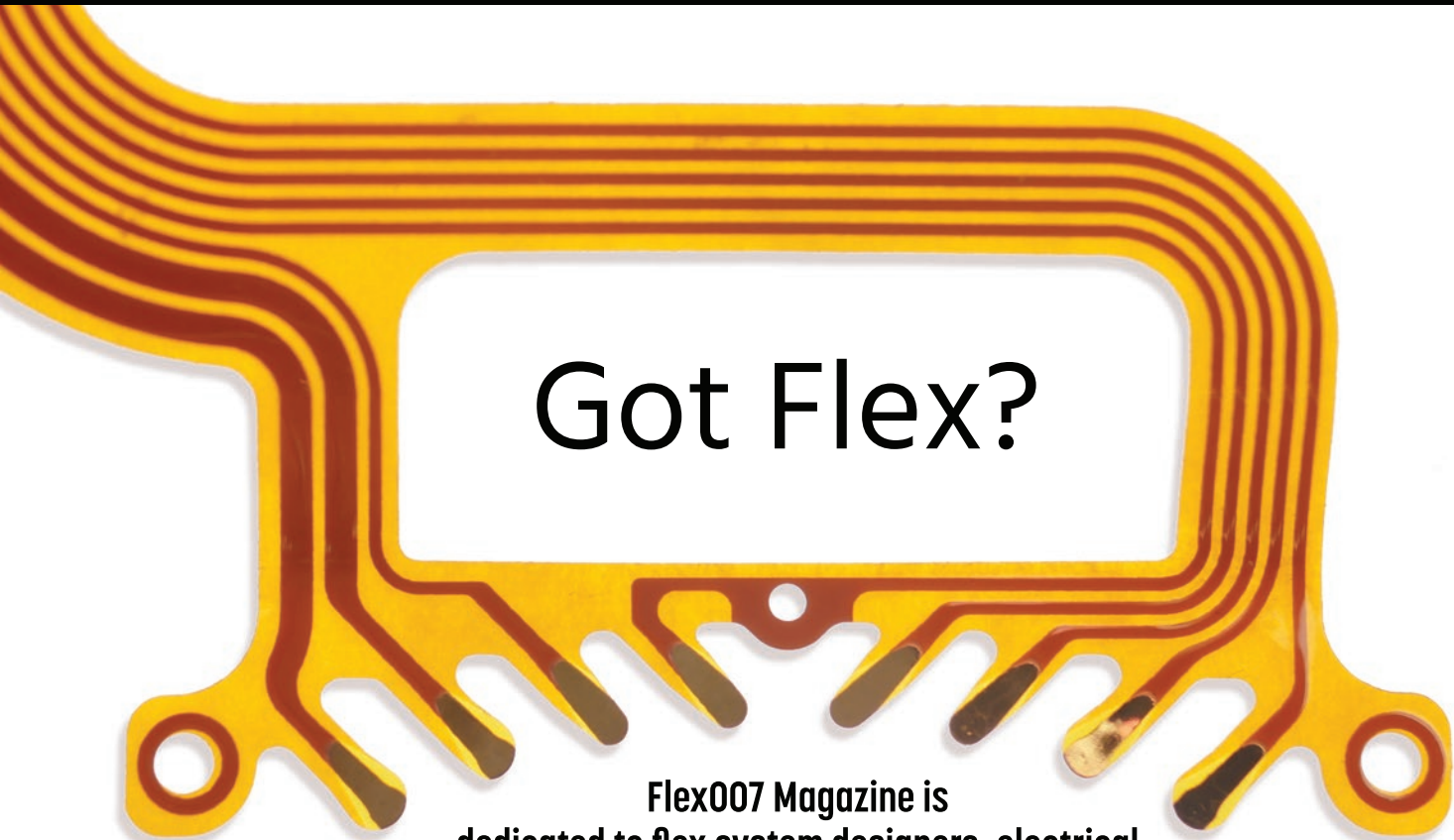


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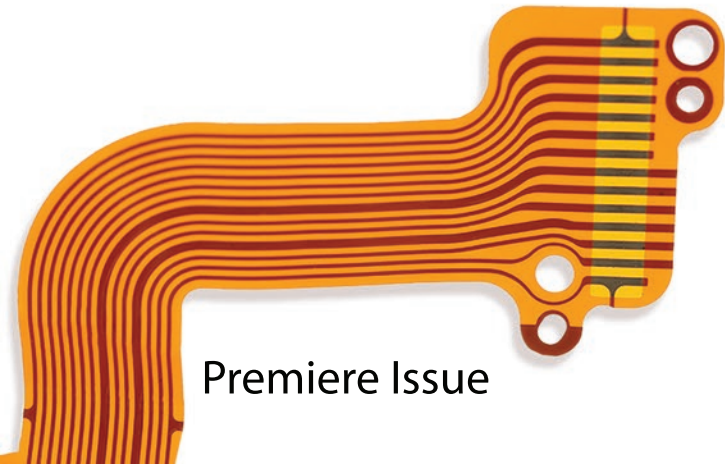
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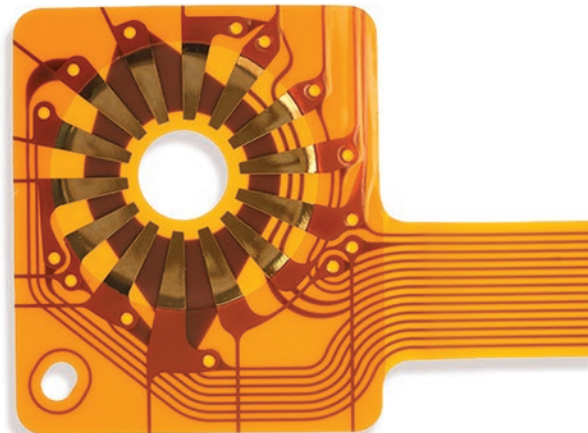


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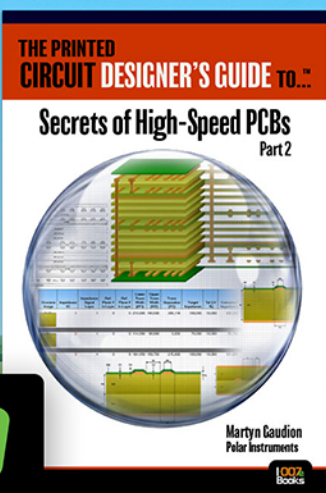
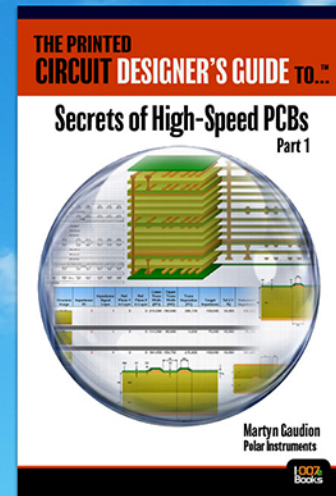
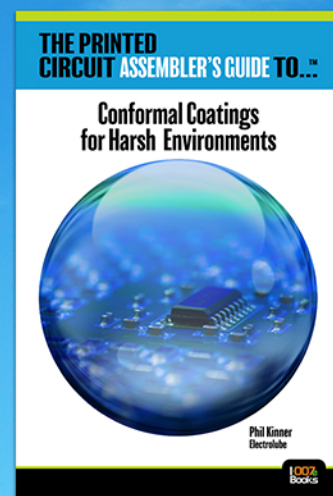
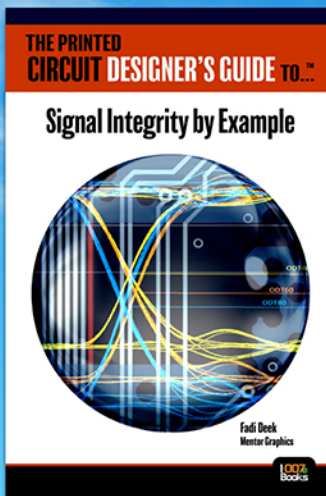
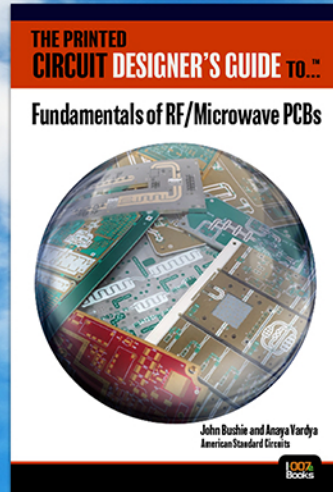
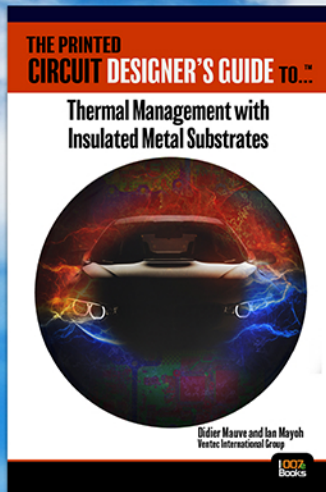
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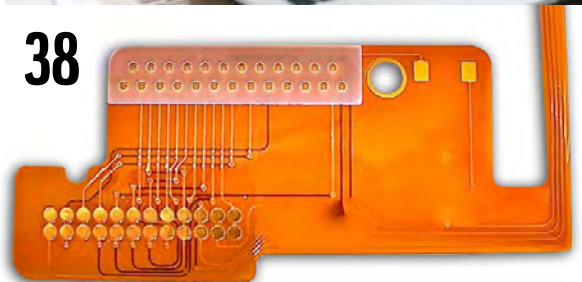
Premiere Issue!

