dialysis; they go to dialysis treatment three times a week. Then, we're looking at congestive heart failure or heart failure at large, since 40% of dialysis patients are diagnosed with heart failure. These are two very big markets in need of innovation, especially in supporting the patients' lives outside of the clinic.

Goldman: Today, we're here to talk about the topic for this issue, which is "From Design Through Final Product." Our thought was to follow a product through from the design—the very beginning—through all of your concerns and what happens to make that product a reality. Let's jump in at the design stage and talk about how everything worked out with Dave and Rich from Lenthor's perspective. I know the end was good, but what happened in between?

David Moody: Tony, if you could give us a brief description of what determined the ultimate solution, that would be great. For example, it had to be a rigid-flex design from the standpoint of what you were trying to accomplish when you were all sitting around the table with a napkin trying to figure out what to do.

Flannery: It's funny. We're all going to sit down and write our memoirs about this company someday. GraftWorx has been around for about six and a half years, and we first cut our teeth on trying to bring a product to market on a monitoring system for peripheral arterial disease. And there's a long, convoluted history that goes beyond the scope of this conversation. What we ended up realizing was there was a tremendous opportunity to do this, and we'd get to market faster in the wearable space.

It's no secret or surprise that there's a tremendous opportunity in medicine to generate data that can make a huge difference in a clinical outcome. As Amit was describing, we're trying to generate quality data that goes back to the clinic and has a positive impact on managing patients with a very difficult disease, end-stage renal disease. We wanted to design something that fits into a patient's lifestyle with very little impact on their lives.

In terms of conveying what we're trying to do, this is something that sits on your skin, such as a small, smart bandage. We wanted it to move with you and be flexible, comfortable, light, and forgettable. But at the same time, it's a very sophisticated device. We have 11 different sensor data streams acquired during a reading. There is encryption that goes on so that we're HIPAA-compliant in terms of how we store and transmit patient data. There is a tremendous optimization that went into power management so that our device lasts as long as it does on the skin, and this data is pulled into our cloud via a medical data relay (Figure 1).

Figure 1: The GraftWorx end-to-end data path. Results from patient monitoring are transmitted via a semi-custom Bluetooth link to our B2H data bridge. Data is transmitted over a cellular IoT network to the Cloud where, after authentication, data is processed and alerts generated. Data and alerts are available to clinicians as part of their standard clinical workflow.

What went into defining this device? Well, one of the things about the medical field that's interesting is we have four different customers: patients, doctors, clinics, and payers. To answer your question about the journey in terms of starting the design, we have to take all of those players into account when we start laying out our product requirements, which then feed into our design inputs.

Clemente: I think you're on a nice track. Would it be safe to say that the onset of wearable electronics helped you find a solution?

Flannery: I'm going to take a little hubris at this point and say we are the onset of wearable electronics (laughs). We're one of the drivers in this field. There are other people on the market, for instance, such as iRhythm, who are out there looking for wearable devices to record EKGs and a number of other players in different spaces.

We're driven by a need to solve a clinical problem. We're not a hammer looking for a nail or a technology-driven solution; technology is our tool to solve a genuine clinical need. In a lot of ways, we're taking the best that technology has to offer and designing it for our own product requirements and needs. We're driving the revolution, not following on the wave. We like to think of ourselves as at the forefront.

Matties: You knew it was going to be a wearable early on and would have to be a flexible circuit at that point, right?

Flannery: Yes. One of the reasons we liked working with Lenthor was we knew we were going to want to push the envelope on a few things to achieve the most efficient form factor—the lightest, most flexible and reliable, and again, highest quality.

There's also certain practicality to the wearable space. You can see a convergence of technical capabilities where the smartphone industry has driven low-power sensors and super-efficient telemetry and made things smaller, lighter, and cheaper. So, there's this technology pool to pull from as you're designing a device for your area.

Wearable sensors are a nice path because unlike an implantable, they can be a non-significant risk (NSR) device. One of the things that drives a lot of our design decisions is, "How is this going to play in the FDA approval cycle?" If I can possibly get it into a wearable device, that's a much easier path to get to market than if I have to build an implantable that is of significant risk. The risks are a lot higher when you break the skin and enter the body.

Wearable sensors are a nice path because, unlike an implantable, they can be a non-significant risk (NSR) device.

Another factor driving wearable innovation is the recognition that the regulatory environment facilitates getting to market faster for an NSR device. We'll admit that we made a pivot early on from an implantable monitoring device for a peripheral bypass graft in part by recognizing this. It's very hard to raise the amount of capital it takes to get an implantable product into the market because of how long you have to support a company before you can ever get your first dollar of revenue. You're seeing so much opportunity in the wearable space due to technical capability meeting regulatory opportunity; that confluence is creating all of the activity in the medical wearable space.

Matties: When you started to design the circuit, what was that process like?

Flannery: There were a number of considerations in each of the core elements of our device. First, we used a Cypress PSoC device because they have a rich library and we can take advantage of their existing FCC certification. We're using a variation of low-energy BLE 4.2 telemetry so that we can stand on those shoulders and adapt them to our market needs. For instance, while we're using a standard BLE 4.2 chip, we tweak the protocol slightly to conform to HIPAA. Our devices won't show up on your smartphone and authentication is handled at the application layer. That makes it extremely difficult to hack, yet we can still leverage all of the development in the existing technology.

In terms of integrated circuits, we don't have to do our own ASIC. We're not trying to do our own FCC certification; it's all about time to market for a startup, so you want to leverage as much as you can that's out there and adapt only as much as you must to meet the specific demands of your market. We chose a very powerful, robust, low-power, fairly mature technology with Cypress PSoC, and we evaluated about four or five different other medical microcontrollers in the market.

The second area of great consideration was power. In this iteration, we're going with a primary cell, which has some advantages. The energy density is usually about twice what you can get out of a rechargeable cell, and self-discharge rates are very low; thus, we can build our device with our power management scheme and still achieve a shelf life of a year with no need to recharge the device or somehow insert a new battery into it.

The second area of great consideration was power. In this iteration, we're going with a primary cell, which has some advantages.

This helped us with our design objective of the forgettable SmartPatch. It goes on your arm, it's very light, and part of the reason we can do that is because of the energy density of our battery. It's a semi-custom battery that we had made by a supplier to meet our form factor requirements, so the power management was optimized. Our quiescent current is about 50 nanoamps, so we're down in the region where we're comparable to the self-discharge of the battery, which enables us to get that super long shelf life.

There's also the sensor suite itself in terms of the circuit design. Every one of those sensors is designed to support a specific aspect of the metrics we're trying to collect. There are optical sensors, which we use to measure hemoglobin/hematocrit, SPO-2, volumetric flow rate, heart rate, etc. We get SPO-2 and hemoglobin hematocrit through some very sophisticated proprietary algorithms. Everybody has a PPG chip on the back of their smartphone, and there are all of these apps for putting your finger up against that to get heart rate and SPO-2, and that's called photoplethysmography (PPG).

But we're doing what we call PPG+. We're pushing that technique to get hematocrit out of a major artery as well as volumetric flow. We do that by combining multiple different data streams and optical channels in a way that we've been developing over the last two years. It's a proprietary approach to generate these metrics, but we're still leveraging off-the-shelf sensors. We're trying to do as much as we can and take advantage of a lot of great work out there to build PPG chipsets and analog front ends. Right now, if you go to the Sensors Expo and Conference or the Embedded Systems Conference, many wonderful chipsets are available to support the wearable space.

We took this circuit design to a couple of different vendors and said, "We want a super flexible region that will be bendable around somebody's arm or the curve of the bone in their arm." At the same time, we had to have regions in the design that were rigid because solder joints don't like to flex, so reliability was a concern. If we had gone with a rigid-flex approach, that probably would have been okay, but one of the things that we liked about Lenthor is they were willing to tackle this problem with what I call rigidized flex, which they had proposed through working together and looking at the cross-sectional structure.

They use these thicker blank core stiffeners in their islands. Then, we only bring out two of the layers in the tethered regions—very thin layers. You can tie the circuit in a knot, and it works just fine. It's a powerful platform upon which to build a wearable, and at the same time, we haven't had any reliability issues in terms of flexing of these stiff and rigidized flex regions. It's super thin, so the form factor is very efficient in terms of volume—a minimum of both surface area and stack height.

Matties: At what point in your design process did you reach out to Lenthor—early on, or after you had the basic circuit designed?

Flannery: We had the basic circuit designs in our architecture. Lenthor was not necessarily a participant in the circuit design; we discussed the PCB platform a lot more as well as some of the assembly requirements. In the accompanying article in this magazine, I detail some of the challenges of the wearables market. For example, when you talk about circuit design and platform in the wearables market, the form factor is every bit as important as the schematic.

In a lot of conventional circuit boards, it's a square, circle, or maybe an L-shape because you have to turn a corner to make a connection. But in the wearables space, the form factor and shape of your layout will determine the shape of your final product on the body. You may be designing a layout that goes around an ankle or a radial bone or across the collarbone or some other piece of physiology. Your layout isn't so much determined by your circuit needs as it is by your product needs. If you look at our PCB, it's barbell-shaped with an island in the middle—very non-orthogonal with curvy lines (Figure 2).

Matties: You mentioned materials. When you did get Lenthor involved, what other impacts did that have on your thinking regarding the circuit?

Flannery: It gave us design rules to work with. This is a new platform; we had to come up with a whole new set of design rules, such as if you're going to make this floppy circuit and move it through production, what's the minimal spacing? Can you still get three-mil spacing and a three-mil feature on the floppy tether that must go through the manufacturing process?

One of the things that Lenthor did that we're happy about is they figured out how to hold a lot of their design tolerances. Even though we were doing this weird multilayer board, there was some definite innovation on their part in terms of how to get this device through their manufacturing process using practical methods. They gave us limits, and through those, we determined how narrow we could make the tethers. We care about every extra millimeter of space around the edge. We're trying to push the envelope on circuit density while still using off-the-shelf parts and keeping the cost reasonable.

Matties: Lenthor, from your point of view, how was this process of what sounds like an R&D project and new product introduction combined?

Rich Clemente: Even though this is a unique product and wearables is a new and growing market, taking a design and working with the customer and customizing it for the end user is not totally unique. I can

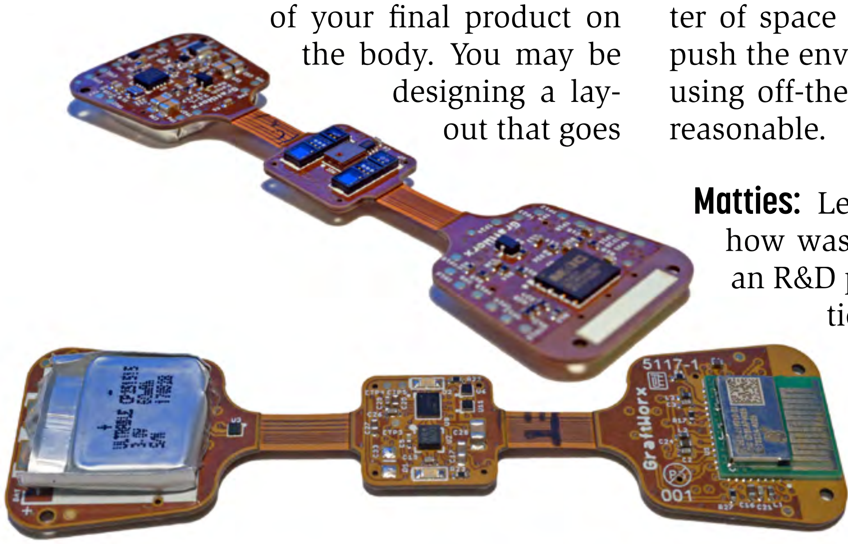


Figure 2: Final shape of the Graftworx SmartPatch PCB.

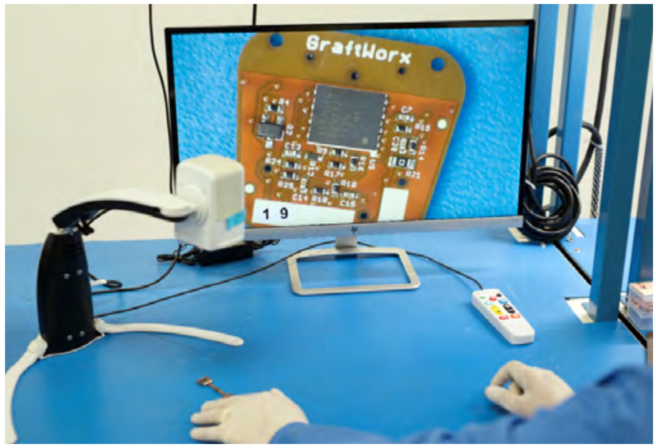


Figure 3: Focusing on quality early during the development process saved time by allowing the company to focus on the product instead of chasing down defects.

certainly appreciate GraftWorx not wanting to make an implantable. Having built several implantable parts here, we know the headaches that go along with that.

Moody: When we were first presented with this, one of the initial conversations was, "This is going to be a rigid-flex design." Then, it became evident talking with Tony that doing a standard rigid-flex construction wasn't going to meet their needs; it was going to be too rigid. To meet the form factors required for the end product, we had to sit back and think about how to make a rigid-flex without any rigid materials and still keep the integrity. There is a very thick stackup on either end of the board connected by two layers of copper with the flex circuit in the middle.

The rigid section has some requirements that we normally address with certain materials used specifically for rigid-flex. Removing the rigid-flex concept, we all had to take our heads out of that box and put them somewhere else to come up with a flexible rigid-flex design. The challenge for us internally concerned what materials to suggest. Typically, you want to keep acrylic adhesive out of a rigidized section of a board, but in this case, there weren't alternatives available to us to meet the end product requirement. We had to go back to using standard flexible materials with acrylic adhesives to hold the rigidized section together, and we knew those challenges were going to be primarily in the drilling and subsequent plating of the through-holes in that area. We had to do some redesigning and reconfiguring in how we were going to drill those sections.

It comes down to a mechanical aspect of feeds and speeds in the drilling department and how to best keep the hole wall integrity for good plating. Again, the end product—medical device sensing—needs to work; it's not a commercial or consumer application. High reliability had to be part of the concept going into it. Those were the primary things that we had to sit back and think about when Tony came to us and said, "No, you can't do a rigid-flex, but those end areas need to be a little rigid because we have a bunch of components out there, battery included." Other than just telling Tony, "We can do this kind of line and space; we can have this kind of pad size, annular ring, etc.," the general requirements of the circuit had to be incorporated into what ended up being a very specialized construction and mechanical build sequence for us internally.

Matties: Tony, you started by saying that this relationship with Lenthor strengthened your results.

Flannery: Absolutely. Our final product is a lot higher quality than if we tried to go a conventional route without the benefit of their innovation. There were times we'd have a phone call about navigating challenges, but they made it look easy all the way through. They did a fantastic job coming up with ways of preserving the quality of their patterning and through-holes and vias, despite the fact we had this weird, wonky, multilayer design. We depended heavily on their level of quality control (Figure 3). By doing 100% continuity testing and X-ray and visual inspection of post-assembled parts, the delivered board yields were near perfect. Lenthor is ISO 9001:2008 certified and IPC-6013 Class 3 qualified. Focusing on quality early in the development cycle meant we could focus on our product and not spend time chasing down gremlins from fabrication defects.

Matties: One thing that we commonly hear is that there's not enough collaboration from design to fabrication to assembly. This is a case where collaboration certainly paid off.

Flannery: Yes.

Moody: To jump in for just a second, Rich asked me a couple of minutes ago to look at the DFM—the report that our CAM group does once the design is submitted to us in a final state for us to review and prepare for manufacturing. At that point, we had done so much work together back and forth that there was only one item on that DFM that we submitted to GraftWorx, and it was a solder mask opening for some components. That was primarily driven by our assembly group after they reviewed it. We wanted to review it from an assembly standpoint because the next aspect after you get it fabricated involved somebody putting components on it. We asked that group to take a look at it, and the only thing that came back after all of the collaboration was a recommendation to open up the solder mask around certain components to facilitate the assembly; these things don't often turn out this clean.

Figure 4: Patch applicator.

Matties: And that's the point of collaboration because otherwise, you may have gone through a few different spins to get to the product quality that you achieved in your first pass.

Flannery: Definitely. My background is in MEMS design where design and process development must go hand in hand. Contrast this with more conventional semiconductor ASIC designers who can design in a very refined, static CMOS process. Collaboration is an absolutely essential component for this kind of innovation. If you try to do something new or you're trying to push the envelope, and you're not getting your designers talking to your manufacturing and process development engineers, it's a recipe for disaster.

One of the things that we're really thankful for is that Lenthor was willing to schedule meetings; we would sit down and talk about issues. I write about some of them in the accompanying article; it's not a complete history of everything we've done, but there were some specific elements, such as handling sensors. With every specific detail that we worked on, they were willing to sit down and walk us through that. What we ended up with was this gorgeous, high-yielding board that looks great. We could not have done that by just throwing it over the wall like a standard process; it wouldn't have happened.