Welcome to the first issue of *Flex007 Magazine*. This new quarterly magazine is dedicated to flex system designers, electrical engineers, flex PCB designers, and anyone responsible for integrating flex into their products at the OEM/CEM level.

For this first issue of *Flex007 Magazine*, we asked some of the top flex experts to share their thoughts about flex, rigid-flex, and the overall flex market.



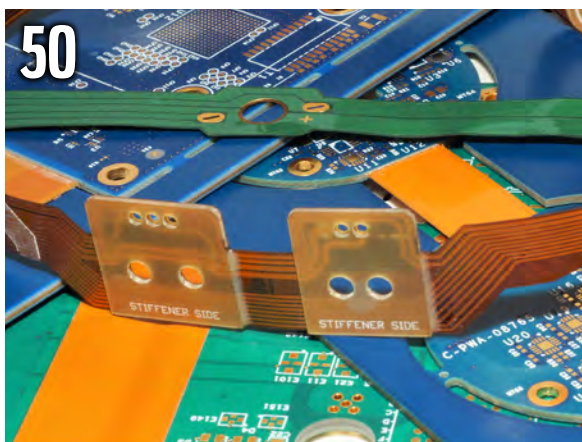
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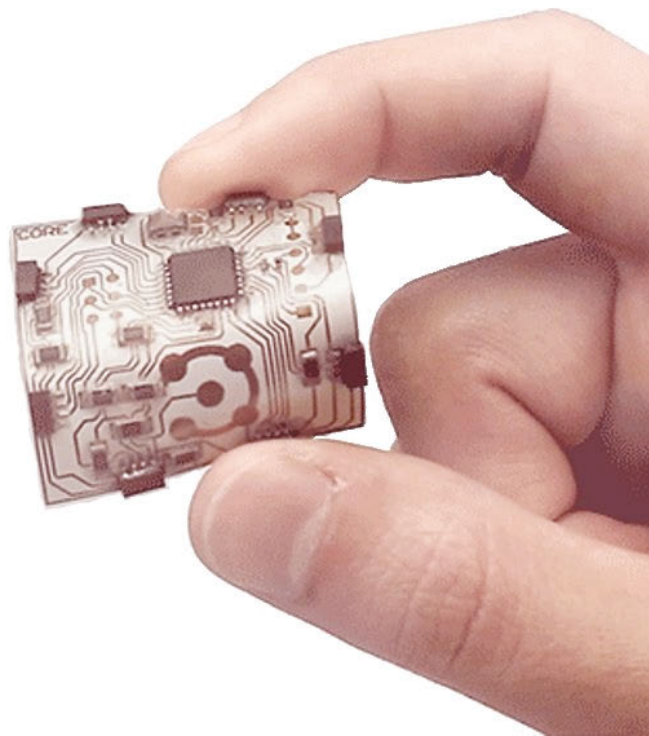


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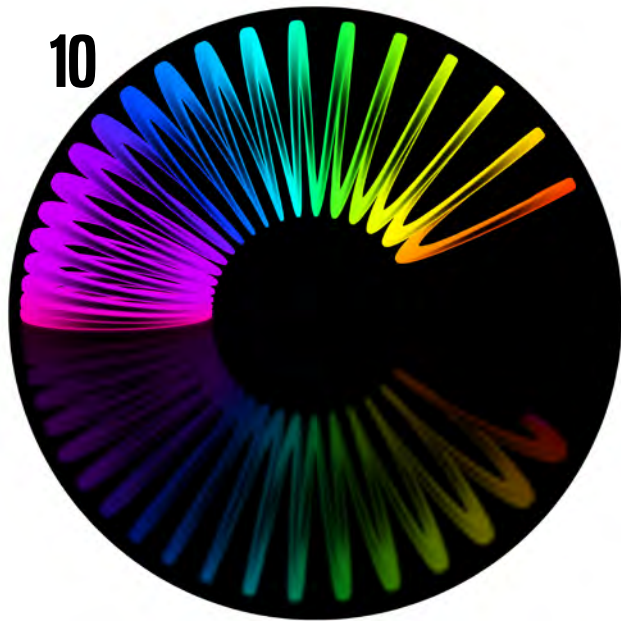
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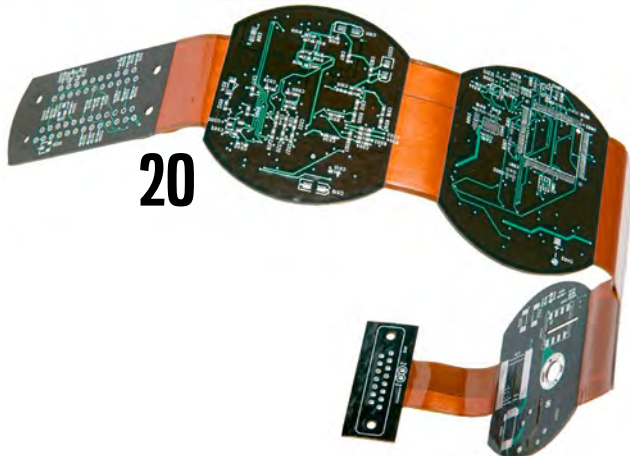
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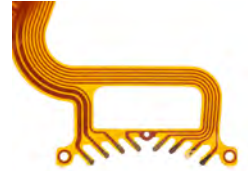
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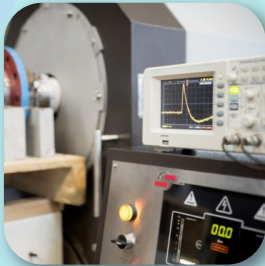


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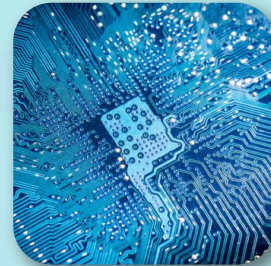
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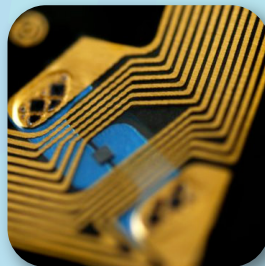
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Got Flex?

ReFLEXions

by Andy Shaughnessy, I-CONNECT007

Welcome to the first issue of *Flex007 Magazine*. This new quarterly magazine is dedicated to flex system designers, electrical engineers, flex PCB designers, and anyone responsible for integrating flex into their products at the OEM/CEM level.

Some of you are longtime readers of our *Flex007 Weekly Newsletter*. After seven years, we realized that it was time to expand from a newsletter to a magazine. Flexible printed circuits (FPC) have become all but ubiquitous, and it's time that flex has its own magazine.

Flex and rigid-flex circuits are now found in many everyday handheld devices, such as tablets, laptops, and smartphones, not to mention automotive electronics, medical, military, and aerospace applications. In a future that includes autonomous and electric vehicles, virtual and altered reality devices, you can expect flex to continue to grow.

We now see all manner of flex circuits: Single-sided, double-sided, multilayered, double-access, sculpted, and, of course, rigid-flex. Flex has gone through quite a few false starts over the years. As recently as the '90s, flex was just

one more expensive type of boutique circuit. FPC was hip and cool, but engineers had to have a real need before they specified a flex circuit. Then the cost of flex materials began dropping, and flex standards started to more or less catch up with the industry.

Fast-forward to today. Many EDA tools now feature flex design capabilities, and many fabricators have mastered the process of making these “flexitos,” as some designers refer to them. Flex is not just a boutique process anymore. (It's still a custom process in many ways, but that's another story.)

More rigid board designers and fabricators are considering moving into flexible circuits, because flex is still a premium product compared to rigid PCBs. (For some of the more successful “double-dipper” fabricators, flex makes up only 25% of their workload but 60% of their revenue.) No wonder flex is an attractive market for US companies. Flex and rigid-flex offer numerous opportunities, but they come with a variety of challenges as well.

For this first issue of *Flex007 Magazine*, we asked some of the top flex experts to share

their thoughts about flex, rigid-flex, and the overall flex market. For our first experts discussion, we spoke with Jonathan Weldon of DuPont Electronic Materials, Mark Finstad of Flexible Circuit Technologies, and Scott McCurdy and Scott Miller of Freedom CAD about how their companies approach flex and the many related issues. In our second experts discussion, John Talbot of Tramonto Circuits discusses the flex trends he's seeing in the overall market, along with some of the uniquely demanding flex products such as extra-long flex circuits. Next, Kelly Dack, CID + , gives us a review of his CID class's trip to Streamline Circuits, and their exploration of flex fabrication processes.

From Dave Lackey and Anaya Vardya of American Standard Circuits, we have an excerpt from their I-Connect007 eBook, *The Printed Circuit Designer's Guide to Flex and Rigid-Flex Fundamentals*. And Steve Robinson of APCT explains his plans for the future after acquiring new flex and rigid-flex capabilities with his acquisition of Cartel's subsidiary Cirtech.

Joe Fjelstad marks the return of his column *Flexible Thinking* with a discussion about how much flexible circuits have changed over the years. John Talbot's column *Consider This*, he explains how to handle returned material authorizations. In *All About Flex*, Dave Becker shares a variety of ways that flex traces can fracture, and some solutions for keeping fractures away. And in his new column *Flex Time*, Bob Burns of Printed Circuits breaks down some of the many reasons that rigid-flex is so expensive compared to rigid and regular flex circuits.

We hope you enjoy this inaugural issue of *Flex007 Magazine* and we'll see you in three months. **FLEX007**



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

Flex Survey: Advice

In a recent survey, we asked our readers who work with flex the following question: What advice, tips, or techniques would you like to share with our readers regarding flex or rigid-flex circuits? Here are a few of the replies, slightly edited for clarity.

Involve the supplier early in the design. This is key. Compared with rigid PCBs, the tolerances and materials for flex and rigid-flex are different and require different rules—and there are different pitfalls. Also, flex requires the designer to think in 3D, and sometimes the most elegant solution may not occur to us. We are an OEM with relatively little experience designing and assembling flex and rigid-flex. We have avoided countless headaches by involving the experts among our suppliers to help us at the earliest stages of layout—even before we have an outline. In some cases, they have helped us save money by suggesting different orientations that help improve panel utilization, or avoid the need for extra layers.

—Todd McFadden, component reliability engineer with Bose

I design flex circuits much less frequently than rigid boards. I have found that it is helpful to reach out to your vendor with your requirements to help determine stack-ups or areas of uncertainty. Most vendors have a best design practices document that is useful to skim over before starting designs. Let the people who actually have to build the thing you're designing guide you; everybody will be happier and you'll get a better product.

—Jarrod Schulte, engineering support specialist with Cadwell Industries



Flexible Thinking Redux

Flexible Thinking

by Joe Fjelstad, VERDANT ELECTRONICS

Welcome to the resurrection of *Flexible Thinking*, a flex circuit monthly column I wrote more years ago than I care to remember, but perhaps some of those reading this still do. I am going to guess that given the passage of time, many of the earlier readers may have moved to retirement or perhaps into other industries. To those of you who do remember, I extend my greetings and my thanks for checking back in to read my humble musings and observations on what I think we can agree is one of the most interesting and useful of all electronic interconnection technologies. To those of you who are new to the industry or first-time readers... Welcome! It is my hope that in the columns to follow, you will find useful thoughts and ideas about this fascinating and continually evolving branch of electronic interconnections.

Flexible circuits are known by a few different names depending on one's global location and language: flexible printed circuits, FPCs, flex circuits, flexi circuits, flexibles, bendables and a few others that are application-specific such as flexible heater circuits and controlled impedance cable constructions. While flex circuits are an original and foundational interconnection technology for electrical and electronic products (one of the first patents for electrical interconnec-

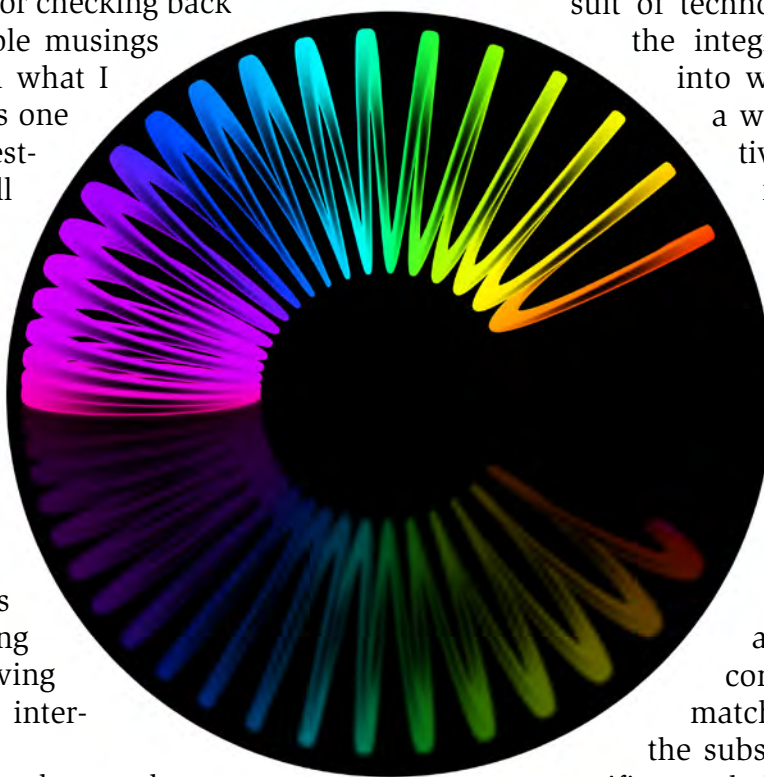
tions, issued at the turn of the last century, was arguably a flexible circuit), over the years there have been several forays into technological extensions of the basic idea. One such area of high and increasing interest in the last several years has been stretchable circuits, which the European Union has made significant investments in over the last decade in the pursuit of technologies that facilitate

the integration of electronics into wearable products for a wide array of prospective applications from medical monitoring, to communications and fashion.

As the name implies, this flex circuit variation is produced on stretchable substrates. The basic manufacturing is not all that difficult but designing and manufacturing conductive circuits that match the stretchiness of the substrate has been a significant challenge and has had

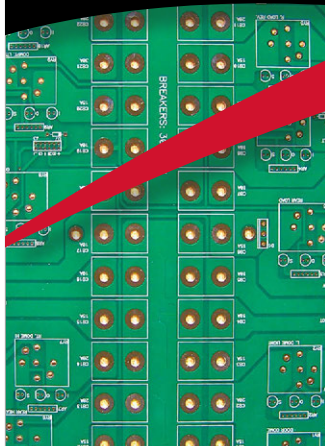
researchers working diligently to find ways to accomplish the objective. (For those interested, there is a chapter on this subject in the 4th edition of my book *Flexible Circuit Technology*.)

There has also been growth of interest in a new branch of electronic interconnection using flexible circuit technology that is being called by some "flexible electronics," which is an integration of components and sensors and to





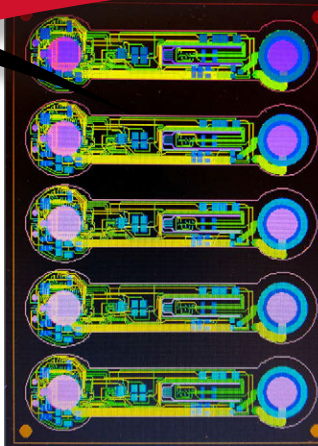
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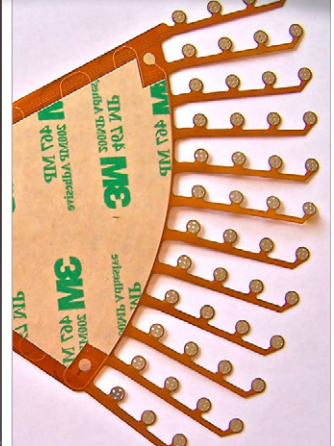
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which the term “flex hybrid electronics” has been applied. This is another area of increasing interest, and the U.S. government has sponsored research and development by both corporations (manufacturers of both materials and finished products) along with a number Institutions of higher learning. There is no real bright line between an assembled flexible circuit and a flex hybrid electronic assembly, but it really does not matter if it helps bring into focus the numerous advantages that can be secured by the integration of flexible interconnections and components.

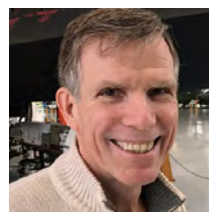
One of the centers for information gathering and investigation into materials and processes is NextFlex, in Silicon Valley. A little over two years old, NextFlex is rapidly getting the word out and facilitating consortium members’ communications and interaction to flesh out the possibilities in a world where electronics are increasingly being integrated into an ever-expanding universe of creative applications, from the whimsical to the highly practical.

It should be evident that there will be a lot of subjects that can be covered in the world of

flexible circuits and this space will be used to explore as many as possible in the future. It is a shared objective of the entirety of this new publication created in service to the electronics industry.

I see this space as a shared one and your individual comments, questions and suggestions are not just welcomed but actively requested. Please feel free to share with me or the editors any thoughts relative to what you might want to see covered in the coming issues, and I will do my best to address the subject matter in a future column.

Again, welcome one and all and I look forward to sharing the path to growth and discovery that lies ahead. **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 reach Fjelstad, [click here](#).

Something New for Everyone **Flex Talk** by Tara Dunn

Just the other day, I was recording a podcast with Altium discussing flexible circuit cost drivers. During that discussion, I was asked a question about what I see as a trend in the market. My first thought was that I am seeing an increase in frequency of questions coming from people that are just new to flex and rigid-flex design. There are enough idiosyncrasies with flex that people are a little unsure and are reaching out with questions. Around this same time, I had been contemplating what would be a good topic to write about for the “New Technology” theme of the March issue of *PCB007 Magazine*. The light bulb went off; there is such a range of experiences one can have with flex and rigid-flex that even more experienced users can feel like they are working with it for the first time, when in fact they’re not. Imagine what it’s like for people who are totally unfamiliar with it! So at the end of the day, brand new to flex and flex-rigid or not, most people who use it feel like they are working with new technology.