For example, one of the challenges with MEMS sensors or other kinds of sensors that you want to put into a wearable—and the wearable space is chock full of sensors—is they're sensitive and exposed to the world. They're not encapsulated in a nice epoxy shell like a standard integrated circuit. Your assembly techniques have to be different. We sat down with Lenthor's assembly line staff and worked through all of the details on our microphone, accelerometer, optical sensors, etc.

Matties: In your process, is there anything that you learned that you would do differently next time?

Flannery: I don't know if they feel the same way. Lenthor has been such a good vendor for us. Our expectations were met 100%. Not that everything went smoothly and we didn't have hiccups around certain items, but we went back and forth on the design. Whether it was a solder mask issue or we wanted to change the shape of the board, study the corners because of the radius of curvature issue, or something else, there was nothing that stood out as problematic. We carefully thought things through from beginning to end, and it helped to have their experience. The nice thing was there was a certain element of, "We've been through this process before, so even though your product is different, we know how to take something different and bring it successfully to the end."

We've been through this process before, so even though your product is different, we know how to take something different and bring it successfully to the end.

Matties: Would earlier collaboration have accelerated the process at all?

Flannery: Maybe, but I'm not sure we were ready at GraftWorx. You have to remember that we were on a learning curve with our product as well, and it becomes inefficient to collaborate too soon. We had to do our homework in terms of coming to the table with what our product requirements were going to be because they were going to put a lot of energy into trying to design a process or a platform to meet our needs. If we started switching before we were ready, it would have been an inefficient dance. Then, you start wasting a lot of time going down dead-end alleys trying to figure out if you can do XYZ, but then you find out you don't need to do XYZ. It behooves both parties to make sure that they are ready to come to the table before starting the collaborative process.

Matties: At what point in the process is that defining moment that triggers you be ready for collaboration?

Flannery: In a standard product development cycle, you go through certain rounds of proof of concept where you're trying to try to build up this foundation of capability that's going to enable your product to meet everything you want it to do. That's the point where you realize, "I need something more. I vetted the fact that I can talk to my microcontroller and I can do standard things, but my value-add—the thing I'm bringing to the market that's special—needs something extra." In the wearable space, it was our form factor and sensor suite. Once you've built your foundation on standard technology and defined that extra bit that you're going to need help with, you're ready to go to the table.

Matties: When you approached this, you knew it had to be a rigid-flex. Were you thinking early on that it was not going to be a traditional rigid?

Flannery: Yes, I was pushing in that direction for a couple of reasons. Being a semiconductor guy, I don't like mixed materials, such as FR-4 and polyimide. I was trying to get the most space-efficient platform. The other aspect is the complexity of it. Often, rigid-flex is more expensive than just doing a flex circuit. I was trying to avoid the complexity of something that I didn't want, and yet I had certain needs for a stiff area to reliably support solder bonds.

Matties: Did you have the solution in mind before going to Lenthor, or was this a solution that was born in that collaboration?

Flannery: I had the needs well-defined, but Lenthor is the one that came up with the solution. We'd ask, "Why do you want it this way? What if we did this? Okay, that's not going to work. What if we did this instead?" There was back-and-forth communication early on, but Lenthor is the expert on PCB technology—not GraftWorx. We're smart, have a lot of experience, and have done this a couple of times, so we're not completely naïve, but they came up with the proposal for the final platform through a series of talks about possibilities.

Matties: That's how collaboration should work. And how important was the price in this model?

Flannery: The standard stock and trade of price are always important. But at this stage in the game, the individual piece price is not critical. I don't need to drive this down to the high-volume cost that we expect to get in production, but the platform that you use to first introduce your product, get it through regulatory approval, and go into clinical trial with should have a path to low-cost without a major redesign. We're a startup. We're cash-poor. Like anything else, every dollar is dear. One of the things I liked about Lenthor's solution was if I want to move to 100,000 units a month or even higher than that, there's a path to get to a low-cost solution without doing a major redesign.

In any startup, there's a period where you're trying to do your initial development and alpha and beta units—the stuff that's going to go out for customer evaluation or through reliability and qualification. In that timeframe, it's tempting to take shortcuts and choose something that may be very quick and cheap to build but doesn't scale. The problem with that approach is you get through the regulatory hurdle or your customer's acceptance tests, and then you suddenly find you cannot meet the volume or price point of your customer. You have to go through redesign and requalification. Most customers or investors will ride through that with you a second time. The platform we eventually settled on had a path to high-volume, low-cost production in its current incarnation. That is very important for us as a medical device company.

Matties: That's critically important thinking in the beginning. You're talking as if many companies don't start critical thinking early. Is this a common process that people don't follow it?

Flannery: More often than you would know, and I'll give you a good example. I was a co-founder of InvenSense. We built the world's first commercial MEMS X/Y gyro and were evaluating foundries. One foundry quoted us a super low number on non-recurring engineering (NRE) to build our first device. We thought, "Wow, that's great!" But when we asked, "When we order 1,000 wafers a month from you, what's going to be the per-wafer cost?" That number was very high.

Figure 4: Hub and carousel.

The second foundry quoted us a much higher number for NRE to get our first prototype out. But they had a plan to get us to 1,000 wafers a month at a much lower cost. It's tempting to say, "Let's save that $100,000 because we're a startup and we are short on cash. We'll worry about transitioning later." But at that point, you're already trying to commercialize, and your burn rate has gone up. You have customer engagement now, and in the middle of that ramp, you must change foundries, test, package, and requalify the line. That kind of thinking has happened more often than it should. If you're prudent, you'll recognize that by investing in a good partnership early on, you'll reap the benefits of that later tenfold. It's the right way to do it.

Matties: In terms of the assembly process, what challenges did you face at Lenthor? You mentioned the solder mask, but were there any other concerns in the assembly? Was it all done by hand or was it automated?

Clemente: It did go through a standard reflow assembly process for the most part, but the key for us was the board construction; again, it wasn't a typical rigid-flex, so it had the advantage of rigid materials. To keep the component area flat, solid, and stable for component attachment, we needed to come up with assembly fixturing that aided in keeping the product in a state that allowed for standard reflow automated pick-and-place assembly attachment. That was our primary mechanical challenge from an assembly standpoint. Tony can maybe discuss some of the other aspects of it, but from the daily mechanical work aspect, we needed to come up with some internal tooling and fixturing to hold the product in place.

Flannery: Yes, I had a lot of meetings with Matt Kan, the assembly manager at Lenthor. We have a lot of sensors; the optical sensors have a sensitive window, the microphone has a port, and the accelerometer is sensitive to certain types of vibration and shock. I had experience in the past where people used the accelerometer that I had built, put it into a smartphone, and their pick-and-place machine was like a jackhammer. They used stainless steel tips, super-fast pick-and-place, and it was hammering the accelerometer and destroying these delicate, inertial navigation elements inside of the accelerometer.

Lenthor had done some MEMS work, but we were pushing the envelope on their experience in terms of all the sensors we were putting into it. We went through each sensor and explained their sensitivities, such as shock or vibration, and gave white papers and app notes on their assembly. For example, the microphone had an open port. Most people use a no-clean flux, but we said, "You have to use a no-clean flux. You can't spray liquid on a microphone port, or it will destroy the part." We also explained, "The optical windows can't be scratched, broken, or have a residue left on them or it will affect our photodetector, LEDs, and the efficiency of their coupling in the skin." We went through all these details even before design and assembly.

I sat down with Matt and said, "My concern is there's a solution for every single one of these, so let's make sure that we're conscious of this and don't build these with zero yield." By carefully stepping through the challenges early on, they were able to program their pick-and-place machine a little bit slower—a little softer hit and land. We also talked about different tip materials and reflow profiles. In the wearables market, almost everyone is dependent on sensors, which have certain challenges. If you're making a solid gel electrode array and trying to couple that into your circuit, you have to take that into account when you think about your assembly and how you're going to build your final product.

In the wearables market, almost everyone is dependent on sensors, which have certain challenges.

The last thing I'll mention is on the battery. You can't reflow a primary cell—the max temp is 65°C—so we had to solder the battery afterward. The great thing about working with Lenthor was they recognized that we had to sort some of this stuff out. We weren't quite ready to deliver a turnkey tester/programmer that could go onto the production floor. They were very accommodating. Our parts would roll off the assembly line. They gave us space in a corner with an engineer who would test and program our power management firmware. If we hadn't done that and they solder-attached the battery, the battery would start draining immediately. We had to get our firmware programmed in immediately to safeguard the battery.

In volume, this is something we could preorder. We could ship 10,000 units to a house, and they would load up our firmware. At the time, even though we couldn't afford 10,000 units, we still had to look like we built 10,000 units because that's what our customers expect. That flexibility to work with us while we sorted out early phase issues was critical. If Lenthor had said, "No, we don't want to work with you like that," it just would have gone south.

Matties: It seems like early collaboration on the assembly side paid off as well.

Flannery: It was essential.

Matties: When you were looking for a supplier, what initially attracted you to Lenthor?

As a medical device company, we were concerned at this stage primarily with quality.

Flannery: As a medical device company, we were concerned at this stage primarily with quality. Lenthor is ISO:9001 certified and complies with FDA standards for Class 3 (high-risk) implantable devices. We're a non-significant risk device; We're a remote monitoring tool, but they have met the needs of people in military, aerospace, and medical who have very demanding quality needs.

The thing that initially attracted us to Lenthor was they were serious about what they built, they did high-quality work, and they had a great quality system. At the same time, they were open and accommodating about describing what their capabilities were, and willing to work with us. It was that combination of being serious, high quality, and confident in what they did yet not so full of themselves that they weren't willing to work with a fledgling company who had to sort some things out that clinched the deal for us.

Matties: Geographically, what is the proximity to Lenthor?

Flannery: We're both in the Bay Area, which was fantastic. I considered at least two other companies in the Bay Area, but they weren't the right fit for a number of different reasons.

Matties: It was nice to find somebody in your backyard.

Flannery: Absolutely. But why can't there be a PCB vendor be in Hawaii (laughs)?

Matties: Is there any final advice that you would give to a company looking to integrate flex into their products?

Flannery: Don't think you know it all. Engage your vendor and learn how they think about your product because they're going to have insights. You may think, "It's my product, so I know it." But Lenthor was really good about educating us on certain aspects of our product. It would have been very easy for us to come in and have said, "Here's what we want. Just build this," and that would have been a mistake.

It worked well for us to say, "Here are some things we think we know and some desires that we have that we're not quite sure how to meet. What do you think about this?" Be open to dialogue and be willing to say, "We definitely know what our core business is and what we're trying to accomplish with this product, but we're interested in your insights on how to get there." Even if you talk with a vendor that you decide not to use, if you listen and you're wise, you can still pick up bits of knowledge that are useful for you as a product developer.

Matties: Dave, do you have any advice that you would like to share?

Moody: To work in a collaborative effort like this, you have to be willing to sit down and listen. You cannot approach the table thinking, "I've done this before. I know exactly what they need. I'm going to give them this," because every project has different drivers.

Rushi: It's all about investing in the partnership. We're the right size for that. We're not so big that you're not going to have our attention, but we're large enough that we can handle the volumes when projects like this do start to ramp up.

Matties: Happy, you have any comments or questions you want to say add?

Happy Holden: Having to wear a medical electronic heart sensor for three weeks, I was wondering if your product is disposable or can it be recycled?

Flannery: The current version has a three-month lifetime; then, it's disposable. There is a roadmap to reduce that impact, but the current version is disposable after three months. We've seen those heart monitors people wear before. Do you have to send it back in the mail?

Holden: Yes.

Flannery: It baffles me that you have this critical piece of hardware you're wearing to get your heart performance, but then you have to mail it to receive the data. If you were wearing it in a way that you're not going to get useful data—such as putting it on wrong, not coupling to your skin correctly, or having a problem with the device itself—they're not going to find out until it comes back in the mail. My only response is, "Did you think about that when you were designing your product?"

Goldman: Not to mention it could get lost.

Holden: At least it didn't come off in the shower or anything like that. In my case, I didn't apply it—a specialized nurse did. Is your device wireless?

Flannery: Yes, we use a Bluetooth-based link. It connects to a small home device that we call our Bridge-to-Health (B2H) medical data relay. It has no buttons or anything to configure; you just plug it into the wall. It connects via the cellular network to our back-end cloud. Any time that the patch is in range and has data to transmit, it wakes up and talks to the hub that transmits it to the cloud. You don't have to do anything; it's fire-and-forget.

You don't have to do anything; it's fire-and-forget.

Also, if you were to wear our patch—or in your case, a heart monitor—and a problem arose, we would find out immediately and remotely light up an indicator on the Bridge to let you know you should change or re-apply the SmartPatch, which saves so much time. Sending that kind of feedback to the patient earlier is critical.

Goldman: Well, excellent. Thank you all so much. This has been very informative.

Flannery: Absolutely.

Matties: Yes, thank you very much.

Flannery: You're welcome. FLEX007

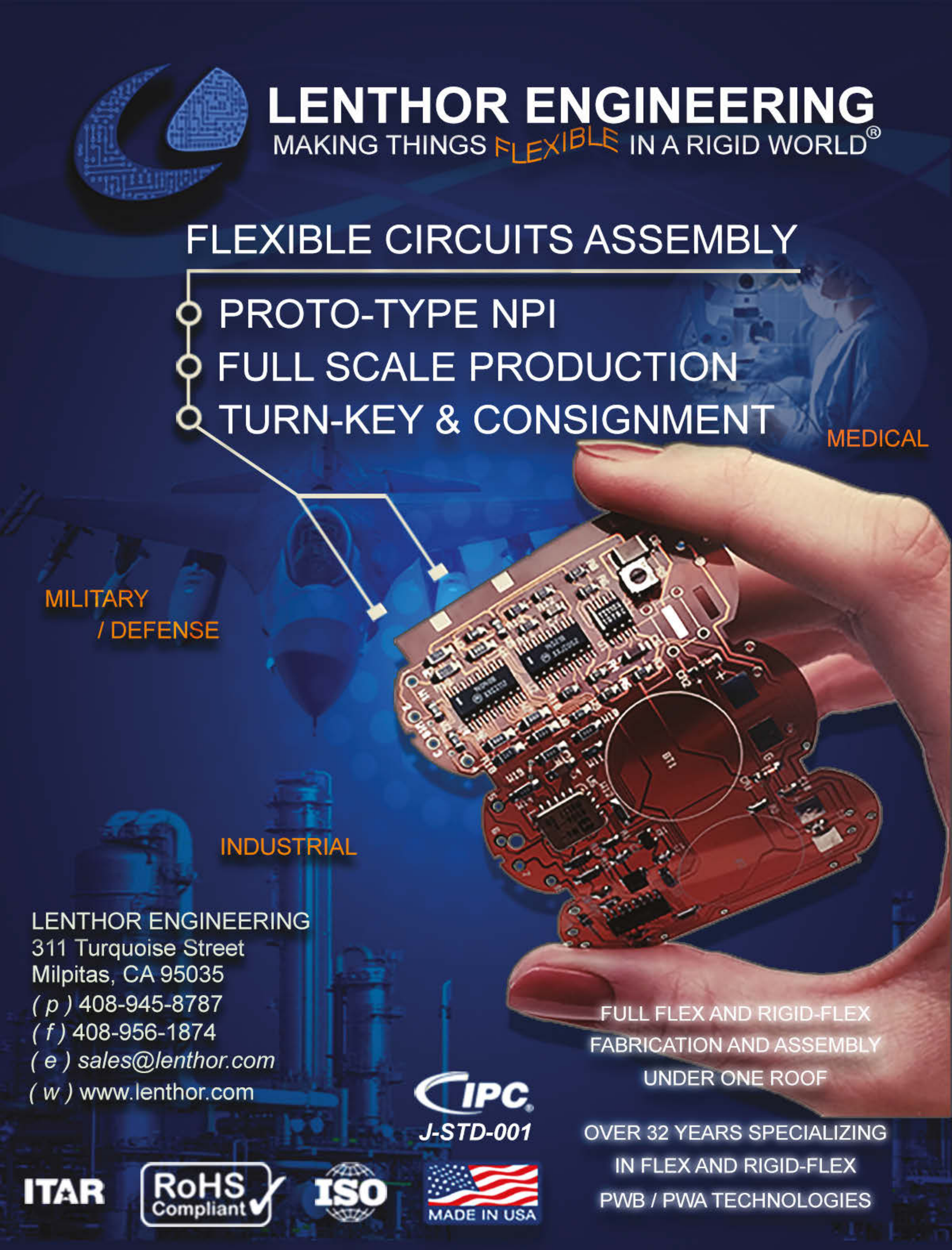
The GraftWorx Fluid Management Patch Story

Feature by Anthony Flannery
GRAFTWORX

The GraftWorx vision is to connect patients to clinicians with clinical data that will have a meaningful impact on their care. Our first application is to monitor patients with end-stage renal disease (ESRD) or kidney failure using a wearable device called the SmartPatch that records numerous clinical cardiovascular metrics. The SmartPatch communicates via BLE 4.2 to a medical grade data relay that transmits the data compliant with PHI and HIPAA over a cellular network into our secure cloud. The entire system works seamlessly without any intervention by either party to put real-time, clinical data where it can be integrated into care management pathways to reduce the incidence of hospitalizations and improve the quality of care for patients with chronic conditions.

Our solution architecture is focused on the design of a comfortable, sophisticated, ultra-low power device that a patient can wear for a week in a "forgettable" manner—quite a challenge! Working with the right electronics vendor as a partner to build our first clinical devices has been critical to the successful execution along our product development timeline. We evaluated a long list of potential partners before choosing Lenthor Engineering in Milpitas, California, as our fabrication partner.

On a technical level, the device itself was challenging to create. First were the requirements on the board itself. Because comfort is so important for our wearable product, we wanted to minimize the rigid areas required for bonding electronics and maximize flexibility in other regions. We also wanted to avoid the complexity and extra cost of a rigid-flex solution. To meet these needs, we partnered with Lenthor to spec out and develop a rigidized flex solution that used thicker blank cores within the 4-layer region of the populated "islands" of the board. The tether region was an extremely flexible thin 2-layer region with minimal coverlay. The flexible inner two layers ran contiguously across the board, con-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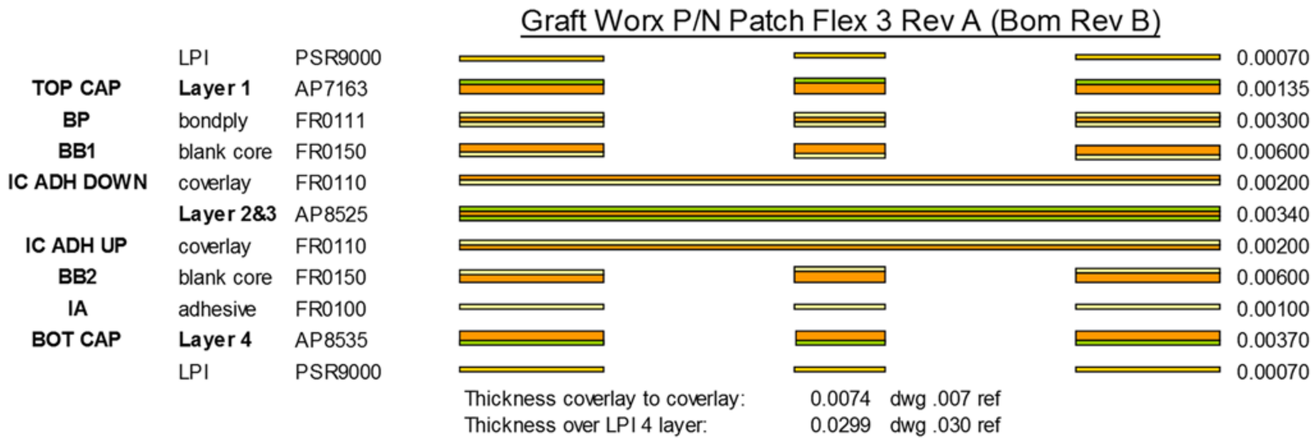


Figure 1: Cross-section of layers in the customized PCB process for the GraftWorx wearable. The blank cores provided sufficient rigidity to meet reliability requirements while the thinner tether regions were extremely light and flexible, enabling maximum comfort for the patient.

necting the rigidized islands without changing materials (Figure 1).

Armed with a solid solution for the flex board, the next challenge involved assembly and sensors. One thing almost all wearables have in common is the need for some form of sensor interface to the real world. The GraftWorx device measures hemoglobin, SpO_2, heart rate, temperature, and volumetric flow with a powerful fusion of 11 sensor data streams. Unfortunately, because of this interface, sensors typically have some form of vulnerability beyond standard ICs. Our MEMS accelerometer can be damaged by excessive shock from a pick-and-place machine. The microphone has a port open to atmosphere, which exposes the delicate internal diaphragm. It can be damaged by particles, fluid, and excessive percussive pressure changes. The optical sensors have transparent windows that can be damaged by aggressive mechanical handling.

Solutions in a high-volume assembly process can be found in the application notes from the component manufacturers and have been developed from experience with other products, such as smartphones. These can include adjustments to a standard assembly process, such as tip material choice, pick-and-place parameters, use of a no-clean flux, and reflow profile. Because each type of sensor can have different sensitivities, all must be reviewed to determine if they can be accommodated in a single pass with regular ICs, or if they are going to require an additional custom pass. Without a willingness to review what may be novel requirements for assembly and adjust and requalify a standard process, sensor components will be damaged, and yields will suffer.

Once fully assembled, we had a challenge with our battery. Our wearable is a single-use device. To achieve an acceptable lifetime, we engineered a very efficient power management scheme with hardware and firmware that can achieve a quiescent current of 50 nA as well as respond to outside stimuli by waking up and performing tasks. The boards had to be tested and programmed with this power management firmware before solder attach of the primary cell, or the battery would start to power the circuit. In sufficiently high volume and with a mature code base, we could have had our firmware image pre-loaded into our microcontroller, but for this stage, the lead time and cost were not supportable. Neither did we have a production worthy pogo or bed-of-nails fixture to test and program the board. Lenthor's flexibility enabled the GraftWorx engineers time to test and program the assembled boards in their facility with a prototype fixture and system just before the final battery attach.

The resulting electronics assembly shown met all of the requirements wonderfully (Figure 2). The tethers were flexible enough that they

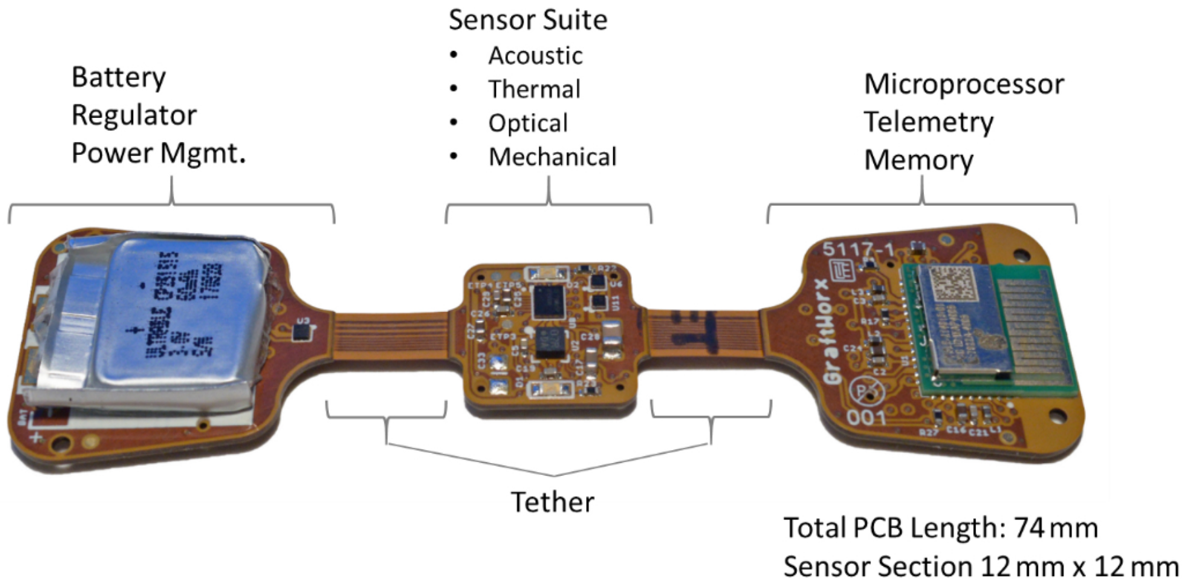


Figure 2: Final electronics assembly for molding into the GraftWorx SmartPatch.

added no significant stiffness to the SmartPatch. Spatial packing of the electronics was very efficient. Asymmetric through holes were designed into the edges of the board to facilitate mounting in a pogo pin test fixture. The electronics are a completely self-contained remote monitoring platform. Once encapsulated, there are no physical connections with the outside world. All functions, including testing, data telemetry, status monitoring, parameter updates, and over-the-air-programming (OTAP), are done wirelessly.

As a cash-strapped startup, it was important to manage some of the risks during development. There is always a tradeoff between the efficiency and cost per unit of a large batch run and the risk of committing those resources to a design that had yet to be verified. Before running the first lot at Lenthor on the customized platform, a small quantity was run through a standard, quick-turn process on FR-4. Being completely rigid, these units were not suitable to be molded and placed on a patient's arm, but running a relatively inexpensive, quick-turn version let us debug the schematic and layout.

They were also invaluable as development tools. As a nearly final version of our product, the embedded team used them to finalize development of the firmware. Also, the testing group used them to bring up and finalize our testing systems. Performance and function were validated against benchtop models with a high degree of confidence that they would function nearly identically to the final flex product. All this pre-run activity primed the company so that there was a minimal delay between receipt of the final flex product and our ability to start manufacturing.

No discussion about a product development experience would be complete without mentioning quality. Almost all industries have norms for quality assurance. Manufacturers of medical devices are governed by ISO 13485, and wearables fall into this category. There is, however, a lot of commonality with other standards. Before committing to our first run at Lenthor, our quality team reviewed their quality system governed by ISO 9001 and verified that all of the requirements under our quality system were satisfied by Lenthor's procedures.

The Lenthor flex circuit is molded into a silicone device (Figure 3) that can be applied to the AV fistula of a patient and capture clinical data remotely, whether from their home, at their workplace, or even while in a dialysis clinic. Once a device is placed, it automatically monitors for seven days, sending data back via the B2H medical relay.

Figure 3: Molded GraftWorx SmartPatch. Extremely flexible regions allow for conformal application on the body. Silicone molding and special gasketing enable the patch to meet IP-64 (splashing/shower) requirements.

The GraftWorx-Lenthor partnership took on the challenge of innovating a device without a standard platform to iterate from. Several elements from both sides were critical to the success in this partnership:

- Willingness to run smaller volumes at a reasonable cost
- Creativity to address specific product requirements and use out-of-the-box thinking
- Ability to learn and adapt to novel requirements that often come with innovative technology
- Preparation on both sides to bring the best thinking and domain knowledge to the table
- Flexibility in accommodating a customer that may still be in an early phase with evolving needs

Happily, the collaboration was a solid success. To date, the resulting SmartPatch has been deployed on 120 patients in clinical studies with more on the way. It has proven successful at measuring hemoglobin and detecting healthy flow from the arteriovenous fistula of patients with ESRD. While the number of units is relatively low from a formal reliability assessment (currently underway), anecdotally, there has not been a single failure in the field or complaint from a patient regarding comfort. The partnership has laid a solid technical foundation for GraftWorx product development and regulatory pathway. **FLEX007**

Anthony Flannery is the CTO at GraftWorx.

Miraco Discusses Flexible Circuit Products and Offerings

Jason Michaud is the vice president of sales and marketing at Miraco Inc. In this interview, Michaud discusses with Joe Fjelstad the history of the company, and their flexible circuit products and offerings. He also talks about how they are helping customers improve their product designs.

Click the image to watch this interview.

How to Get From Here to There

Flexible Thinking

Feature Column by Joe Fjelstad, VERDANT ELECTRONICS

"One day Alice came to a fork in the road
and saw a Cheshire cat in a tree.
'Which road do I take?' she asked.
'Where do you want to go?' was his response.
'I don't know,' Alice answered.
'Then,' said the cat, 'it doesn't matter."

—Lewis Carroll, author of
Alice's Adventures in Wonderland

Lewis Carroll is said to have written *Alice's Adventures in Wonderland* originally for the entertainment of the seven-year-old daughter of a family friend named Alice Liddell. While it has since delighted countless children (and adults, I am certain) with the imaginative and fanciful world it presents since it was first published, the book is also full of playfully thoughtful dialogue that often seems to have meaning deeper than the humorous exchanges belie.

The quoted excerpt includes one such exchange, and it is an instructive life lesson for all who read and take it in fully. To begin the process, you must first know where you are going. This is true for any project or life pursuit, I believe, and I often try to bring it to mind as I start any new project. With respect to developing products that might benefit from flexible circuit technology, this is no less true.

From Concept to Product

In my book *Flexible Circuit Technology, 4th Edition*, I mapped out a number of steps for getting from concept to product using flexible circuits in "Chapter 6: Implementing Flexible Circuit Technology." The pathway was not paved in stone because the evolution of flexible circuit technology is ongoing, and new materials, processes, and processing equipment continue to come online, opening the doors to new opportunities and prospective ways of getting the job done. However, the basics of the process remain the same. So, here in brief are

some of the process touchstones that I think are important.

First, there is the product concept. What specific design should be used for elements of the product that make flexible circuits attractive? This question needs to be asked to make sure that flexible circuit technology is truly required for the product. Because the thinness of the circuit is frequently an objective, flexible circuits are usually tapped to provide the sought-after benefit. However, sometimes—even often—a thin reinforced laminate circuit will suffice, and typically, at a lower cost. Thus, do a quick reality check; there is no need to make a product more expensive than necessary.

Sometimes—even often—a thin reinforced laminate circuit will suffice, and typically, at a lower cost. Thus, do a quick reality check; there is no need to make a product more expensive than necessary.

Second, flexible circuits have the obvious ability to interconnect electronic elements (e.g., modules, displays, connectors, etc.) that are distal from one another, commonly in three-dimensional space. Moreover, these electronic elements may be required to move relative to each other when in use (e.g., disk drives, read-write heads, printer cables, etc.) or during maintenance or upgrading of a system to facilitate access to the elements of interest. Understanding the mechanical requirements associated with this movement will influence design choices, including the type of materials used and the type and weight of metal foil (most frequently rolled annealed copper).

In addition, there are many seemingly insignificant details (e.g., copper foil grain direction) that need to be addressed to ensure that the product will perform to expectations for the duration of its anticipated lifetime. The type and thickness of the coverlayer used in the circuit also plays into this equation as well as the objective of keeping the copper foil at the center of the construction, especially in areas designed for bending or flexing.

The first topic is somewhat macro, and the second is a bit more micro and nuanced, but both topics are germane to this subject.

Designing Flex Right the First Time

Circling back to the bigger, yet often overlooked, items associated with the process of getting a flex circuit designed right the first time, there is a need to consider the operating environment for the end product. For example, consider the temperature excursion range and humidity expectations over its life and use as well as the processes that will be used in its fabrication. These factors will impact and likely limit the choices of materials used. Solder remains a commonly used method for assembly. And with higher temperature lead-free solders in use today, it is necessary to choose a material that will stand up to requirements.

Another matter to consider relative to field use is the mechanical stresses and strains that may be encountered by the product. Designers use flex with great frequency in dynamic applications, such as those mentioned earlier (e.g., disc drives read/write heads, printer cables, etc.), and they pay special attention to the circuit features that pass through the dynamic bend areas of the design.

However, products that are deemed to be non-dynamic applications can and sometimes do fail due to copper fatigue failure as a result of shock and vibration endured in a field application. These are not the visible flexural cycles that can be seen with the unaided eye, but microscopic flexural cycles that are characteristic of vibration. While in the former case, the cycles tend to be high amplitude and moderately low frequency, in the latter case, the frequency tends to be high and the amplitude low. I have seen such failures and heard of others over the years.

Conclusion

The intent of this column was to make you aware of some of the issues that need to be considered as you navigate the waters that stretch between product conception and manufacture using flexible circuit technology. Flexible circuits are a very attractive interconnection technology, but you must be attentive to the many factors that can spell the difference between success and failure.

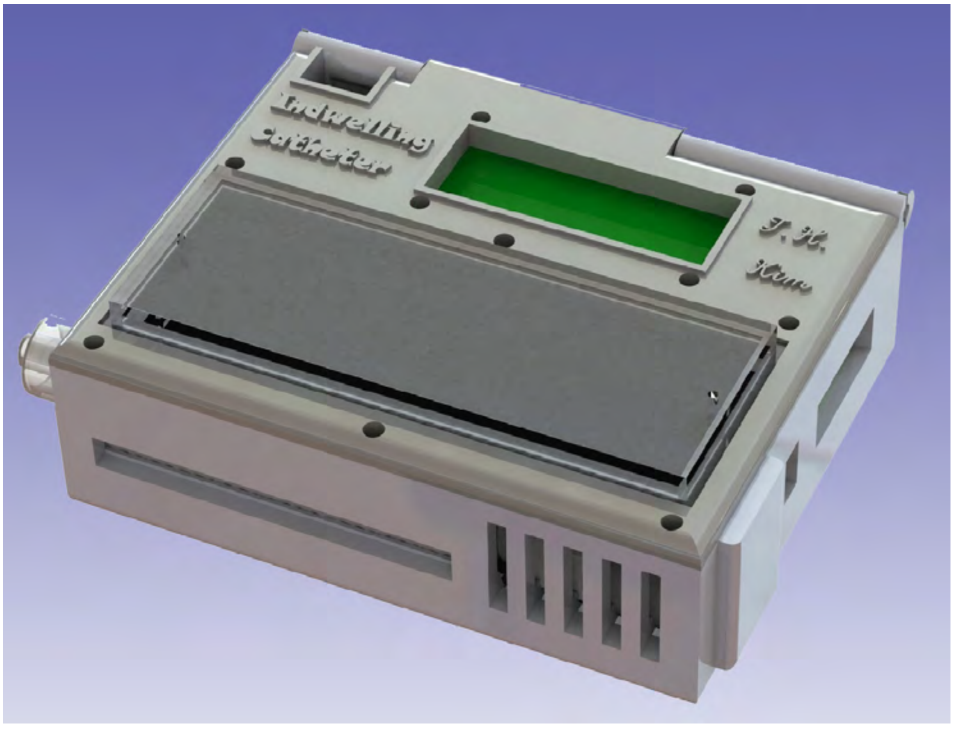
In closing, I invite you to download a free copy of *Flexible Circuit Technology, 4th Edition* to fill in more of the detail needed to make the journey. The book can be found and downloaded at flexiblecircuittechnology.com. **FLEX007**

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

Wearable Device Captures Cancer Cells From Blood

A prototype wearable device, tested in animal models, can continuously collect live cancer cells directly from a patient's blood. Developed by a team of engineers and doctors at the University of Michigan, it could help doctors diagnose and treat cancer more effectively.