Single- and Double-Sided Flex

Single-layer flex, flex with one layer of copper, is a place many new to flexible circuits start. This is used when all conductors can be routed on one layer of copper. This may be replacing wire, solving a packaging problem or even be used for aesthetic reasons in a package that will be visible to the end user. When circuitry can’t be routed on a single layer, or shielding is needed, the progression is to move to double-sided (two copper layers) flex, or even multilayer flex.

(Continue reading at [Flex007.com](#))

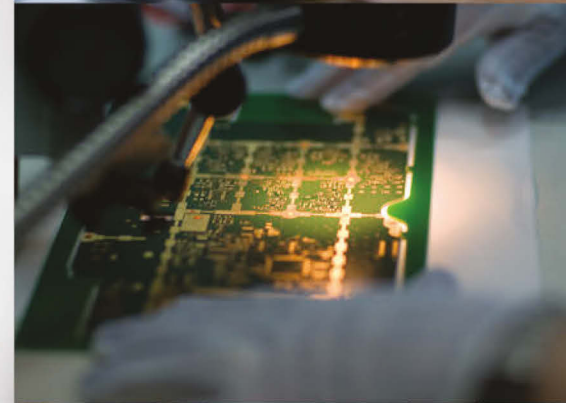
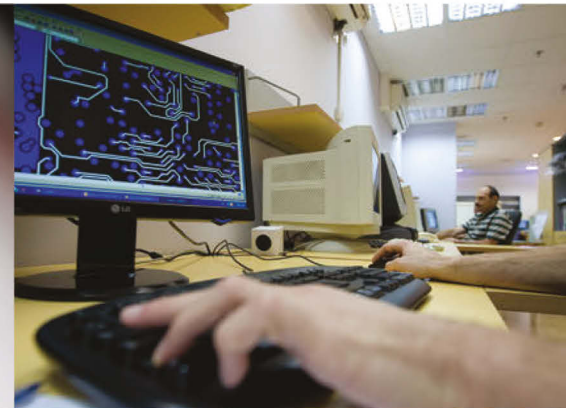


Tara Dunn is the president of Omni PCB, a manufacturer’s rep firm specializing in the printed circuit board industry. To read past columns or to contact Dunn, [click here](#).

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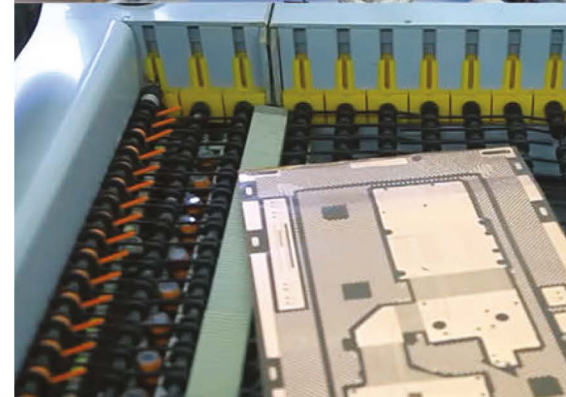
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RMA: Negative Experience or Valuable Opportunity?

Consider This

by John Talbot, TRAMONTO CIRCUITS

Returned product is inevitable if you work in manufacturing. That does not imply that it is easy to address. No matter what the reason for the returned material, it disrupts the normal flow of the quality and manufacturing teams. An inspector must first review the defect and agree that it is indeed a defect. This seems like a simple task and can be if the material doesn't match a customer specific requirement.

However, if the material must adhere to an industry-wide standard, such as an IPC standard in the circuit industry, it becomes a little more tedious. In most cases the manufacturer will be more familiar with the specification

than their customer. Also, they are more likely to keep the latest revision of the requirements in their library. This can cause a situation where the customer has identified a reject that isn't agreed upon when compared to the standard it was built to. Tedious indeed!

As well, there are other cases that have been witnessed by the author that create a less-than-easy situation. For instance, if the customer sends back rejected material that wasn't built by your company. This is typically easy to determine by company markings. Or they send back materials that have obviously been damaged by handling at their own facility. It complicates an already difficult process.

How does it happen?

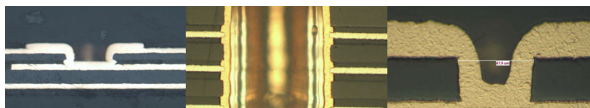
In the flexible circuit industry (and any other industry, for that matter), there are times when all the material delivered to the customer fails to meet the specifications. This can happen for a number of reasons and typically depends on the final inspection process. Two common final inspection processes used are sampling and 100%. When a product utilizes the 100% inspection process, every part that is shipped to your customer will also have been inspected. A sampling process is intuitively a partial inspection, typically 10-25 % of



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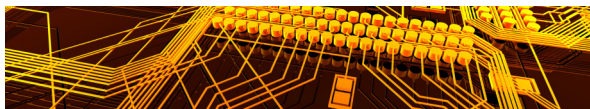
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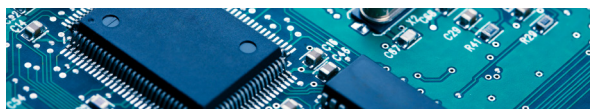
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the total, and is used on products that have a long history of zero defects.

The product may have started out with a 100% inspection and proved over time that the manufacturing process was solid enough that it didn't output any rejects. Another example of when the sampling practice may be used is on very high volumes where 100% inspection would prove too costly. In either case, there are times when a part could be shipped with a defect. In the case of sampling, it's obvious that a defect could be shipped because not all of the product is inspected at the final stage. With the 100% inspection process one would think that nothing shipped would have a defect. However, it's understandable that an inspector could mistakenly place a rejected circuit in the approved container for shipment to the customer, or simply miss a defect. No matter the cause, any materials that reach the customer without meeting all specifications should be addressed and rectified expediently.

No matter the cause, any materials that reach the customer without meeting all specifications should be addressed and rectified expediently.

What is to be done?

A typical process for addressing a customer request is to issue a returned material authorization (RMA) and ask them to send the product back for re-inspection and confirmation. It is best to trust your customer and treat them with utmost respect. At this time more than any other they count on you to help resolve a problem. Communications should be swift and thorough to assure your customer that you are their partner when things go wrong

as well as when they are going smoothly. Once the returned material has arrived, it should be confirmed and, if necessary, the entire shipment should be inspected to segregate all products that are suspect. It is easy at this point to cut corners because of the disruption it causes. You can fault the customer's employees for handling improperly. You can state defiantly that all products meet the requirements that we have on file and blame poor documentation. Or you can take a deep breath and handle the issue for the customer the same way you would handle the issue if it were yours. After all, they trust you enough to build their precious products. Assistance when things are not quite right should be the least they can expect.

Root Cause Analysis

With the material in hand and the non-compliance recognized and accepted, it's time to find out what happened. Or in the case of a recurring product, what has changed. The quality team is the first to see the returned products. But after the reject is identified they will need to recruit assistance and expertise from the manufacturing team. An inspector may be very good at identifying the non-compliance, but it will ultimately take collaboration with the team that builds the product to identify the root cause. This is a very important step and may take a lot of time and patience. There are many times when the first cause identified is not the culprit. Each theory should be identified and tested to verify the cause. It is imperative to find the root cause of the defect and test solutions until the best one is agreed upon.

As you may guess from the disruption mentioned earlier, this is not always an easy process. The manufacturing team must interrupt their ongoing schedule to help the quality team, who has also interrupted their schedule to find definitively both the root cause and the corrective action taken to resolve it.

Document and Verify

Now that all the hard work has been done to identify the cause and solution, it is time to document our findings. This is done formally

on a so-called corrective action report (CAR). During the arduous testing that was done to confirm the findings and then resolve them, a lot of information was gathered. That information is invaluable to the manufacturer. It has added experience and knowledge to the team that could not have been offered without going through the process properly. A typical CAR will include the initial findings from the customer, analysis done by the supplier, corrective measures that resolve the current problem and preventive measures that assure the same issue is not repeated on future builds. At this point one may think that the process has been completed. However, the resolution should be tested and verified for at least three future builds to confirm its validity. At that point, one may be confident that the root cause was properly identified and resolved!

Negative Experience or Valuable Opportunity

Non-conforming material that is sent back by the customer can easily be interpreted as a

negative experience. However, if it is perceived as an opportunity to learn and support the customer it becomes a much more pleasant and satisfying endeavor. The knowledge gained, however painful it may be, is an asset to the manufacturer. It can and should be used to inform and educate the entire team, from the designers to the final inspection team and anyone who touches products in between.

When a story is reported in the news today about one stranger who helped another, it is termed a “feel-good story.” In flexible and rigid PCB manufacturing, the feeling is the same each time we resolve a customer’s issue with confidence and enthusiasm. **FLEX007**



John Talbot is president and owner of Tramonto Circuits.

DuPont's Jonathan Weldon on Controlled Impedance Flex Lines

Editor Pete Starkey speaks with Jonathan Weldon of DuPont Electronic Materials about several factors that affect the signal integrity of controlled impedance lines

on flex circuits with cross-hatched ground planes. Jonathan discusses their impact on electrical performance, and his work with the High-Density Packaging User Group.