Tumors can release more than 1,000 cancer cells into the bloodstream in a single minute. Current methods of capturing cancer cells from blood rely on samples from the patient–usually no more than a tablespoon taken in a single draw. Some blood draws come back with no cancer cells, even in patients with advanced cancer, and a typical sample contains no more than 10 cancer cells.



The new device could continuously capture cancer cells directly from the vein, screening much larger volumes of a patient's blood. In animal tests, the cell-grabbing chip in the device trapped 3.5 times as many cancer cells per milliliter of blood compared to the traditional blood draw samples.

The device shrinks a machine that is typically the size of an oven down to something that could be worn on the wrist and connected to a vein in the arm.

In the next steps for the device, the team hopes to increase the blood processing rate. Then, they will use the optimized system to capture cancer cells from pet dogs that come to the cancer center as patients. Chips targeting proteins on the surfaces of canine breast cancer cells are under development in the Nagrath lab now.

Hayes estimates the device could begin human trials in three to five years. It would be used to help to optimize treatments for human cancers by enabling doctors to see if the cancer cells are making the molecules that serve as targets for many newer cancer drugs.

[Source: University of Michigan]

Alternative Constructions in Rigid-flex Designs

Flex Time

by Bob Burns, PRINTED CIRCUITS LLC

In my last column, I discussed how manufacturers of rigid-flex boards use techniques similar to those used by manufacturers of hard boards and flexible circuits, and how techniques vary. That column's discussion was for a standard, straightforward rigid-flex design. This column will talk more about non-standard designs, which can present process difficulties and require extra care for effective yields.

Asymmetrical Rigid-flex Material Layups

Asymmetrical rigid-flex designs are fairly common but not recommended (IPC-2223A.8.1), as they can be very difficult, and depending on the design, impossible to build. Using materials with differing properties without balance and symmetry can cause manufacturing issues with your board, and there are two common types.

One is where the flexible layers are off center of the neutral axis in the material layup, putting more of the glass-reinforced layers on one side versus the other (Figure 1). Manufacturing panels with this construction are prone to warp during manufacturing. Since most PWB processes are planar, a warped panel can be very difficult to drill, image, and plate correctly, resulting in reduced yields. Once removed from the production panel, those parts can present great difficulty at assem-

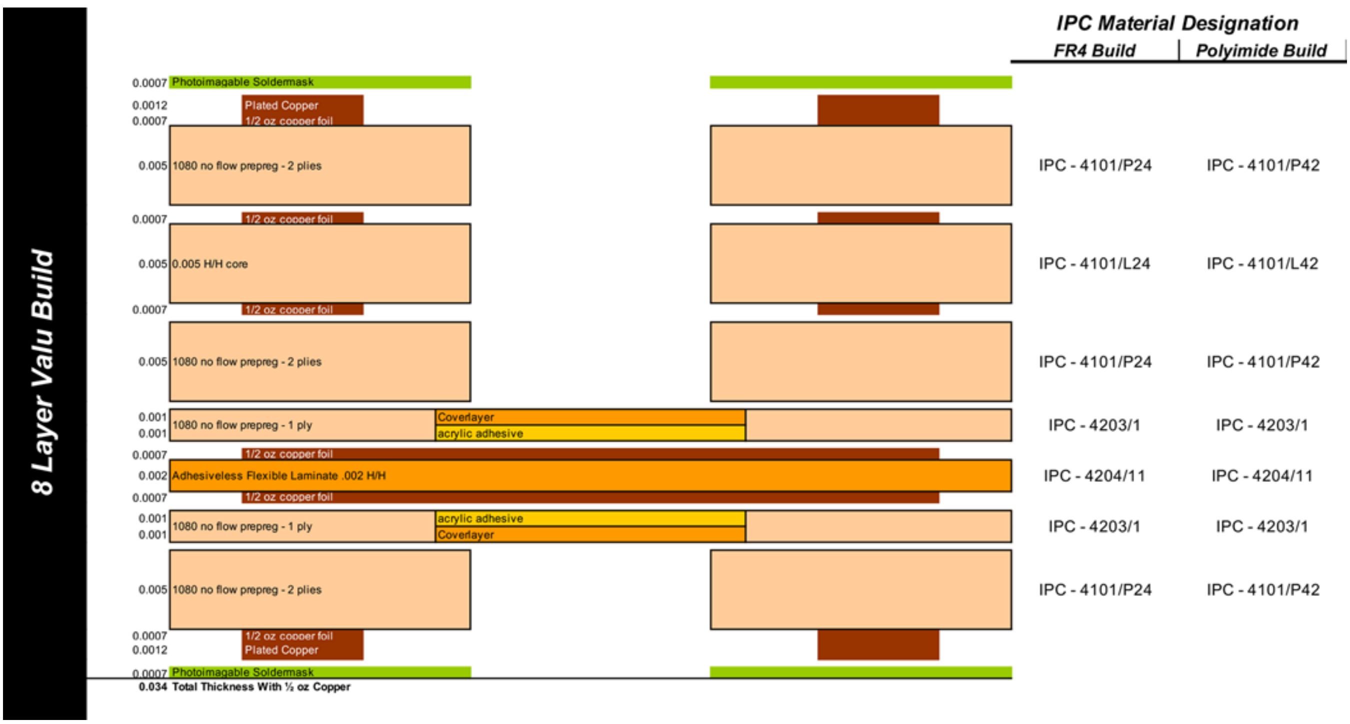


Figure 1: Six-layer rigid-flex with flex layers off-center of the neutral axis.

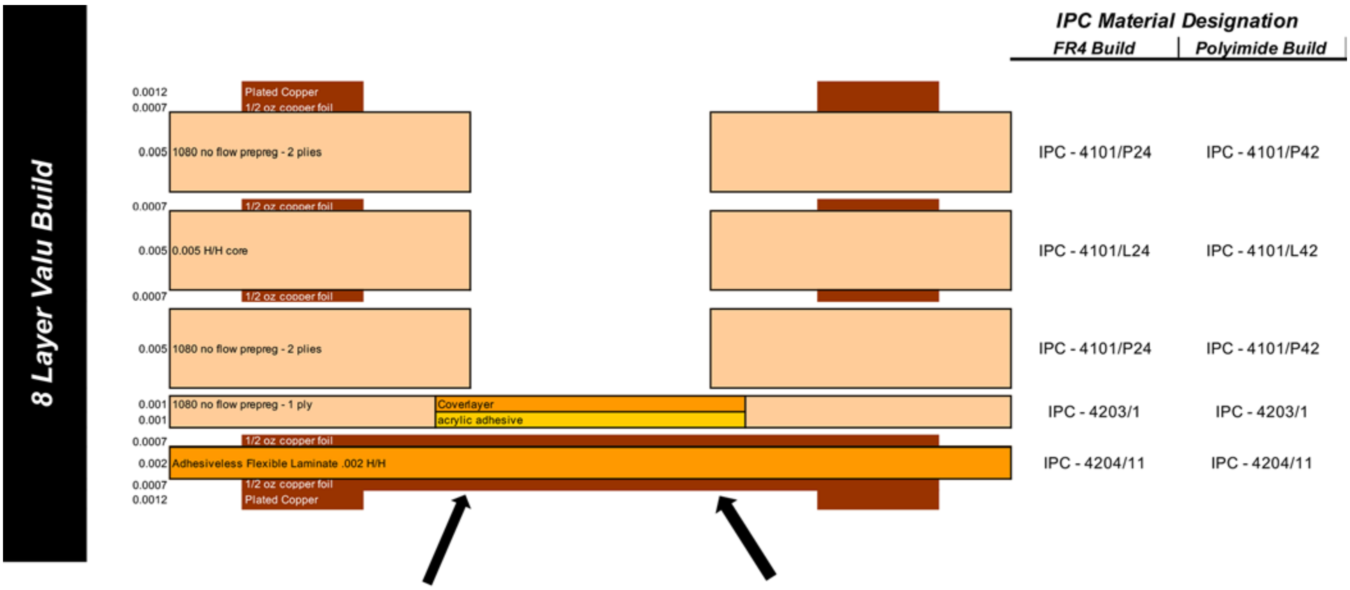


Figure 2: Pressure points at the rigid-to-flex interface.

bly because the processes are planar as well. Thus, it is wise to avoid these constructions if at all possible to improve both manufacturing and assembly yields.

The second one is where the flexible layers are placed on the external layers of the board. These designs are rarer, but they do come in from time to time. Rigid-flex boards with flexible layers as the external layers share the same risk of warp as any asymmetrical board construction due to the CTE mismatch between flexible materials and glass-reinforced materials. They also struggle in photoimaging and plating. Depending on the thickness of the base flexible laminate(s), the distance between the rigid boards, and the width of the circuits being imaged, these designs will have significant yield loss—typically, over 50%. Also, depending on your fabricator, these designs might be unmanufacturable.

The reason is that the flexible areas of the board deform during dry-film lamination, which is crucial to faithfully reproduce the circuits on your design. A material layup with the flexible layers on the outer layers is shown in Figure 2; layers four and five are flexible laminate. During dry-film lamination, the laminator applies pressure to the dry film, so it adheres to the base laminate. The rigid layers remain stable, but the flexible layers conform to the pressure, creating pinch points at the rigid-to-flex interface. The strain deforms the dry-film photoresist and can even deform the flexible layers at the same time. The copper on the flex layers is very soft—rolled annealed copper foil—and is prone to stretching easily when stressed.

Rigid-flex Designs With Flex Arms

A very common technique in rigid-flex design is to have one or more of the flex arms terminate in a flexible board rather than a rigid board. These are often used to accommodate ZIF connectors, hot bar solder joints, conventional connectors, through-hole assembly, etc.

An example of a conventional rigid-flex board and a rigid-flex where one arm is a flexible board are shown in Figure 3. The board on the right is a conventional rigid-flex board where each arm terminates in a rigid board. The board on the left is very similar, but the center arm terminates in a flexible board designed to mate with a ZIF connector. This flex arm was designed to accommodate in-circuit test of the final assembly and was then removed and discarded.

Rigid-flex designs similar to the board on the right are generally very high yielding and run through the manufacturing sequencing with few or no issues, which results in lower costs

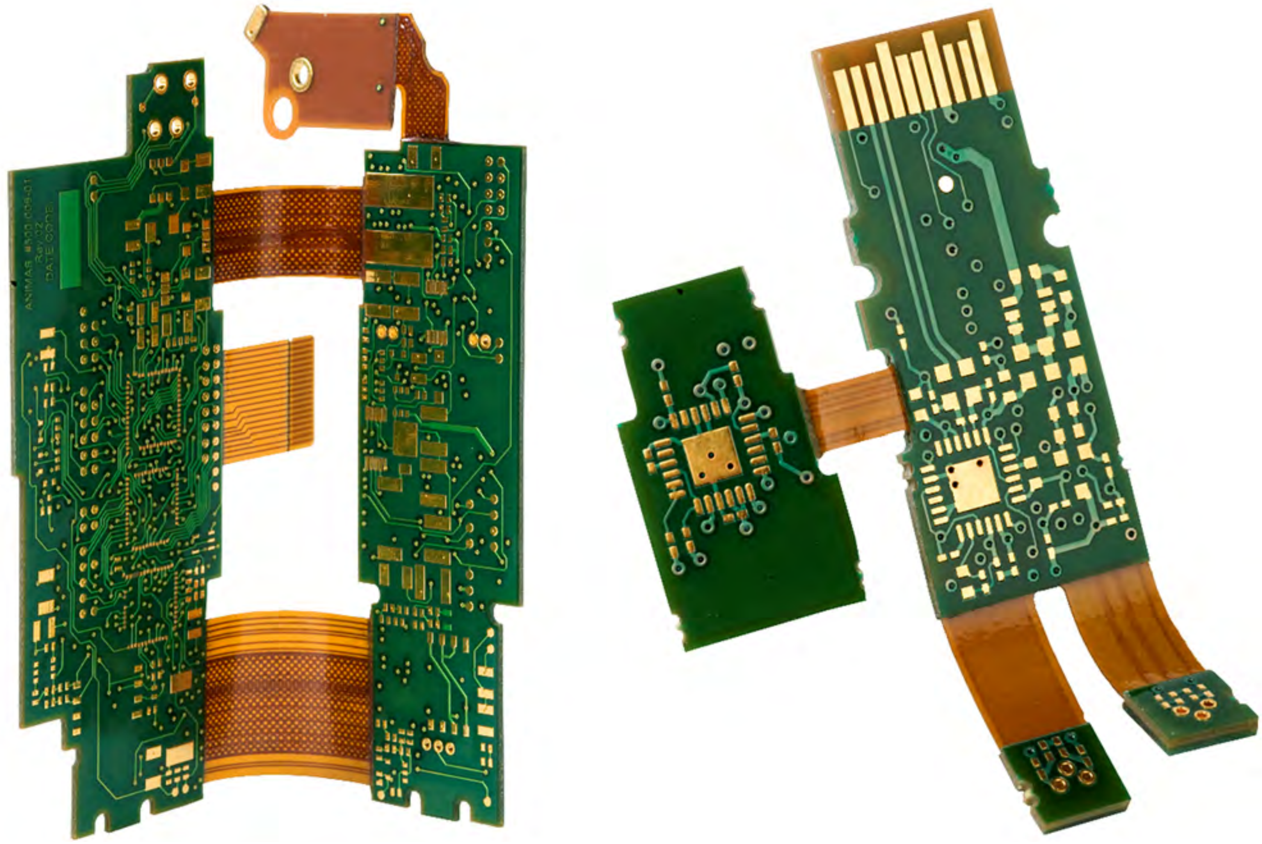


Figure 3: Rigid-flex with flex arm (L) and conventional rigid-flex (R).

for your design. Rigid-flex designs with one or more flex arms that terminate in flex rather than hardboard take longer to build and generally have lower yields.

To build rigid-flex boards with flex arms, we have to build the flexible layers to completion somewhat akin to building a whole board. Then, we take that flex circuit and bury it within the rigid board, using a common technique called "pouching." The pouch protects the inner flexible circuit during outer layer processing. If we were to leave the flexible circuit exposed during outer layer processing, the etching and plating chemistries would attack the circuits and pads on the flexible circuit. Figure 4 shows how a typical rigid-flex with a flex arm is processed.

The core material on the external layers forms a protective pouch for the circuitry on the internal flex layers. This pouch remains throughout the entire rigid-flex manufacturing process and isn't removed until the board is completed through all imaging, drilling, etching, plating, solder mask, etc. It is usually removed just before electrical test so that the connections on the flexible circuits can be tested at the same time as the rest of the board.

Although these designs are very common, their manufacturing sequencing is slower than conventional rigid-flex boards. First, we have to build the flex layers to completion—drilling, imaging, plating, coverlayer lamination, laser route, etc. Often, buyers think we build the whole board all at the same time and don't understand why these designs take longer. The only way to get them to yield effectively is to build them in sequence.

Generally, pouched constructions don't cost much more than conventional rigid-flex, but they are much slower builds. The pouches are usually removed by hand, though under certain parameters can be removed by laser or controlled depth routing. If you have a design with four flex arms that are pouched, that is eight pieces of material that are being removed on each part. If your order is for 1,000 pieces,

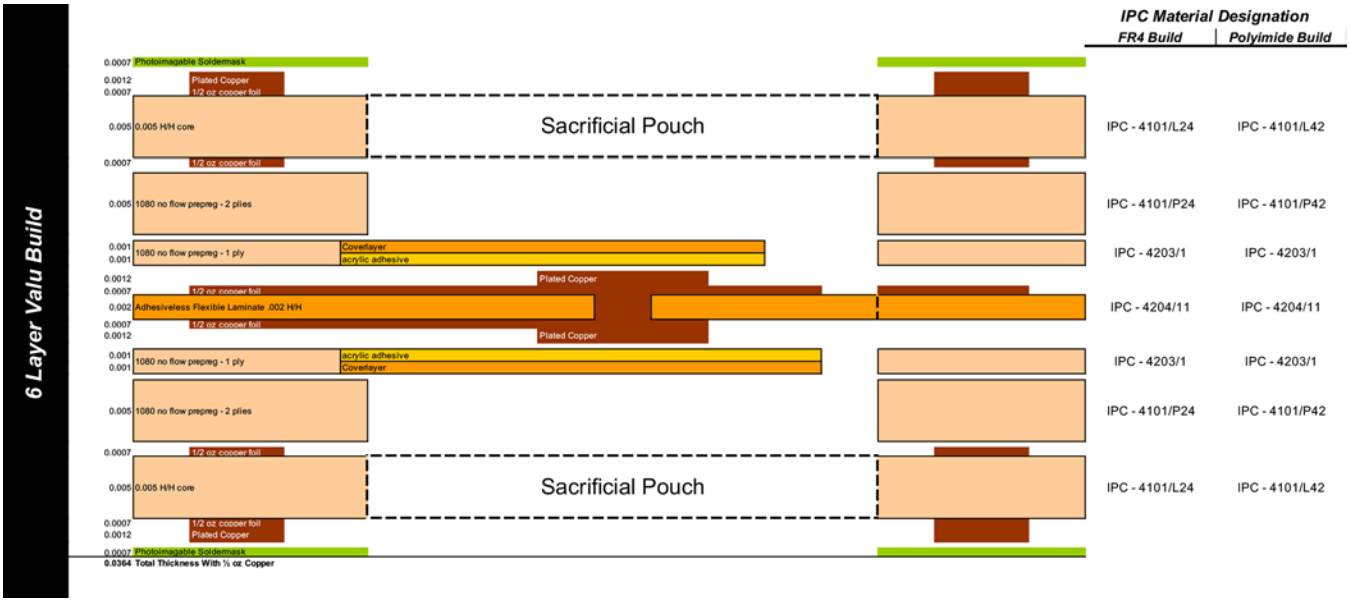


Figure 4: Rigid-flex board with pouch construction.

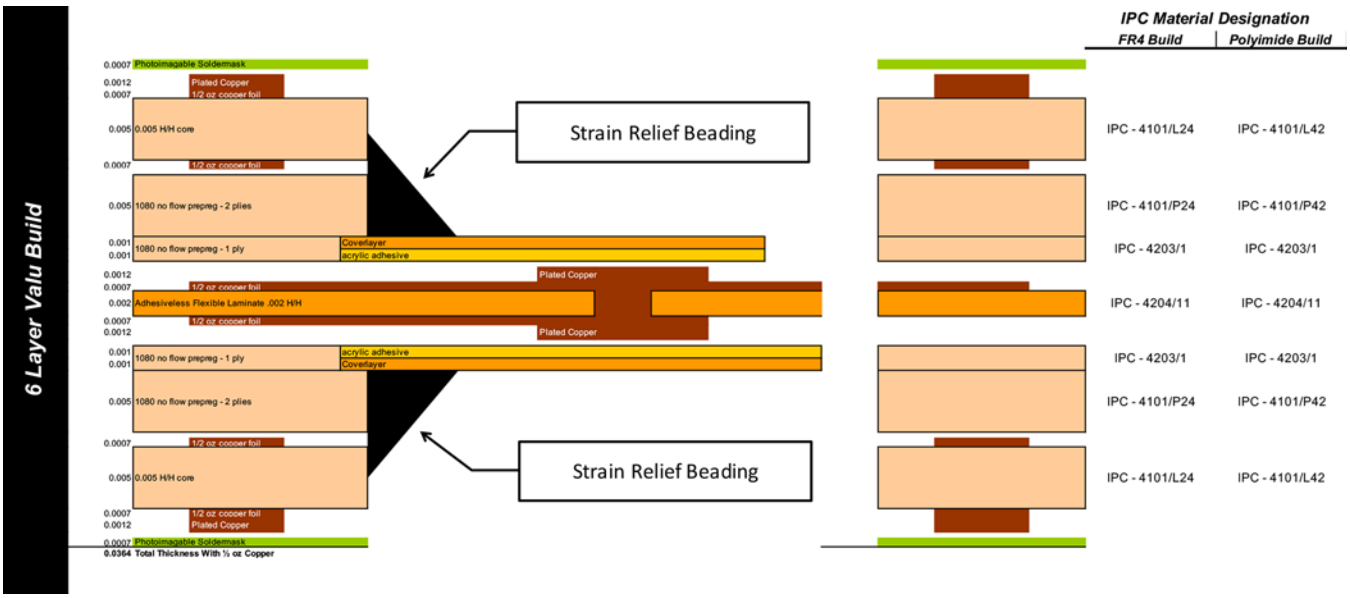


Figure 5: Strain-relief beads applied to the edge of rigid areas to protect flex.

that is 8,000 pieces of core material that must be removed. Again, pouch removal is done at the end of manufacturing just before electrical test where, often, a buyer won't understand why their parts are taking so long to complete.

Pouches also leave an edge along the rigid-to-flex transition area that is exposed glass fabric. It is customary to bead these edges—especially with high-reliability applications—to protect the flexible arm from coming into contact with the glass fabric edge and to protect it from abrasion (Figure 5). The beading material is usually epoxy-based but is soft, similar to silicone. The beading material is also placed by hand, resulting in longer lead times. In the previous example, each flex arm will have two beads placed by hand for a total of 16,000 beads, which can take time to process as well.

One other issue with pouched constructions that needs to be accommodated is dimensioning of the rigid-to-flex transition area—the line of which is defined by no-flow prepreg. The no-flow prepreg actually does flow, and that flow can vary from manufacturer to manufacturer and lot to lot. There will be some variability, which means that the line of your transition can be up to ±0.030". If that dimension is critical to your design, it would be best to consider another method for that flex arm other than pouching it.

In my next column I will discuss other rigid-flex design and manufacturing techniques that may not be the most straightforward, but can definitely be new tools in your toolkit for answering challenging customer design requirements. **FLEX007**

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

Electronic Textiles Research Develops Color-changing and Antibacterial Fabrics

Researchers in the Smart Electronics and Materials (SEMS) Group in Electronics and Computer Science (ECS) and the Synthesis, Catalysis, and Flow Group in chemistry at the University of Southampton are investigating a new technique for achieving light-emitting textiles which could be used in future medical, performance sports, automotive, architecture, and fashion materials.

The new project, funded by the Engineering and Physical Sciences Research Council, is formulating light-emitting films on the surface of standard textiles through electronically functional inks and spray coating, along with cutting-edge inkjet and dispenser printing processes.

"Textiles are demanding substrates for device printing due to their rough surface topology, porosity, and the necessary low processing temperatures. The achievement of suitable functional materials along with reliable, consistent fabrication processes will enable a huge range of new textile products," says Professor Steve Beeby, head of SEMS and the principal investigator.

The research is investigating the fabrication of textile organic light emitting electrochemical cells (OLECs) that can selectively operate at visible and UV wavelengths, representing a step change in e-textile capability. OLECs are electrochemically stable in air, require a low turn-on voltage, and have demonstrated a high luminance level, allowing them to be clearly visible in everyday lighting.

The use of UV-OLEC technology will enable photochromic color-changing textiles capable of fast color change and low operation voltage and power consumption with a more diverse choice of colors and a clearer, more pronounced change in appearance. UV-OLECs will also support textiles to perform ultraviolet germicidal irradiation (UVGI), which is a disinfection method that uses short wavelength UVC light. Textile-based UVGI can be incorporated into medical applications, such as smart bandages, to treat or prevent infection and reduce reliance on antibiotics.

Co-investigators Dr. John Tudor and Professor David Harrowven are drawing upon their groups' complementary expertise in e-textiles, printed devices and processing, the chemical synthesis of complex molecules, and materials formulation.

(Source: University of Southampton)

DuPont on New Beginnings and Empowering the Industry

Andy Kannurpatti

Interview by the I-Connect007 Editorial Team

Andy Kannurpatti gives the I-Connect007 team an overview of the latest news from DuPont Electronics and Imaging. including investments toward the new production assets in Ohio, Silicon Valley Technology Center, and other facilities. He also details how the company is engaging OEMs and PCB fabricators and design teams, as well as some exciting business updates coming this spring and summer.

Patty Goldman: Thanks for joining us to discuss what is happening at DuPont Electronics and Imaging. Can you please tell us about yourself?

Andy Kannurpatti: I lead DuPont's Interconnect Solutions business in the West, meaning the Americas, Europe, Middle East, and Africa. We've opened a new Silicon Valley Technology Center (SVTC) in Sunnyvale, California, which is where I am located. The SVTC is right in the heart of a lot of the new development going on—especially as it relates to high-speed, high-frequency electronics and automotive. This is a great place for us to be. We opened this facility in September 2018, and I moved to this role on October 1. I've been at DuPont for about 22 years in various roles from technical to manufacturing, marketing, and business, so this has been an exciting transition for me.

DuPont Interconnect Solutions focuses on addressing the needs of rigid and flex circuit designers and manufacturers. For our circuits customers, complementary products from our heritage DuPont and Dow businesses coming together allows us to deliver well-known products like Pyralux® and Riston® as well as support fabricators' needs with industry-leading chemistry and plating solutions. Our team also serves industrial applications that use Kapton® as well as industrial plating applications that use Dow chemistries. With the breadth of portfolio, we have an interesting perspective on our customers' needs, and it's a wonderful opportunity for us to help customers in these diverse segments.

Goldman: The reason we asked to speak with you is the recent press release that we published concerning a new facility that you're building in the U.S. Please tell us about that.

Kannurpatti: It's really exciting. What we announced is that we're investing about $220

million to build new production assets in Circleville, Ohio. The driver for that is all of the growth that we expect our customers to see because there is increased demand for very high-reliability polyimide materials with the growth in high-speed, high-frequency applications in telecommunications, consumer electronics, and automotive. Beyond that, we're looking at all the AI work that's going on, not just in the autonomous driving, but with Industry 4.0, etc. Then, there's also this whole area of flexible displays, and we certainly see a need there where we can contribute.

Our teams are working on a variety of products. So, when you look at all of that opportunity in total, it made a lot of sense for our business to request additional investment as the company focuses on how best to help customers in these markets. It is an exciting time to be involved in this growing electronics materials space.

Goldman: It certainly is a growing area. I was especially pleased to see that expansion was going on in the U.S. as opposed to somewhere else in the world. Not very many companies have done that recently. I'm curious if other locations were considered or if it was always going to be in the U.S.?

Kannurpatti: We look at a multitude of factors when deciding where to put additional assets. In this instance, we have a very strong R&D team in Circleville, Ohio, that has been working for many years on the types of materials that we use for these markets and applications. Plus, we also have a long history of producing polyimide film for various purposes at the Ohio site; we've produced Kapton® there for over 60 years. There's a wealth of information and expertise already there.

In our announcement, we also said we're making concurrent investments in Taiwan because we recognize that we need to be close to Asia customers to deliver quickly products they need. So, we're adding investments in Ohio, which is very exciting from a U.S.-based manufacturing standpoint, but we're also are doing things that we need to in Taiwan.

Barry Matties: We are seeing a lot of technology companies moving into the Bay Area, especially around the automotive sector. Are you dealing more with OEMs or the manufacturers? Is there a shift in interest there?

Kannurpatti: That's a great question, Barry. The simple, straightforward answer is we work both with OEMs and circuit fabricators. We

Figure 1: Entrance to DuPont's Circleville, Ohio, plant site where they recently announced an expansion.

feel the best way for us to continue to innovate is to be connected with specifiers of functionality, which tends to be the OEM. We also need to work with the rigid and flex circuit manufacturers because we can come up with the best material, but if the material is not easy to fabricate with, that doesn't help, so we need to talk and work with both parties.

As you point out, the interaction in the Bay Area with participants in all of these new focus areas—especially as you think about autonomous driving and AI being embedded in many different applications—is very dynamic. Working closely with OEMs and manufacturers is critical.

Matties: We're seeing a shift in the design community and the need for more collaboration early on—having circuit designers actually talk to material suppliers—so it's not just the OEMs looking for functionality; it's the designers too.

Figure 2: Leaders celebrate the recent opening of DuPont's Silicon Valley Technology Center.

Kannurpatti: Absolutely. In the SVTC as well as across the globe, we have teams of engineers and scientists talking not only to OEMs but also to the circuit manufacturers. In both of those interfaces, our conversations are around the design, including how to put different materials or structures together.

This is especially important when you think about some of these higher-reliability applications that must last a long time or withstand high temperatures. A lot of testing has to happen during the design phase. So, naturally, we engage with designers early on.

Andy Shaughnessy: We've recently seen a lot of OEMs being forced into flex because the rigid boards just won't fit in the products anymore. Do you spend a lot of time educating new people on flex?

Kannurpatti: To some extent, yes. There's recognition that flex is a real need, so we try to educate people on it, and that quickly translates into, "Can we do some prototyping or test something?" Our team is involved with that along with the OEMs and fabricators.

Nolan Johnson: I have a question about your SVTC facility and making it available to OEMs, which is what I believe you said earlier. There could be a lot of OEMs out there who want some hands-on experience with products, and it sounds like you have some pretty extensive and specialized expertise on staff. If somebody is coming in—such as a five-person design shop doing designs for somebody else as a contractor—are they going to get time and attention at your facility? Is this open to everybody?

Kannurpatti: We certainly want to talk to customers that are engaged in flex and rigid-flex and in applications that we're focused on, and we are open to having conversations and discussions with folks—whether or not they walk in with projects that we're able to support right away. We are open to having conversations with everybody.

Matties: At your Taiwan facility, will it be the same sort of experience and set-up?

Kannurpatti: Taiwan is an important site for us to produce many of our Pyralux® products. It's addressing the broad needs that we talked about, whether that's in consumer electronics, telecommunications, high-speed/high-frequency applications, automotive, etc. So, yes, our investments are related to the same growth drivers.

Matties: One of the things I'm hearing in China now is the trade war is front and center. In the opening ceremonies at the CPCA show, they mentioned the trade wars as being a challenge and having an impact on business in China. What effect has that brought to your company that you recognize?

Our strategies are built on long-term trends. Like every other company, we have to deal with macroeconomic or geopolitical challenges.

Kannurpatti: Our strategies are built on long-term trends. Like every other company, we have to deal with macroeconomic or geopolitical challenges. But when you're thinking about making investments in innovation and assets like what we're doing in Circleville, you want to focus on the long-term. Where are people going, and what kinds of things can we help them with?

Our company today, the new DuPont, is going to be spun out at the beginning of June. Our company purpose is to empower the world with essential innovations to thrive. In the long term, we see that innovation in polyimides and producing new Kapton®, Pyralux®, Riston®, and metallization products is going to be helpful for the electronics industry.

Matties: Great answer. I think that's the right strategy. It's about the long game. It can be easy to get caught up in the short term—which certainly impacts business—but you have to navigate through those waters. You mentioned "the new DuPont." What's driving that? Obviously, there are changes in market conditions, but what is the impetus behind that for you?

Kannurpatti: Dow and DuPont merged in 2017, and we've been on this journey of not only integrating the businesses together but creating three strong, independent companies. As of April 1, a materials science company came out called Dow. On June 1, the remaining portions will split into two. One will be an agricultural enterprise called Corteva. And the new DuPont I referred to, which sits in DowDuPont as a specialty products division, will be an independent company on June 1 as well. We sit in DuPont Electronics and Imaging, which is part of this specialty products division that is going to become the new DuPont.

Matties: So, with the new DuPont, will you be carrying the mission statement of "empowering the world with innovations to thrive" to the industry?

Kannurpatti: Absolutely, and that makes it all the more exciting because the focus in the specialty products division, which is going to be the new DuPont, is all around innovation and growth. We're very excited to address some of those growing needs by investing in innovation and new assets that support where we're heading. Again, to your point earlier, this is about the long game, so we're looking at how to support our customers in the long term.

Matties: It's interesting timing because there's a shift in thinking in manufacturing, leadership, and collaboration in technology. You are bringing in technology centers to support the

continuing growth. It seems like you're on a good path here.

Kannurpatti: We believe so. We are driving in that direction and receiving positive responses from our customers too. This is an exciting time for us.

Goldman: Regarding this expansion, is it going to be all new products?

Kannurpatti: We plan to make new as well as existing products in the assets.

Goldman: Are you developing for semi-additive and additive processes?

Kannurpatti: Absolutely. Our customers use those processes, so we support them. Part of the power of bringing both the heritage DuPont and Dow sides of our portfolio is being able to support that. Not only do we supply the dielectric materials and the photoresist materials—such as Kapton®, Pyralux®, and Riston®, which come from the heritage DuPont side—but we also have all of the plating and processing chemistries for metallization from the Dow side. When you think about semi-additive or modified semi-additive processes, having expertise and products that come from both sides helps deliver an integrated solution for customers.

Thank you for giving us the opportunity to talk to you. We are looking forward to continuing to share where we stand on things and would be more than happy to have more conversations when there is news to share.

Goldman: Yes, it sounds like there will be more news in June. Thank you for your time.

Johnson: Thanks for giving us an overview. This has been very informative for me.