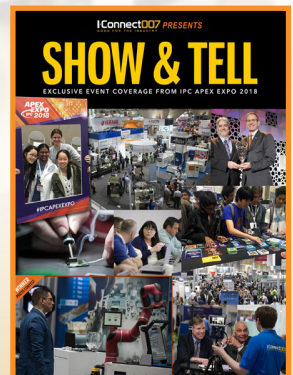


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Why is Rigid-Flex So Expensive?

Flex Time

by Bob Burns, PRINTED CIRCUITS

One question that I hear fairly often, particularly after an initial quotation, is “Why is rigid-flex so expensive?” In this article, I’ll share with you the cost drivers in rigid-flex relative to standard rigid boards and flex circuits with stiffeners.

A typical rigid-flex PWB will cost about seven times the cost of the same design on a hard board, and two to three times an equivalent flex circuit with stiffeners. A good way to estimate the cost of rigid-flex board in low-level production quantities is 35 to 40 cents per square inch, per layer. So, if you have an eight-layer board that measures 4” x 6”, your costing would look like this:

8 layers x 4” x 6” x .4 = \$ 76.80 each

Again, this applies only to low-level production quantities.

This is a helpful calculation for getting a quick, rough idea of what your part might cost as a rigid-flex.

Rigid-flex PWBs cost quite a bit more, primarily because of the higher cost of the raw materials we use to build them, relative to standard rigid boards or even flex boards. The number one cost driver is the no-flow prepreg. Rigid-flex manufacturers have to use no-flow, or sometimes low-flow prepreg, so that the resin does not flow out onto the flexible areas of the board. No-flow prepreps are designed to offer just enough flow to fill the circuits in the hardboard areas, but not enough to flow out onto the flexible areas of the boards.

No-flow and low-flow prepreps run from \$1.50 to \$3 per square foot. Conventional rigid board high-flow prepreps run around \$.25 per square foot, so there is a large differential in price just for the prepreg.

A couple of other things contribute to the cost as well. No-flow prepreg is only available in 1080 and 106 glass cloth styles, which typically press out at .0025” and .002” respectively, so they are thin. Rigid-flex manufacturers don’t have 2113, 2116, 7628 glass styles available to manufacture your board.

It is wise to use two plies of prepreg between layers within your construction. The no-flow resin resists flowing, so to assure adequate fill, we use two plies of prepreg between each layer.

Also, prepreg, like all manufactured items, has some variability across the sheet,

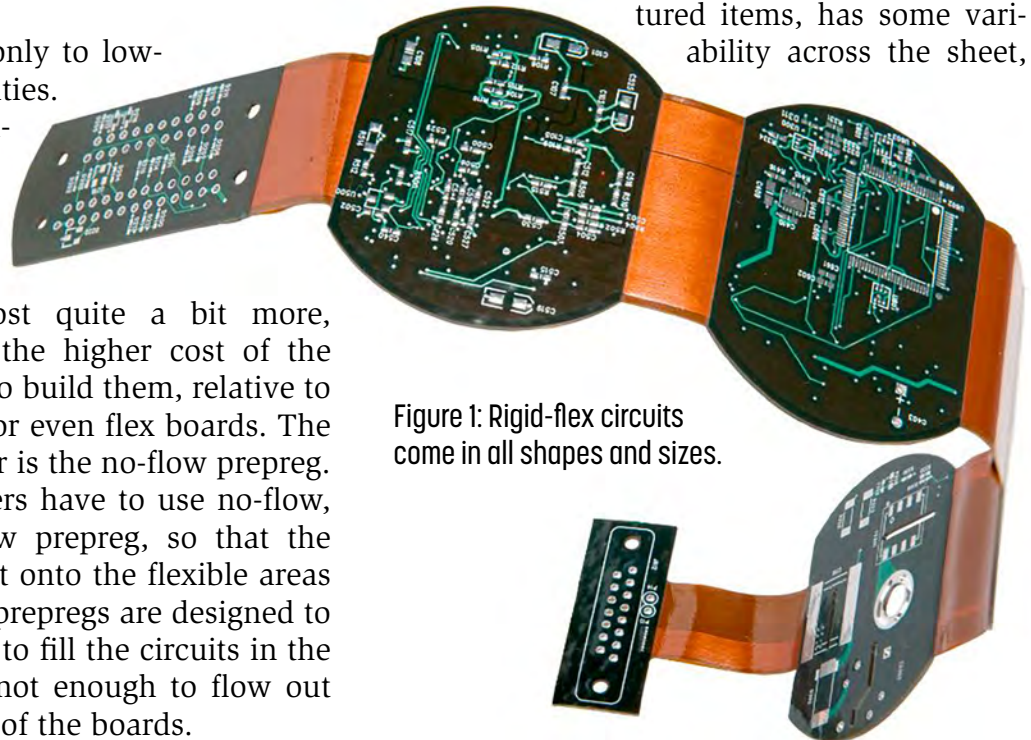


Figure 1: Rigid-flex circuits come in all shapes and sizes.

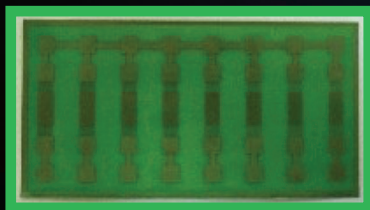
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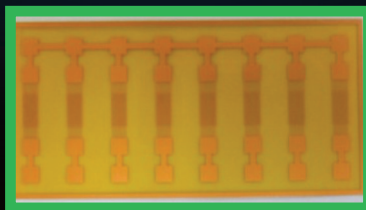
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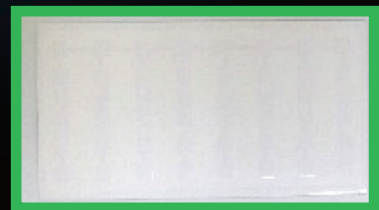
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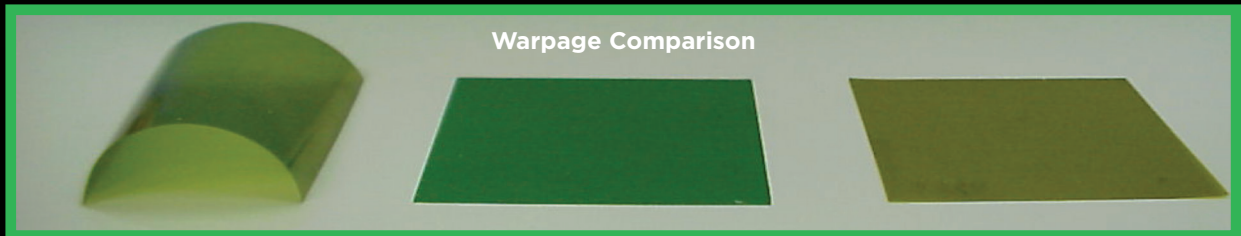
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which includes resin content. If there is an area that is low(er) in resin content, you might not fill adequately, causing resin starvation and ultimately shorts. There are times when we do build boards with a single sheet of prepreg (with half-ounce copper or less), but there is always a risk of inadequate flow, which will allow air entrapment, and ultimately shorted circuits.

A simple, straightforward 8-layer rigid-flex will have 10 sheets of no-flow prepreg. Eight sheets are used to bond the package, and two sheets are used to mate up to the coverlayer to create a cut back coverlayer design for high reliability packaging (Figure 2).

Now, 10 sheets of prepreg at three square feet each, and \$2 per square foot is \$60. The equiv-

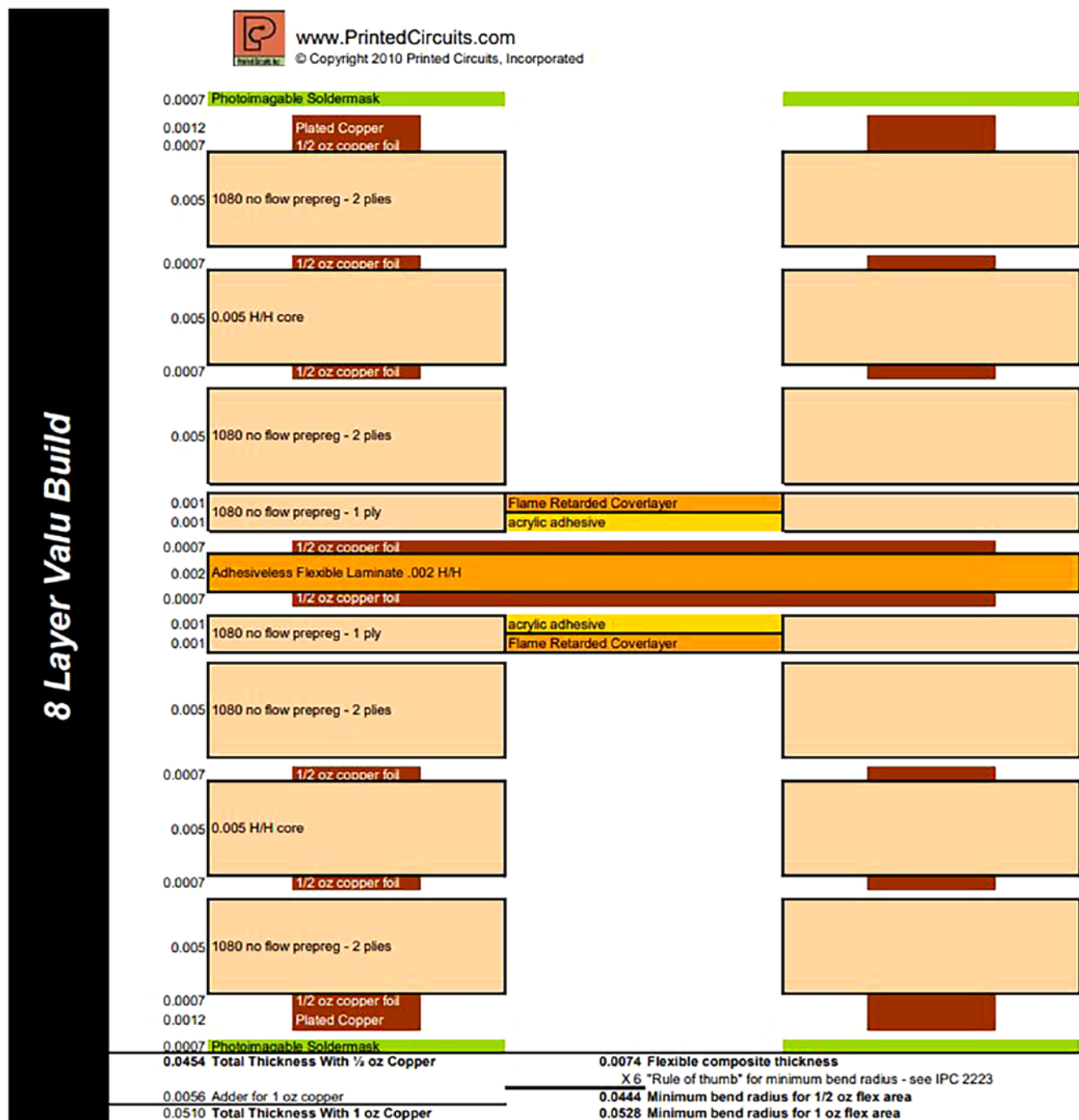


Figure 2: An 8-layer rigid-flex circuit.

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The challenges include:

- Handling and protecting thin and small components made from brittle materials (silicon, III-V compounds, etc.)
- Flexible interconnects on a wide range of scales from microns to millimeters
- Reliability with thermal expansion coefficients of different components ranging from a few ppm to hundreds
- Cost-effective process techniques for putting it all together

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alent in standard prepreg would be \$7.50. These costs can add up pretty quickly, even for basic low-layer-count designs. With high-layer-count designs, the cost impact is even more profound.

If your design is primarily half-ounce and/or one-ounce copper weights, we will usually use 1080 glass styles, which are lower in cost. If your design has two-ounce or three-ounce copper weights, we will use the 106 glass

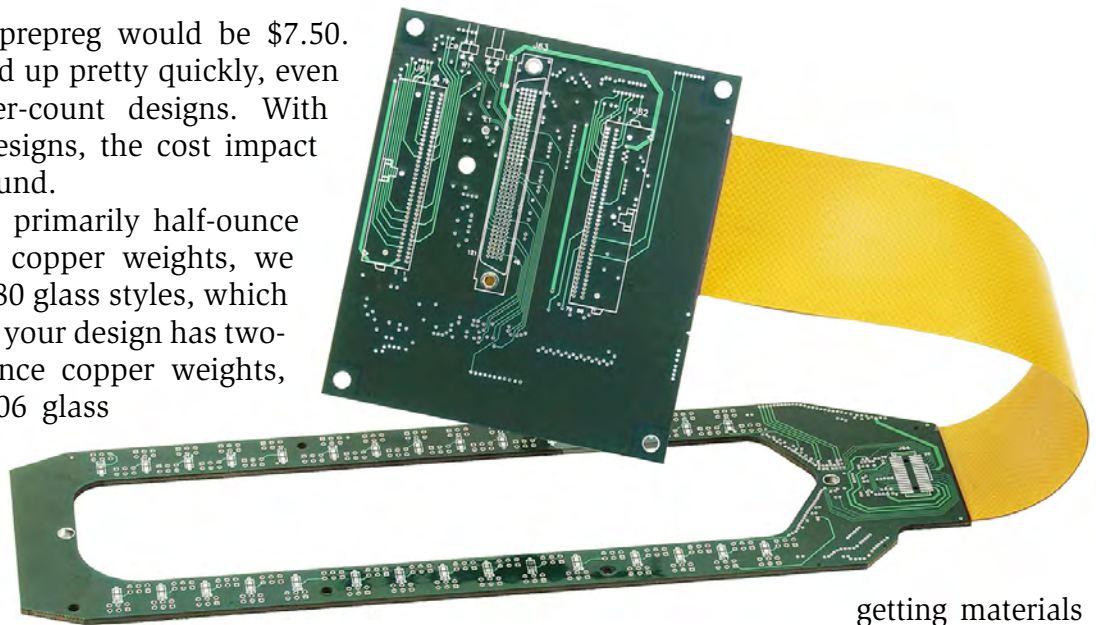
styles, because of their slightly more favorable flow characteristics, but they cost 50% more than the 1080 prepreg.

Using multiple plies of 106 to fill the thicker copper weights can drive up the panel price very quickly.

A smaller cost driver in rigid-flex construction is the flexible copper-clad laminate. We use adhesiveless flex materials almost exclusively, which are recommended by IPC (IPC 2223 5.2.2.2) for high-reliability rigid-flex constructions. Adhesiveless flex materials run \$6 to \$10 per square foot. Equivalent hard board laminates are closer to \$2 per square foot, so we can see that there is a 3–5x cost increase when using flexible adhesiveless laminates.

However, if your design has controlled impedance requirements (most of our multi-layer work now is controlled impedance), we usually use thicker flex dielectrics to meet the most popular values. Those thicker flex materials have an exponential price curve—the price doubles with each additional mil of thickness. In rigid boards, a 0.014” core laminate is fairly equivalent in price to a 0.003” laminate; this is not the case in flexible laminates, where thickness of the base dielectric determines price. Controlled impedance rigid-flex boards usually incorporate the thicker dielectrics at an elevated price.

Rigid-flex manufacturers start building with some relatively expensive materials to begin with. They face the additional challenge of



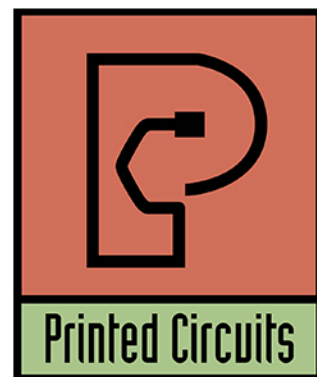
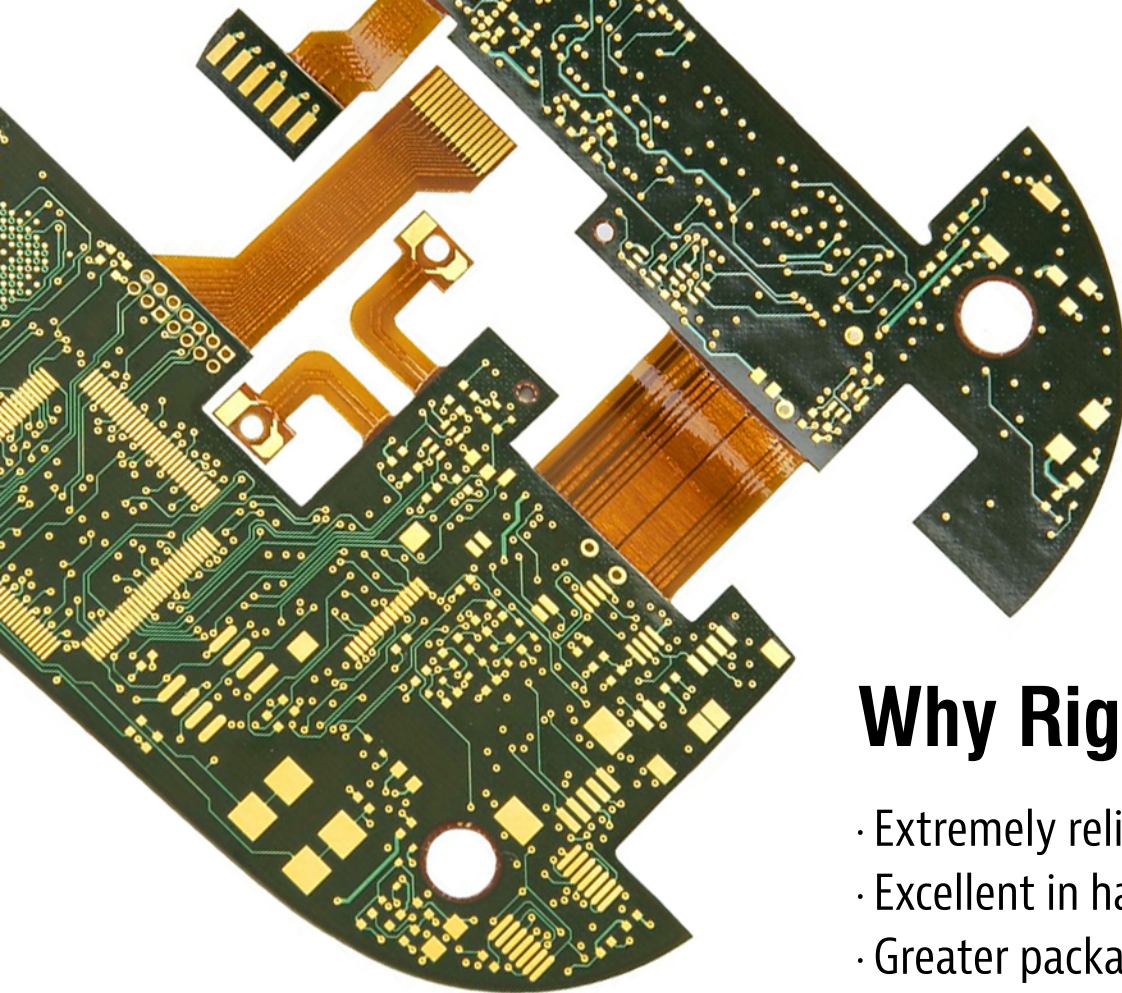
getting materials with widely varying X and Y CTE values to still line up within your design, so that all the pads are where they are supposed to be. A 0.002” Kapton® flex dielectric moves dramatically differently, and less consistently, than a 0.004” glass reinforced core material. Adding coverlayer, multiple lamination cycles to build the internal flex layers makes material movement even harder to predict accurately. This is especially true with first-run designs.