Kannurpatti: Thank you. **FLEX007**

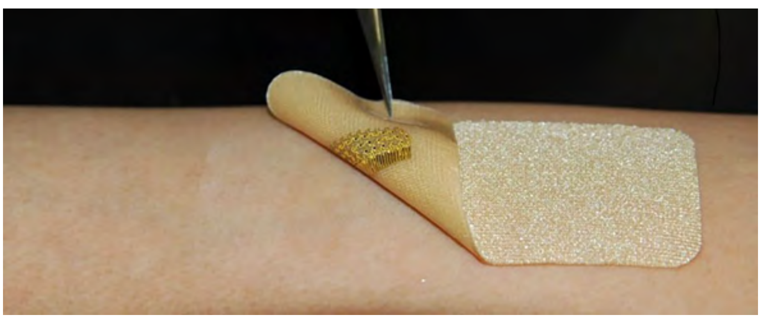
Wearable Sensors Mimic Skin to Help With Wound Healing Process

Researchers at Binghamton University's Intimately Bio-Integrated Biosensors lab have developed skin-inspired, open-mesh electromechanical sensor that is capable of monitoring lactate and oxygen on the skin, allowing for long-term, high-performance, real-time wound monitoring in users.

"We are focused on developing next-generation platforms that can integrate with biological tissue," said Matthew Brown, a Ph.D. student at Binghamton University. Under the guidance of Assistant Professor of Biomedical Engineering Ahyeon Koh, Brown, master's students Brandon Ashely and Youjoong Park, and undergraduate student Sally Kuan designed a sensor that is structured similarly to that of the skin's micro architecture. This wearable sensor is equipped with gold sensor cables capable of exhibiting similar mechanics to that of skin elasticity.

The researchers hope to create a new mode of sensor that will meld seamlessly with the wearer's body to maximize body analysis to help understand chemical and physiological information.

Hopefully, future research will utilize this skin-inspired sensor design to incorporate more biomarkers and create even more multifunctional sensors to help with wound healing. The sensors could be incorporated into internal organs to gain an increased understanding about the diseases that affect these organs and the human body.



"The bio-mimicry structured sensor platform allows free mass transfer between biological tissue and bio-interfaced electronics," said Koh. "This intimately bio-integrated sensing system is capable of determining critical biochemical events while being invisible to the biological system or not evoking an inflammatory response."

[Source: Binghamton University]

FlexFactor Program

Informs, Inspires, Attracts, and Recruits Talent

Emily McGrath, Clarence Chi, Mikayla Ridi, and Brynt Parmeter.

Interview by Barry Matties and Nolan Johnson
I-CONNECT007

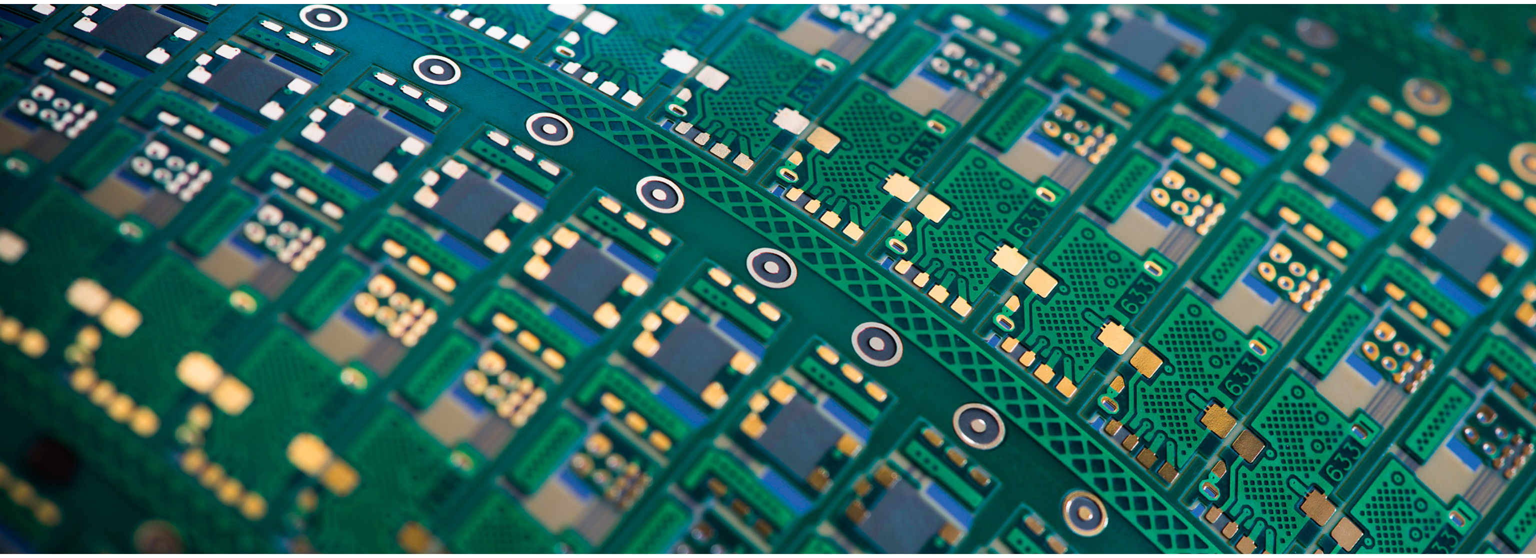
Barry Matties and Nolan Johnson speak with Brynt Parmeter, Emily McGrath, Clarence Chi, and Mikayla Ridi about the NextFlex program FlexFactor. This initiative aims to help high school and college students see potential futures in the advanced manufacturing sector and combat common misperceptions young people might have about modern-day manufacturing.

Nolan Johnson: Brynt, tell us about your role at NextFlex and what the company does.

Brynt Parmeter: I am the director of workforce development, education, and training for NextFlex. We are a 501(c)(6) public-private partnership with nearly 100 members across the U.S., and we've been in existence for three and a half years. Our goal is to advance the technology associated with the manufacturing of flexible hybrid electronics in conjunction with our members. We operate under a cooperative agreement with the Department of Defense, and we are working toward becoming a self-sustaining organization. In addition to the 501(c)(6), we run our workforce development and learning programs under a 501(c)(3) nonprofit and our design and manufacturing services under a C corporation to include fabrication operations within a 20,000-square-foot cleanroom facility at our headquarters in San Jose, California.

Johnson: We could do an entire interview just on NextFlex, but today, could you talk about the vision of the FlexFactor program?

Parmeter: Since our start, we have focused on enabling the creation of the talent needed by our industry partners over time. We are very much looking at the problem from the demand side to identify and quantify the knowledge and attributes needed to tackle what is commonly known as the "skills gap" across the advanced manufacturing and technology sector. We don't have enough young people aware of the sector or the pathways that will lead

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them to become competitive hires. We have a gender imbalance and need to figure out how to reach more women to join this sector as well as non-traditional populations.

We've have put a lot of energy into tackling this problem and are seeing some impressive results. Our flagship program is called FlexFactor, and it's intended to do three things. First, the program aims to provide first-hand experiences that allow the next generation to see what a career in advanced manufacturing looks like. They learn what it is like to work in the field.

Second, it helps engage and familiarize students with the education pathways that lead into the sector and provide the skills and competencies necessary to become the competitive hires that our members, and those they represent, need in their future workforce when Industry 4.0 becomes a reality. Finally, as a project-based learning activity, FlexFactor gives participants the motivation and sense of purpose to want to take that journey and pursue the relevant education pathways to become competitive hires because they've become informed, inspired, attracted, and recruited into the sector through this immersive experience.

Barry Matties: What is the primary age group in the FlexFactor program?

We started with high school students in grades 9–12 and then we expanded the program to include middle school and elementary school students.

Parmeter: We started with high school students in grades 9–12 and then we expanded the program to include middle school and elementary school students. We're also launching a program segment for transitioning service members, veterans, and their spouses and dependent children in the school systems around military installations. We'll start to see the first pilots of these cohorts happen across the country in late 2019 and early 2020.

Matties: How responsive are the schools to this program?

Parmeter: They are very responsive because what is unique about the program is its ability to meet the needs of a range of stakeholders. Companies engage with the program as a strategic talent acquisition activity. Institutions of higher education use it to attract students into the pathways needed by various industries so they can fill seats in classes aligned to the coursework and relevant material. Finally, high schools and middle schools have a vested interest because they need to engage their students with real-world experiences in both higher education and multiple industries. In the words of one high school principal, "Schools and teachers need help understanding the world they're preparing their kids for rather than remaining insulated in purely theoretical settings." That's a large part of what this program does.

Matties: That might be the toughest challenge right there.

Parmeter: It's very difficult. We went through a significant learning curve and a lot of trial and error in the early stages of the program. This is a good bridge for Emily to discuss the strategy, including what we've learned and how the program has evolved into what it is today.

Emily McGrath: The program is intended to unite all stakeholders across a geographically aligned ecosystem who need to be engaged for effective workforce development. But those aren't players who traditionally communicate with each other. We find that high schools are talking to higher education to some extent, but they aren't talking to the industry. And the industry doesn't often engage with higher education outside of specific programs.

What we had to do was figure out coordination steps that allowed these groups to interact smoothly on a regular basis. The program acts as a "Rosetta Stone" of sorts and speaks three different "languages." The key to the success of the program are the project managers, such as Clarence and Mikayla. They need to be able to speak all three languages and ensure that all three stakeholders can communicate with one another about the challenges they have in common. FlexFactor's coordination process is what allows the program to unfold smoothly and achieve the desired outcomes.

Matties: What is the greatest challenge?

Clarence Chi: Industry participation is one of the most critical aspects of the program. Our ability to directly engage students with advanced technologies and professional mentors is transformative, and you see their faces light up after they see how advanced technologies are changing the world around us.

Johnson: For example, a U-2 spy plane just took off and is flying right above us.

Parmeter: That plane is a perfect example because we work with a range of industry partners, including Boeing, Lockheed Martin, and others. FlexFactor is designed to get students interested not just in the technology of flexible electronics but also in the advanced manufacturing sector in general. Many students don't realize that amazing products—such as the U-2 that just flew over, medical devices that are helping to save our loved ones, or automotive technologies—are all products from the advanced manufacturing industry.

Chi: To expand on that idea, the program casts a wide net because it works with existing classes—it's not something students self-select into. The program's touchpoints were designed in a way that allows it to work with any subject—English language development, AP biology, environmental science, mathematics, history, robotics, etc. What all the students have in common is their reaction to seeing modern manufacturing in action. Touring advanced facilities gets them really excited about what's ahead for them in the future and what they can actually do, and they picture themselves working in these environments.

Clarence Chi

Matties: In this environment, there are jobs for every level. You can come right out of high school and be in a job, or you can advance through higher education or specific corporate training.

Chi: Yes. Our industry partners offer a wide variety of career opportunities and pathways, ranging from technicians who come in right out of high school to technologists who need a two-year degree and engineers who need bachelor, master, or Ph.D. degrees. In addition to the technical pathways most people think about when they consider advanced manufacturing, there are also career opportunities in business development, marketing, supply chain management, and other fields that support advanced manufacturing but don't necessarily require a STEM-based education.

Matties: What excites the students?

Chi: The combination of being exposed to this high-performance, high-technology environment and working on projects they care about. During the program, students work in teams to identify a real-world problem that they want to solve and conceptualize an advanced hardware device to solve that problem. They then build a business model around their product concepts. Next, we immerse them in experiences with higher education and various industries to help them understand the range of technology and entrepreneurship considerations. Through these experiences, they think about problems they want to solve rather than simply the degree they want to pursue. By going through this program, they can picture themselves doing the jobs that will let them address the problems they are interested in solving in the future.

Johnson: Can you describe that process of how they go from problem to product and the business-model pitch?

Chi: The program uses a project-based learning approach and seven touchpoints that include basic instruction in hardware development and entrepreneurship as well as field trips to companies in numerous industry and post-secondary education campuses. At the end of their experience, student teams give a four-minute pitch on their product concept and business model to a small panel of mentors. Each team is responsible for identifying a problem and researching and designing their hardware solution and business model.

Through this process, they learn how to develop an argument, create a value proposition, and research empirical evidence to support their value proposition. Along the way, they also learn to engage both business and technology themes to come up with innovative, logic-based products and think through details like how much it will cost to manufacture and distribute to their target markets as well as a range of other considerations.

Johnson: Do you go as far as prototyping and actually building these? Obviously, you work through concept design, starting to plan out the components that go into it. How far down the design path do you go with students?

Chi: Most of the products are conceptual, although students do need to explain what their product sensors will measure or detect, what boundary conditions their processors will use, and other aspects of hardware devices, such as power sources and communication capabilities. Some technical classes will create prototypes of components of the device or use AutoCAD to create a mechanical drawing or rendering.

Parmeter: That largely depends on the class too. The beauty of the program is that we don't sign up individual students; we sign up classes. For example, if it's an engineering design class, their learning objectives may include taking more time to develop a prototype whereas the English class may want to focus on the concept and other learning objectives that this program helps reinforce for the teacher and subject. Regardless of whether the class is going to conceptualize the product or try to build a prototype, the program layers over the existing curriculum and is equally applicable to a wide range of subjects.

Matties: Clarence and Mikayla, both of you are project managers. What does your typical day look like?

Mikayla Ridi: A typical day usually involves implementing one or more of the seven program touchpoints with the classes going through the program. We might start at 8:00 a.m. and go into a class that's just beginning the program to do a kick-off presentation where we give the students an overview of FlexFactor, and tell them what they're going to be working on for the next four to five weeks as well as some basic instruction in technology and entrepreneurship.

On another day, with a class that's a little further along in the program, we might have Industry Engagement Day. That usually starts around 9 am, and we meet the students at the industry partner we'll be visiting that day—locally, that's usually either Jabil or DuPont. Students tour the facility where they see everything from advanced robotic assembly lines to supply chain management processes. They also interact with the people working at the facility who act as mentors to the students and can describe their jobs and what they studied to get their job.

Afterward, the students participate in a product development workshop and have the chance to begin defining the components of their devices. We tell them to not treat this as a field trip but as a work trip so that they can gain a full experience of what a day at work could be like in the advanced manufacturing and technology sector. On another day, we would take them to a college partner to tour the campus, meet instructors and students, and learn about the education programs they can study to acquire the knowledge needed to work at a company like the one they toured the previous week.

Matties: You're tour guides of their future.

Parmeter: Exactly.

Matties: How does the school become engaged? Do they approach you or do you approach the schools?

McGrath: Locally, the program has grown very naturally in Santa Clara County (California) where we run it with our industry partners and our primary college partner, Evergreen Valley College. We usually engage with the school district through the career technical education (CTE) coordinator who identifies a principal in their school district who further identifies the teachers who are creative enough to run the program.

Johnson: Are you expanding nationally?

McGrath: Yes. We're in the middle of a national expansion of the program. We currently have several expansion sites underway, including one in Elyria, Ohio, with Lorrain County Community College and two in Huntsville, Alabama, in partnership with the Alabama Community College System and Boeing. We're further expanding across both New England, the southern portion of the U.S., and several other regions throughout 2019 and early 2020.

Matties: Do you track the progress of a student who has been at this for a number of years?

Parmeter: One of the aspects of the program that we're working on is developing a series of national metrics so that we can track the students who have gone through the program to chart their subsequent education and career pathways. The program is still very young—we launched our initial pilot in 2016 with eight students—so the majority of FlexFactor students are still in high school (e.g., the sophomores are now in 11th grade, etc.).

In the interim period before we launch our formal national study on the program, we're measuring the impact through survey tools with the students before and after to gather an initial set of data points and feedback. One metric we have as a result of these surveys is that upward of 80% of our students indicate a higher degree of familiarity and affinity for this type of career field than they did before the program, which is a huge win for us going back to our goal of helping them see potential futures in the sector.

Students are impacted by the opportunity to engage with the educational pathways that they are exposed to as part of the program.

Further, students are impacted by the opportunity to engage with the educational pathways that they are exposed to as part of the program. In Santa Clara, for example, all students who go through the program are enrolled with our partner Evergreen Valley College. We also track the impact on teachers, and one of the metrics that we're very proud of is that every teacher who has done the program—and we've had upwards of 80 iterations of this across the country—has asked to do it again.

Matties: Do the teachers go on the facility tours with the students?

Parmeter: Yes, the teachers participate in every step. The program is truly a partnership between the project manager—who provides technology, entrepreneurship instruction, mentorship, and external coordination—while the teacher ensures students meet their learning objectives and project milestones and coordinates the activities.

Matties: You're also teaching the teachers some new skills to take into the classroom. What is the greatest challenge about teaching a teacher a new skill set?

Chi: The teachers have varying degrees of technological savviness. So, we have the opportunity to help participating teachers learn how the technology works and how they can incorporate FlexFactor to reinforce or build on their existing in-class learning objectives.

The teachers have varying degrees of technological savviness.

Parmeter: One of the teachers who implemented the program was actually Clarence's teacher about 10 years ago—a computer science teacher at one of the schools we work with.

Chi: She was so shocked to see me! Her class is incredible. And working with my former instructor again is an amazing thing. She is a big fan of FlexFactor and wants to do it every year. She does an amazing job, and her students won the FlexFactor Finals—all three of her classes. The FlexFactor Finals is an event we throw at the end of the year where the top teams from each class compete. It has been a great joy working with her.

Matties: I think that schools must see this as a breath of fresh air too in many ways.

Ridi: The exposure that students gain through our industry and college partners is very impactful. When I was in high school, I didn't know what the real world looked like. Being able to expose these students to the real world is great and something I wish I had when I was in high school.

Johnson: What response do you get from working with the universities watching this program? Are you getting much feedback from them?

McGrath: We highlight the range of educational pathways available to students, which means we emphasize the variety of institutions of higher education that can provide the skills needed by our industry partners, including both two-year and four-year options. Locally, we engage students with both Evergreen Valley College (EVC), which is a two-year program, and San Jose State University (SJSU), highlighting the fact that students can go to either school or they can transition from EVC to SJSU.

Parmeter: We've also had some fairly advanced conversations with the University of Massachusetts System as well. They see this as an interesting program because of its value as an economic and workforce development bridge to create the talent needed by industries in the region. FlexFactor can be used by university systems not just to recruit students directly to the school but also students from the two-year systems as well.

Matties: We see a lot of interest in computer technology jobs and not in manufacturing. However, there's a shift in manufacturing jobs. It's not loading a board into a machine; it's more of an activity that blends computer and

production technology. Is that something that is appealing? What sort of response do you get toward a manufacturing job of the future?

Parmeter: We have been very conscientious about approaching Generation Z as a generation that's uniquely suited to Industry 4.0. If you look at Industry 4.0 as defined by IoT blended with the internet of people (IoP), that looks a lot like the world that young people are growing up in right now; they fully expect to be communicating with machines through technologies designed to facilitate human-machine interface and interaction. Generation Z is uniquely suited to adapt to Industry 4.0 environments.

One of the most rewarding things we have overcome through the program is the common misperception about working in advanced manufacturing. After students tour an innovative manufacturing facility, they realize that working in the field requires them to operate in extremely advanced environments. That is the most important aspect of Industry Engagement Day where students get to see that future for themselves and make decisions based on firsthand experience instead of what their parents or guidance counselors have told them. As Clarence said before, it is a very high-performance, high-technology environment that excites the students—one that lets them solve problems they care about for our whole society.

McGrath: One of the things that the program highlights is that technology is used to solve problems for students who really want to do good for the world and have a positive impact on people. Students often think the best way to help people is through a medical profession or something similar, but once they get to a place like Jabil or DuPont, they realize that helping invent a new technology is a way to impact far more people than they could if they were just going patient to patient. It really opens their eyes.

Matties: There are definitely a lot of ways to contribute to society.

McGrath: Yes, we've partnered with the Morgan Family Foundation, which is a nonprofit that focuses on several things, including environmental education. To help achieve their objectives of increasing student engagement with local environmental issues, we are running several iterations of FlexFactor focused on problem areas related to forestry, water resource, and global climate change. Students in those classes are looking at the intersection of environmental challenges and technology and learning how advanced products and materials can make a positive impact. Clarence and Mikayla just kicked off the first iteration. Do you want to talk about that and what the students saw at DuPont and the Silicon Valley Water District?

Ridi: Yes, we brought the first Morgan Family Foundation class to DuPont's new Silicon Valley Technology Center where the students toured the facility to learn about the range of products and materials DuPont makes and see how they can be used to lower greenhouse gas emissions, etc. Additionally, DuPont's CTO, Alexa Dembek, gave the students a presentation on the biggest challenges the world is facing and how technology can be used to address them. Her remarks helped the students to think about their own product ideas.

Mikayla Ridi

Chi: After that, we took them to the Silicon Valley Water District where they toured the facility and learned about the complicated process of water purification. This was really helpful because most students probably think clean water just comes out of the faucet like magic. Seeing the entire range of activities involved in water purification not only helped them understand how complex this process is but gave them good ideas for their own product concepts.

Matties: How many people are currently at NextFlex?

Parmeter: Right now, 31.

Matties: How many students are involved in the programs at any given time?

Parmeter: We're approaching 3,500 students who have completed the program since we launched in the fall of 2016 with our pilot cohort. At any given time, there are approximately 200–300 students in various stages of the program between our local program and the national expansion. By this time next year, we'll triple or quadruple that number.

Johnson: That's quite a reach.

Parmeter: Yes, it's done in a very scalable way. Through our supporting materials and training process, adopting FlexFactor into a given ecosystem is turn-key. For any industry that's having trouble finding local talent, this program is a comprehensive solution that can help recruit students into the pathways where they will become the talent you are looking to hire in the future.

Matties: How are you funding all of this?

Parmeter: We started using a combination of sweat equity and investment from NextFlex. After a few months, we realized that the program was creating a spectrum of value, including education, workforce development, economic development, talent acquisition, and social responsibility for a wide variety of stakeholders across the labor market. Once we identified the groups the program was creating value for, we used a cost-share approach where each of the partners helps resource a bit of the program, and the result is far larger than any one entity could create or support on their own.

Matties: Did a group of people want to form an organization or what was the impetus?

Parmeter: The program started with the workforce development team at NextFlex. We were interested in creating a program that achieved strategic talent acquisition objectives for our industry partners, but we were eventually able to do so in a way that generated enough revenue to support itself. A program is only able to do that if it solves problems for the actors in the ecosystem. We worked hard to align the program to the needs of multiple stakeholders, including K–12, higher education, government, nonprofit, and industry partners. The program is supported on a cost-share basis by all of the entities who benefit from it.

Matties: And is it zero cost for the individual students who go through the program as a part of their classes?

Parmeter: Correct.

Matties: That's fantastic.

Johnson: Where do you want to see this program in five years?

Parmeter: I would love to see FlexFactor in as many ecosystems across the country as needed. I don't want to say we want to have five million kids, though, because we don't want to create a workforce that exceeds the needs of various industries. But if we need 20 million employees in the workforce, I hope we're able to put 20 million students through. We want to meet the demand of the market in a way that effectively allows a lot of different groups to work together to fire up young people about their futures in advanced manufacturing.

Matties: Has there been any thought given to troubled youths, maybe in detention centers or something along those lines?

Parmeter: Yes, we've run the program with foster youth, and with a continuation school for students who have struggled in the conventional school system. These iterations highlight the social responsibility aspect of the program because you engage a population of students who would not normally find themselves exposed to this type of environment. We also work with a wide variety of public schools—many of which have student populations that are largely on low-cost and free lunch programs.

Interestingly, we often come across student teams from these schools with drastically different product ideas than those from more affluent school systems. One team had a member whose cousin was recently incarcerated for drug use, so they conceptualized a low-profile, flexible parole monitor that used advanced sensors and microfluidics to flag drug use. If drugs were detected, the bracelet would alert friends or family members so that they could intervene before the wearer got in trouble.

> **Interestingly, we often come across student teams from these schools with drastically different product ideas than those from more affluent school systems.**

A team of 16-year old students conceptualized this device, embracing advanced technology to solve real problems. Creating the drive in students to solve the world's big problems goes back to the program's ability to engage students with a range of career opportunities in advanced manufacturing. We aim to create that kind of drive, inspiring and empowering them to solve the big problems facing society and giving them the tools to do that.

Matties: Part of the change is knowing that there is employment out there too. This is a new climate for kids coming out of college; they're able to get a job that is meaningful for which they now owe a quarter of a million dollars or whatever the number might be for education costs.

Parmeter: Many of our industry partners have described this. One of the NextFlex Governing Council members stated that he will take a person who graduates from this program at the same time they graduate high school, and if they demonstrate the propensity and desire to want to work, he will bring them in. He will then work with the company to help fund their two-year college and four-year college if that fits both the student's and employee's future pathway.

Matties: It's a different climate, and foundational knowledge is everything, so great job. Is there anything that we haven't talked about that you want to include?

Parmeter: It's a rewarding program across the board. As I said, for any of the audience that wants to be a part of it, we're a phone call away and can be up and running in just a matter of months. We also have great partners, such as Evergreen Valley College, Lorain County Community College, Jabil, DuPont, Boeing, the Alabama Community College System, and many others. This program is for them and the myriad of others they represent so that they can help inform, inspire, attract, and recruit the future of advanced manufacturing one class of students at a time.

Matties: This has been wonderful. Thank you.

Parmeter: Yes, thank you for the opportunity to chat about it.

Ridi: Thank you.

McGrath: Thank you. **FLEX007**

Flex007 News Highlights

MacDermid Alpha, DuPont Teijin Films and Sheldahl Enter into Strategic Relationship

This collaboration will enable a complete and holistic solution, starting from world class polyester films, to state-of-the art FPC fabrication and low temperature soldering assembly.

Rogers Introduces New Waterproof Flexible Heater Substrate

Available for use in a vast range of industries, the new substrate is designed to improve performance and reliability of both etched-foil and wire-wound flex heaters, particularly those operating in high moisture or underwater environments.

Flexible Circuits Adds DIS Direct Optical Registration

Flexible Circuits Inc. has officially added DIS Inc's latest rigid-flex and flex PCB technology. The RFS system went through rigorous testing not only to prove its ready for production but redundancy as well.

DuPont Expanding Production of Kapton and Pyralux

The new assets will expand production of DuPont Kapton polyimide film and Pyralux flexible circuit materials to meet growing market demand in automotive, consumer electronics, telecom and defense.

ESI Inks Significant Asia Order for FPC Laser Via Drilling Solution

Electro Scientific Industries (ESI), a division of MKS Instruments, Inc. and an innovator in laser-based manufacturing solutions for the micro-machining industry, receives an order for its recently released CapStone laser drilling solution for processing flexible printed circuits (FPC).

FCCL Makers Keen to Develop New Material Solutions for 5G

Taiwan makers of flexible copper clad laminate (FCCL) and coverlay, materials for flexible PCBs, are gearing up to develop new material solutions and build new production lines to cash in on huge demand for FPCBs for 5G smartphones.

Insulectro to Distribute Pacothane Products Across Canada

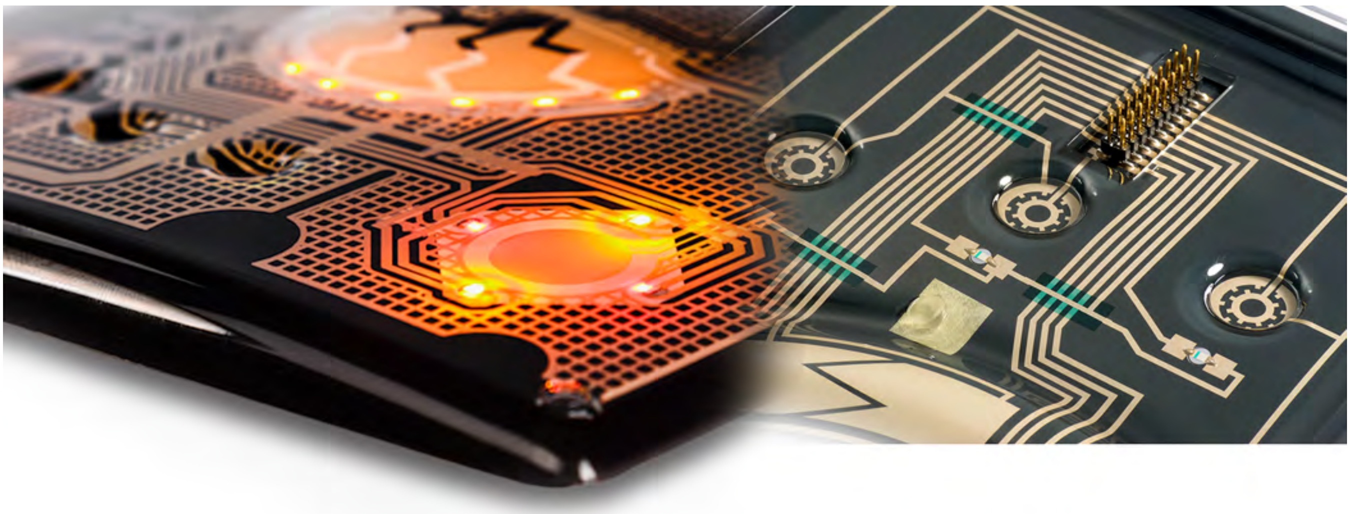
Insulectro, the largest distributor of materials for use in the printed circuit board and printed electronics industries, has announced it will distribute Pacothane lamination-assist products across Canada beginning April 1, 2019.

Trackwise Ships 26m-Long Flexible Printed Circuit

Trackwise has shipped a 26-metre long multilayer, flexible printed circuit (FPC), believed to be world's longest ever produced, for distributing power and control signals across the wings of a solar-powered, unmanned aerial vehicle (UAV). The circuit is one of over fifty supplied by Trackwise into this vehicle.

New eBook Explores Tips for Executing Complex PCB Designs

I-Connect007 is excited to announce the release of the latest title in our educational library: *The Printed Circuit Designer's Guide to… Executing Complex PCBs.*



Creating Smart Surfaces With Electronic Functionality

Article by Pete Starkey
I-CONNECT007

Of all of the technical user presentations I attended at the AltiumLive design summit in Munich, the one I found most fascinating introduced an innovative technology that encouraged a bit of lateral thinking and appealed to my creative side. "IMSE: Creating Smart Surfaces with Electronic Functionality" was the title of the presentation by Sini Rytky, VP of product management, and Tuomas Heikkilä, senior hardware specialist, both from TactoTek in Finland.

Rytky explained that IMSE stood for injection-moulded structural electronics—a technique for integrating flexible printed circuitry and electronic components into three-dimensional moulded structures with touch-sensitive functional surfaces, using standard high-speed manufacturing methods and equipment.

The IMSE manufacturing process was logical and straightforward in concept. Starting with a flat thermoplastic film—typically a polyurethane or an in-mould labelling film—standard printed-electronics techniques were used to apply conductive features such as circuitry, touch controls, and antennas as well as decorative features and user-interface graphics. Surface-mounted components and LEDs were added by standard pick-and-place techniques while the substrate was still flat—presumably using conductive adhesive, although this was not disclosed. Then, the assembly was thermoformed into a three-dimensional shape and injection-moulded to form a thin, lightweight, functional unit with a smart, touch-sensitive surface and all of the electronics fully encapsulated and embedded. Of the numerous potential application areas, the most obvious was the integration of touch controls into automotive interior trim.

Designs could incorporate one or two films with electronics on one or both. Rytky showed an example of the stackup for a two-film structure. The top surface layer was an in-mould labelling film—although it could have been a natural material like leather or wood—printed with decorative inks. Next, came the first electronic layer, which was printed with conductive and dielectric inks and assembled with SMT components. At the centre of the stack was a layer of thermoplastic resin, polycarbonate, or polyurethane; then, the second electronic layer; and finally, an in-mould labelling film. Rytky stressed that the essence of IMSE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design was to understand how these different materials and components would behave once they were put together, stretched to a three-dimensional form, and ultimately injection-moulded into a single unit.

Because IMSE enabled electronic functionality to be integrated into three-dimensional surfaces and in space-limited locations, there was enormous scope for innovative design, and decorative surfaces could be made functional without changing their mechanical structure. Further, conventional electronic assemblies could be substantially reduced in thickness, weight, and complexity.

An example demonstrated by Rytky and passed around the audience was a typical automotive overhead control panel. In its conventional form, it was a bulky structure, 45-mm thick, and weighing up to 1.4 kg with 64 individual mechanical parts, and its assembly required 30 separate operations. In terms of durability and reliability, the structure was fully encapsulated and protected from debris and moisture, and fully functional over a -40°C to +80°C temperature range. In another automotive example, touch-sensitive illuminated seat controls had been integrated within a real-wood door trim and the overall thickness was only 3 mm.

Electronic functionality could even be integrated into fabrics for wearable electronics, and a fully encapsulated smart connector had been developed that could withstand more than 10,000 twists and bends and more than 50 cycles of machine washing.

Clearly, traditional electronic and mechanical design rules and guidelines were generally not applicable to the design of IMSE where an entire design team could be working in parallel to define the layout of the thermoplastic film, which carried the user-interface graphics, the part geometry, and the electronics. It had been necessary to collaborate with suppliers of familiar design tools to create add-ons specific to its features and characteristics. And because the full film assembly—including its electronics—would subsequently be thermoformed and injection-moulded. Additional challenges had been overcome in the simulation of electromagnetic performance, thermoforming, and injection-mould flow.