Those are some of the main cost drivers in rigid-flex PWBs. There are others too, but they tend to be less impactful than the ones listed above.

In my next article, I’ll share when and where rigid-flex packaging makes the most sense and can be more economical than traditional rigid and flex packaging. Then, in future issues of *Flex007 Magazine*, we’ll discuss what you can do to manage and reduce your design’s cost, in addition to tips and techniques to keep rigid-flex costs as low as possible. **FLEX007**



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



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Causes of Trace Fracturing in Flexible Circuits

All About Flex

by Dave Becker, ALL FLEX

Flexible circuits are used in applications requiring millions of flex cycles. But this does not suggest they are indestructible. In fact, occurrences of performance issues as the result of fractured traces have been experienced in a variety of applications. Solutions are often the result of design, construction, and feature location modifications. But a much better solution is to avoid the problem in the first place!

A flexible circuit's ability to be bent, twisted, folded and continuously flexed is a significant advantage offered as a designer considers this interconnect method in a new product. The design options are myriad, with origami-style packaging being an accurate description of how the product is often used. But it is true that improper designs and/or specifications have resulted in bad experience anecdotes about trace fracturing problems.

The following are some pitfalls to avoid and help minimize the chance a design will experience premature failure.

Creating High-Stress Points

There are several ways a designer might inadvertently lay out traces and create a higher level of mechanical stress during bending. Designs with traces on opposite sides of the dielectric laying directly over each other will create an "I-beam affect" (Figure 1).

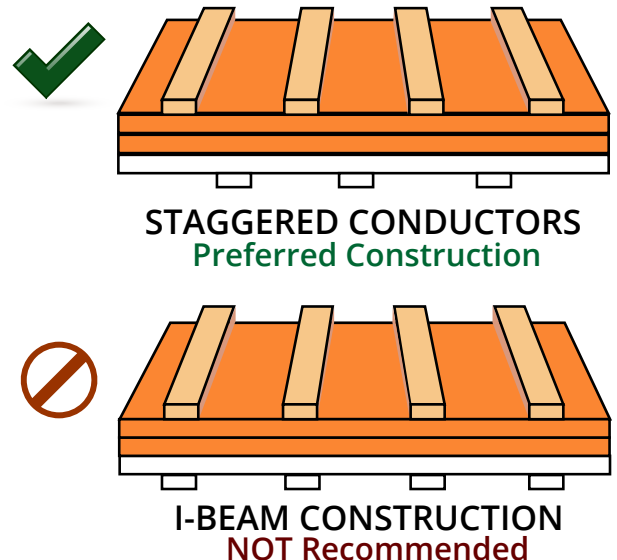


Figure 1. Staggered conductors are more reliable than the I-beam format.

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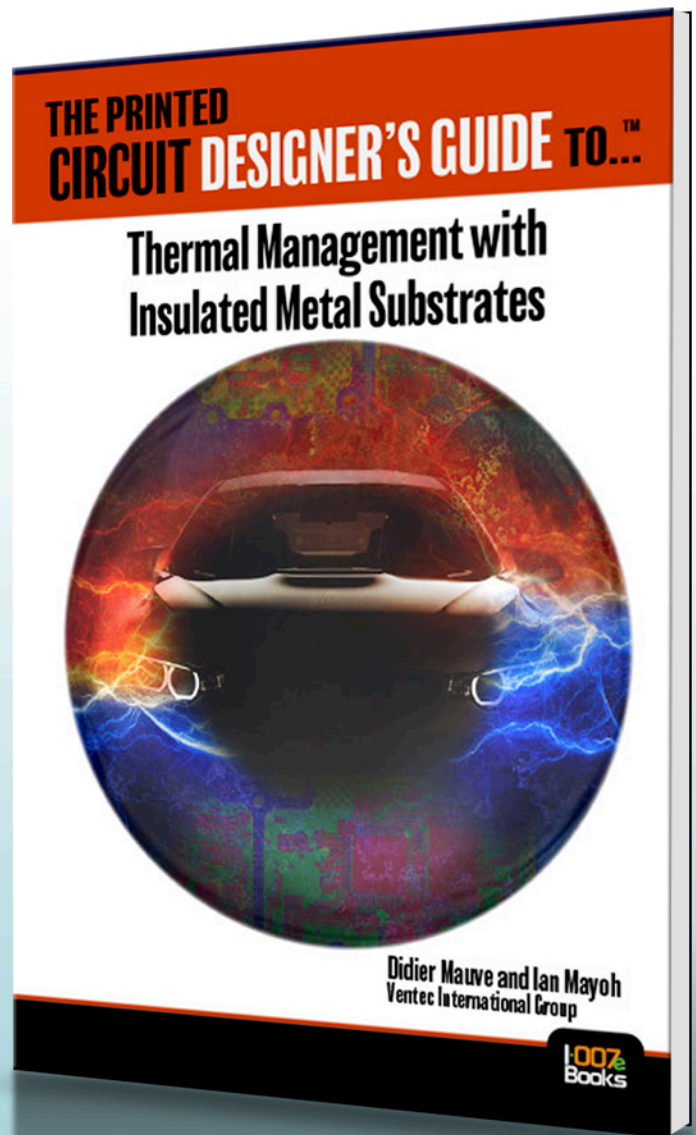
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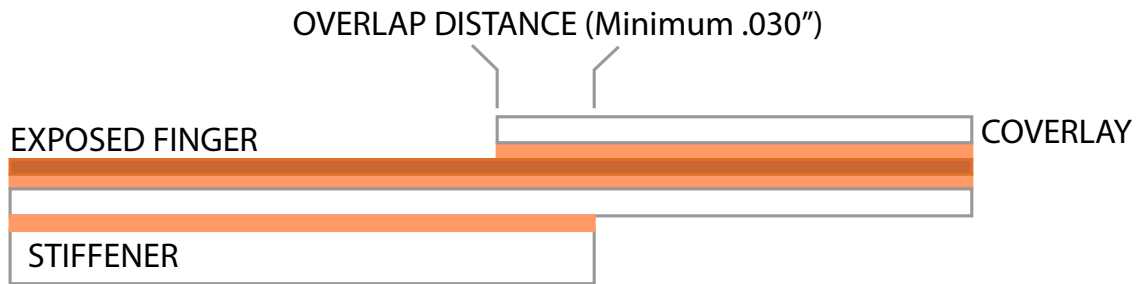
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Written by Didier Mauve and Ian Mayoh of Ventec International Group, this book highlights the need to dissipate heat from electronic devices.

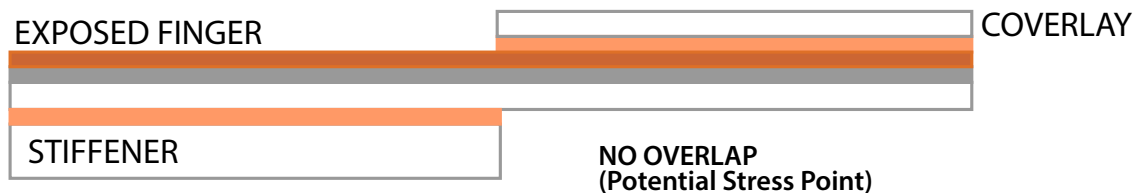


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This is the PREFERRED METHOD because there is not a common ending point of the coverlay and stiffener.



This form is NOT RECOMMENDED because it allows potential stress and cracking points where the coverlay and stiffener end at a common edge.

Figure 2: Overlapping the coverlay is the preferred method.

With traces mapped directly over each other, added stress occurs on the traces located on the outside of a bend radius. The traces on the outside of a bend radius are in tension mode, and the layers on the inside are in compression. Traces in tension tend to develop microfractures if they are flexed repeatedly. These can be particularly difficult to identify as the open circuit often occurs intermittently.