Sini Rytky

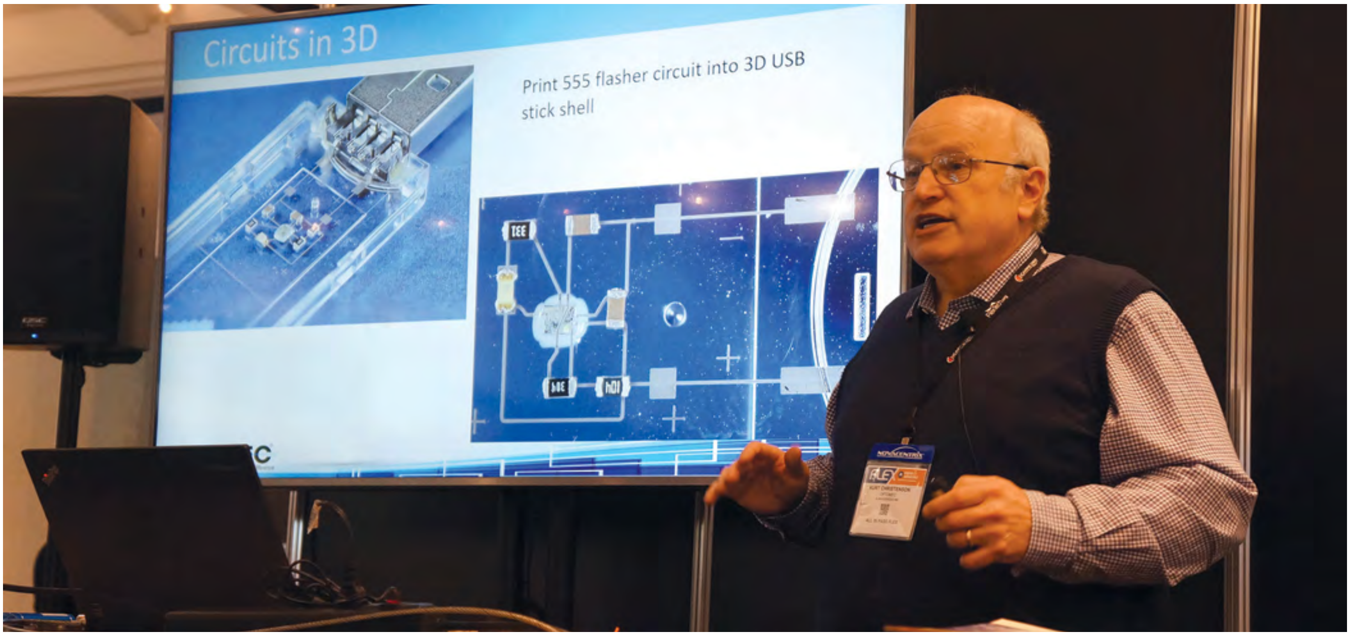
Tuomas Heikkilä

Rytky handed over to Tuomas Heikkilä to discuss the IMSE electronics design flow and review the main design-for-manufacture differences comparing IMSE with traditional PCB technology. Apart from the obvious dissimilarities in the nature of the substrate—because the conductors were composed of silver flakes and polymers rather than solid copper—their dimensions and current-carrying capacities followed completely different design rules. Dielectric bridges had to be designed in at conductor crossovers and components carefully placed to avoid areas that would be significantly stretched during the process of forming from two-dimensional to three-dimensional.

Using the automotive overhead control panel as his example, Heikkilä identified the principal electrical and mechanical features, and explained how the stackup had been created and the layout defined, design-rule checked, and simulated before the output of the tooling and fabrication files.

Although TactoTek had the in-house capability to design, develop, and validate products according to customer requirements, they were also prepared to licence design and manufacturing expertise to enable customers to exercise their own creativity with proven technology. As the closing slide of the presentation declared, "This is not the future; this is today!" **FLEX007**

Pete Starkey is technical editor for I-Connect007. Based in the UK, Starkey has more than 40 years experience in PCB manufacturing technology, with a background in process development and technical service. To contact Starkey, click here.



Growing Opportunities With 3D Printed Electronics

Interview by Barry Matties
I-CONNECT007

Dr. Kurt Christenson, senior scientist at Optomec, discusses the company's Aerosol Jet technology, which eliminates the need for wire bonding by printing interconnects on 3D surfaces. Christenson also explores the current state of the technology and highlights the market segments and applications with the most to benefit from being able 3D print electronic components, such as resistors, capacitors, antennas, and transistors.

Barry Matties: Kurt, can you tell us a little bit about your company?

Dr. Kurt Christenson: Optomec makes additive manufacturing equipment. We have two divisions. One division makes a product called LENS that makes a melt pool in metal with a laser and then sprays powdered metal in to add material. When it cools and freezes, it follows the crystal structure, so we can repair a single crystal turbine blade or make full 3D metal parts. My part of the company makes a product called Aerosol Jet, which atomizes an ink. We don't care what's in the ink as long as we can make roughly three-micron droplets. Then, we aerodynamically focus it down to a size where we can make from 10-micron lines to three-millimeter strips, depending on the need. My personal focus has been on connecting integrated circuits. We call it three-dimensional IC or 3D IC.

Matties: A while back, I did an interview with your colleague [Pascal Pierra] where we discussed printing on the wings of airplanes and such.

Christenson: Yes. That was the Aerosol Jet, which is my side of things. One of the things we do is print on aircraft wings. For instance, antennas on drone wings is a common interest that we get. A second would be heaters on specialty windows or headlight heaters.

Matties: Now, you're showing me all of these miniature parts, which is quite the opposite.

Christenson: For larger things, we are a precision company. We call it mesoscale printing between nanolithography and something larger like screen printing, but there is a need for mid-range printing also. Our wider nozzle is

three millimeters, and we're working on larger widths yet. For instance, high-temperature fuel cells run at hundreds of degrees and have multiple layers; further, they are not expansion matched, so they tend to crack at the interface. We print very thin layers and slowly grade it from A to B so that there isn't a sudden change from large to small expansion, but something in the middle.

Matties: In your presentation, you talked about the harsh environments that you're able to withstand. That's quite an achievement too.

Christenson: Yes, that's because we can tailor the materials and structure. Metamaterials is a buzz word now. For example, I mentioned the idea of a BGA bump between the circuit board and chip that was compliant. If you form the bump out of something rubbery and put silver or some other ductile, moveable conductor on top of it, you don't have to worry about expansion and contraction. Imagine connecting stiff silicon to a stiff circuit board that expands at different rates with even a solder drop; it will fail, so we're really excited about some of these technologies.

Matties: That's an elegant solution. What types of challenges are customers coming to you with? What's the typical desire for this technology?

Christenson: I'm in the applications lab, so people come to us when they're considering buying equipment, saying, "I'd like you to make me one of my parts or a hundred of my parts first." We get requests for a serial number or a specialty marking printed on six-foot, 100-pound turbine blades to the microcircuits we're talking about here. We also get a lot of stuff for medical, such as printing on catheters, and antenna work. IoT is making everything smaller and smaller, so antennas are getting smaller as well. And they're small, but they're still big enough that they could be screen printed—but they're wrapped around the inside or the surface of the device. Thus, much of our business is three-dimensional where something else can print the pattern but not on a given shape.

Matties: Are there any limits to what you can print on?

Christenson: We have to be able to harden whatever it is we print. If it's a dielectric, which a lot of those are UV cured, that's fine. But if it's a metal, we don't have any inks right now that cure below 80°C, and those still have compromises. Companies that make inks are making rapid progress in metal inks, but there are always trade-offs, and there's still more progress to be made. For instance, I tested an ink last week that had fantastic conductivity, 120°C sintering, but it fell off the substrate. And when you add adhesion promoters, that degrades the conductivity.

Also, people want to use copper instead of silver because it should be cheaper in the long run, for example, so that's just coming online. For substrates, our biggest problem is stretching. We don't have a very conductive ink that is stretchable. Wires don't stretch well, and that's just the way life goes, and the medical segment loves silicone. If you've ever tried gluing anything to silicone, it's not a good thing.

Matties: Are there applications where the military is using this in the field?

Christenson: I can't comment on in the field, but I can tell you what they're looking at. One of the things I showed was a nose cone antenna on a missile nose cone—the spiral—so we put a lot of antennas in weird places for military use. We also talked about the thermal expansion coefficient earlier; their stuff gets stored in the desert and in space, so they have huge temperature swings. Further, they are the leaders for high frequency, 10–20 gigahertz and above, and wire bonds, and those little wires that arc between the circuit board and silicon have a high inductance.

We normally think of wires as being perfect with maybe a little bit of resistance, but they have inductance and capacitance too, which causes them a real problem. We can print conductors that are more ribbon-shaped, which is what they need for their ultra-high frequency

Dr. Kurt Christenson

work. In the last month, I've done two of those demonstrations, so they're very interested.

Matties: So, the rate of acceptance and integration of 3D printing into our world is a hockey stick now.

Christenson: Absolutely. The difficulty is that a lot of these have long qualifications. Thankfully, medical device companies and the FDA are very conservative. Also, military stuff has to work for 20 years; it's not cheap consumer stuff that will be replaced in a year and doesn't matter if it doesn't work. People's lives depend on this stuff, so it's going to take a while and a lot of successful tests before they will bet their lives on it.

Matties: Really, the IP that you're offering is the jet.

Christenson: Actually, we're a printer company. We make the printhead, so that's our main product. We do automation just because a lot of our customers don't want to do the automation themselves. So, if our automation fits your need, fine. If not, we'll help you bolt our head onto your automation. For instance, with the people printing on the turbine blade, that didn't fit our automation, so they made their own.

Matties: But they're using your printhead.

Christenson: Yes. And likewise, our automation is fairly general and used for a wide number of purposes. Let's say that you're going to replace wire bonding. A company may have 1,000 wire bonders. It's cost effective to make an automation solution that only does exactly what they need and nothing more. So, those are the things we're working with now.

Matties: Now, when someone takes or uses your printhead, what's that revenue model?

Christenson: This time, they're just purchasing it. And there are spares that they will be purchasing, but we do not supply inks. We are dependent on the materials vendors. And if you think of all the skill set out there in materials vendors with names like DuPont and HD MicroSystems, there's not a chance we can keep up with them. So, we are ink agnostic. We'll tell you what you need, and we'd love for you to bring us a sample.

Matties: And the technology has grown. How many years have you been at this now?

Christenson: I believe it's about 12. It has been slow in coming partially because the materials are just catching up. I think it was an answer before the question was fully formed, but the question is formed now. If you want to print the circuit on the inside surface of your hearing aid case, I think we're the only game in town.

Matties: What is your role in the company?

Christenson: They call me a senior scientist. I'm involved with proof of concept. For example, I become involved when a company comes and says, "We want you to connect our chip for an image sensor. We don't have room for a 45-micron arc of wire bonds, so we have to have all of these connections. And, by the way, they have to have these properties. And how steep can you make the slope? And will it stick to this material?" I have to deal with all of those problems and make their part before they buy the equipment.

Also, we have to do R&D to come up with new ways to do printing, such as shuttering. Historically, we've had a mechanical shutter. I was involved in the development of an internal shutter that sucks the mist to the side so that there's no buildup on a mechanical shutter. I'm a part of the applications group that does those kinds of advances.

Matties: That's fun.

Christenson: On any given day, you could be doing chemistry or fluid dynamics. It's pretty amazing.

Matties: And geometry of shape is not an issue whatsoever?

Christenson: Well, it's an issue in that the more 3D it is, the more axes you need. I have a picture of a globe on a small plastic ball where we printed the continents. It takes five axes to do that, and the issue is programming those five axes. We have machine tool software that came from the five-axis mill industry, and we're working with a company that makes the software. One of the big problems is, let's say you're going around a corner, it's all right for a mill to slow down and just creep along the corner and then come back up to speed. We have to hold a constant speed, and they're looking at us and going, "What?"

Matties: Do you have to hold a constant speed because of volume?

Christenson: Yes, because of what's coming out.

Matties: Could you adjust for volume?

Christenson: We're working on that. We can adjust it.

Matties: It seems like the simple solution.

Christenson: It is, but if it's a sharp corner, it basically has to go to zero while it prints around. Typically, if you want to do a sharp corner, the first thing I do is try to talk you out of it. Give me some radius. The second thing I do is print off one edge, print up the horizontal plane, and print up the vertical plane and let it connect. Or better yet, let me come in at 45 degrees; I'll hit them both and go through it both directions.

And if you saw the picture of printing wraparound circuits on one-half-millimeter glass, that's how that was done—twice at 45 degrees. We've spent a lot of time figuring out how to do stuff, so we can get you pretty close on what ink and hardware you need, and the programming techniques. We have a lot of expertise that was very expensive to acquire, and you don't have time to acquire it.

Matties: Nor do we want to spend the time, right?

Christenson: Correct. You want to buy a solution.

Matties: Is there anything we haven't mentioned that you feel we should cover?

Christenson: The only other thing is we're working with passives, making capacitors, resistors, and inductors. That's a work in progress. We're doing okay on resistors. Inductors are three-dimensional and a little tougher. But we can even print transistors. We work with Dr. Frisbie at the University of Minnesota, who's the chair of the material science department, printing MoS transistors. When that material set gets done, that's going to be very valuable. Then, for very large area things like signage, you can just put the drive transistors locally.

Matties: Well, it's fast-moving, and we're going to see a lot of changes. Electronics are everywhere. Thank you for your time, Kurt.

Christenson: Thank you very much. I'm glad you came by. **FLEX007**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1 Flex/MSTC Joint Conference: A Collaborative Week in Monterey ▶

Collaboration filled the air at the Hyatt Regency in Monterey, California, as the 18th annual Flex Mems&Sensors technical conference brought flex technology and sensor experts and 550+ attendees together to network and share ideas.

2 Staying Current on Flex Manufacturing is Smart Business ▶

This discussion revolves around how to better design for flex, and ways designers can stay current on manufacturing technology that can impact their flex boards.

Brendan Hogan

3 Laser Focus on Flex and Rigid-flex ▶

ESI's Chris Ryder, director of Product Management, and Shane Noel, Flex Systems product manager, discuss laser vias for flex users and the increasing necessity for companies to collaborate early on and become more and more involved, whether that be in the product design, or with the process or base material manufacturers.

Shane Noel

4 AltiumLive Munich: Day 2 Keynotes ▶

Having enjoyed the conference dinner and robot battles of the previous evening, a good night's sleep, and a hearty breakfast, Altium's family of over 220 electronics engineers and designers eagerly returned to the conference room. Many jostled to secure the best seats for the second day of the European AltiumLive design summit in Munich, keen to make the most of the "learn, connect, and get inspired" opportunity it offered.

5 Institute of Circuit Technology Evening Seminar ▸


Andy Cobley

The Institute of Circuit Technology hosted its first 2019 seminar at the Woodland Grange Hotel in Royal Leamington Spa in the Midlands of England on February 26. The diverse programme of four presentations was introduced by ICT Chairman Andy Cobley, a professor at Coventry University, who stood in for Bill Wilkie, who had been taken ill at short notice.

6 EPTE Newsletter: Printable and Flexible Electronics in Taiwan ▸

As the keynote speaker of Printable and Flexible Electronics, a two-day conference held at the Industrial Technology Research Institute (ITRI) in Taiwan, my presentation included current business trends and future forecast for the global printable and flexible electronics industry.

7 The PCB Norsemen: PCB Standards for Medical Device Applications—A Hard Nut to Crack! ▸


Jan Pedersen

With digitalization, AI, and IoT, the traceability and transparency to how a PCB is produced will be even more important. We must rule out the PCBs that follow the standards to the ones that do not. The day will come when you or someone you know might need a medical device, and you want to make sure it does its job correctly.

8 Flex Talk: FlexFactor—Imagination and Innovation ▸


Tara Dunn

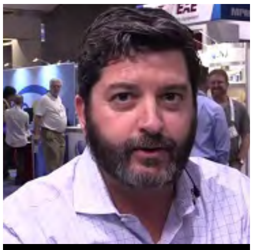
The ultimate goal of FlexFactor is to create a generation of students who use their critical thinking, creativity, communication, and collaboration skills to create the materials and devices that will address and mitigate the biggest challenges of the future.

9 Standard of Excellence: Microwave PCB Bonding Methods—What Designers Need to Know ▸


Anaya Vardya

There are three methods commonly used for bonding multiple layers of RF and microwave PCB laminates such as PTFE (Teflon) materials like Rogers Duroid. Each has their own pros and cons that PCB designers need to understand to balance cost and performance.

10 Video: Lenthor Discusses Facility Expansion and New Equipment ▸


Rich Clemente

Rich Clemente, general manager of Lenthor Engineering, discusses with Dan Feinberg, I-Connect007 Guest Editor, the company's expansion and new facility and equipment. He also talks about his outlook for the electronics manufacturing industry in North America.

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Events Calendar

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

IPC Automotive Electronics High Reliability Forum ▶
May 6–7, 2019
Nuremburg, Germany

CPES2019–presented by intelliFLEX ▶
May 16–17, 2019
Bromont, Quebec, Canada

IPC IMPACT Washington, D.C. ▶
May 21, 2019
Washington, D.C., USA

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

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

EIPC 2019 Summer Conference ▶
June 13–14, 2019
Leoben, Austria

IPC SummerCom and Materials Conference ▶
June 15–20, 2019
Raleigh, North Carolina, USA

IPC E-TEXTILES 2019 Conference ▶
September 11, 2019
Philadelphia, Pennsylvania, USA

IPC E-TEXTILES Symposium ▶
November 11–12, 2019
Munich, Germany

Additional Event Calendars

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