Another mechanical stress point occurs at the end of a stiffener, which will tend to focus stress at the stiffener termination line. A simple design feature solution is often to overlap the coverlay termination on the opposite side (Figure 2).

Solder Joints/Vias too Close to Bend Points

While copper foil is ductile, the alloy resulting on a solder joint is much more brittle. These regions are particularly susceptible to trace fractures as the region defined by the junction of cover film and solder pad cannot take significant bending. Figure 3 shows a safe distance between the bend location and a solder joint or plated through-hole.

Unbalanced Dielectric Thickness

This issue is avoided by locating the copper traces in the “neutral axis” (i.e., by having equivalent material thicknesses above and below copper in regions to be repeatedly flexed). Polyimide film has been proven as a robust material for dynamic flex applications

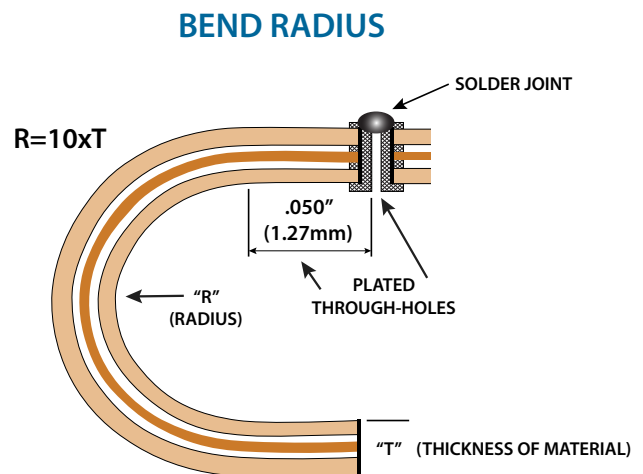


Figure 3. Bend radius of a flexible interconnect should be approximately 10 times the material thickness and at least .050" away from the plated through hole.

and is used almost exclusively in these applications. Although screen printed and photo-imaged solder mask are sometimes used as dielectrics, it is rare to find these alternative materials used in applications requiring high-flex life, because they tend to be brittle and are likely to craze or crack when folded or repeatedly bent.

In some applications, it is necessary to use photo-imaged solder mask for its high-resolution capability for component openings. But if these parts are also to be dynamically flexed, polyimide is again used in the flexing region of the circuit, creating a circuit with dual insulation materials and processing.

Errors in Copper Selection

There are two basic types of copper foil: electrodeposited (ED) and rolled annealed (RA). They have significantly different grain structures and bending properties. Using ED copper for high-flex applications may cause infant mortality. RA copper offers significantly better flex life. Also important is the copper grain direction on RA copper, as flex life is much higher when the fold or bend line is perpendicular to the grain. Copper thickness of one ounce or thinner is also a good design practice.

Copper selection errors can also occur with flex circuits of two layers or more when creating plated through-holes. Avoiding the addition of electroplated copper in a flex region is possible by masking during copper plating. This restricts electroplated copper to the copper pads and the vias. This fabrication method avoids the addition of electroplated copper in a flex zone and keeps copper thicknesses to a minimum. This is a pretty common process known as “pads only plating” or “button plating.” Both these features can be key to a robust design and are often called out specifically as requirements on a customer’s drawing. **FLEX007**

This column originally appeared in the Flex007 Weekly Newsletter.



Dave Becker is vice president of sales and marketing for All Flex Inc.

Flex Survey: Challenges

In a recent survey, we asked our readers who work with flex the following question: What are the biggest challenges you face when working with flex or rigid-flex circuits? Here are a few of the replies, slightly edited for clarity.

Bend radii of flex circuits need to be taken into consideration. On a multilayer rigid-flex circuit, you will have compressive stresses on the inner layers of a bend and tensile stresses on the outer layers. There are minimum bend radii that you can specify. These must be defined early in your design. If you have impedance-controlled flex circuits, consider double-sided flex material rather than single-sided flex material. If the flex is dynamic (a moving flex), the copper should be rolled annealed rather than electro-deposited, which is more brittle.

—Steve Knobel, specialist PCB designer with Denel Dynamics

Customers who do not understand that these are not rigid boards. The design considerations are not the same.

—Steve Kelly, general manager with PFC Flex Circuits Limited

When designing flex circuits, my biggest challenge is determining which materials are available from the vendor and their respective thicknesses when trying to hit a specific bend radius, for example. I also face issues with my software (Cadstar), as it doesn’t seem to like curved traces when routing in a dynamic environment that allows push/pull and spring back.

—Jarrod Schulte, engineering support specialist with Cadwell Industries





EXPERTS DISCUSSION: The Flex Technologists Speak

Feature Interview

BY THE I-CONNECT007 EDITORIAL TEAM

For our first issue of the *Flex007 Magazine*, we invited a group of flexible circuit experts to discuss their work in this rapidly growing segment. Participants included Jonathan Weldon of DuPont, Mark Finstad of Flexible Circuit Technologies, and Scott McCurdy and Scott Miller of Freedom CAD. In a free-wheeling discussion with Andy Shaughnessy and Barry Matties, these technologists share their thoughts on the challenges and opportunities in flexible circuits, as well as what constitutes the cutting edge of flex right now.

Andy Shaughnessy: Why don't we just start with some introductions? Jonathan, would you tell us about yourself?

Jonathan Weldon: I've been with DuPont for about two and a half years. I'm an RF application engineer so I focus primarily on Pyralux™ flexible copper-clad laminates and

the Kapton™ films that go with those. They're used in everything from consumer electronics through industrial applications.

I'm an EE undergrad, EE grad, and all focused in electromagnetics. I was in the Air Force for about eight years doing electro-optics, radar work, and all sorts of jammer work developing jam patterns and a few other things for the systems. And then I worked at Sandia National Labs before coming to DuPont. I'm typically an analog guy. I came from the defense side. I still try to stay close to the defense side, but have been sort of mixing into the consumer electronics world since being in this industry.

Shaughnessy: Scott McCurdy, how about your background?

Scott McCurdy: I'm with Freedom CAD. I've been in the PCB design world for the last dozen years. In a past life, I owned a printed circuit board manufacturing company for 32 years. Also, I've been the president for the last 15 years of the Orange County IPC Designers

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Council, the largest chapter in the country. I just started my 50th year in the printed circuit world. I started when I was four. (Laughs)

Scott Miller: I'm the chief operating officer at Freedom CAD Services. We perform contract printed circuit board design and layout services and provide prototype assemblies. I started my career with DuPont back in 1978 and it was a division of DuPont called Berg Electronics, which was a connector manufacturer. I've been with Freedom CAD for about 15 years and I always enjoy keeping up on what's going on between the materials and the design world.

Shaughnessy: All right. Give us a little background, Mark.

Mark Finstad: I'm the senior application engineer at Flexible Circuit Technologies. I've been there for about eight years. Prior to that, I was with Minco for 27 years. During that time, I was heavy into the military and avionics. Now, at Flexible Circuit Technologies, I design flex for commercial and non-implantable medical and other applications like that. I've been doing this for 35+ years. I co-chair the IPC 2223 committee and I'm on the 6013 committee, and the Flex Materials committees. I've been on those committees for decades now, so I guess I'm a lifer at this point.

Shaughnessy: Jonathan, what's important to you and your flex customers?

Weldon: It's been kind of tough starting into the 5G world. I throw it out there just to get the words out because I know it's sort of a hot topic right now everywhere. For me, I still view it as high-speed/high-frequency materials, right? But, 5G has become the trend in all of those discussions.

One thing that seems to be true is that I'm

not seeing anybody break any of that down into what I'll call components. They'll talk about base stations, they'll talk about nodes, and they'll talk about handsets. But none of that trickles down to requirements, constructions, antenna types, material choices, and fabrication challenges, or any of those sorts of subsets that are the real meat of 5G.

I don't know if other people are finding good sources for that, but everywhere I've looked it's still been a little thin or a little ambiguous. It's still very high level. So, that would be one of the first things I would add to the first flush. This would be useful for me looking at a magazine, getting into those sorts of details about that whole market and what that's going to look like.

Shaughnessy: How about flex materials? That's one of the things we always hear. The designers are always saying that they need to know more about materials.

Weldon: There are two sides to every story, right? I work on one side, looking at new materials and how we can get our current materials in. I hear a lot of talk about LCP still. I hear a lot of talk about other sorts of exotics that are out there. But I don't really have any field-covered reviews. If I look at an iPhone or something like that, maybe it has 10 to 20 flex circuits in there and those flex circuits all have different requirements. Different flex requirements, different materials requirements. Nowhere is that really broken down. Obviously, that's proprietary to that specific fabricator,

but where does LCP need to go there? Maybe that may be the kind of feed line and antenna. Where you can go with the polyimide? Where can you go with a lower performing polyimide? Where can you swap out ED copper for RA copper? That is some of the specific details that I might be looking at.



Jonathan Weldon

From the material choice, I'd like to see what the actual requirements are. A lot of times, and from the OEM side, they'll just spec in the best they can possibly get. If we look at polyimide for instance, as an example, if you go look at cast on copper products like single-sided copper-clad, you'll see these extremely awesome mechanical numbers. And then those can get transferred sometimes from the OEM level down to other flex circuits. It might be the double-sided copper clad with the single-sided copper-clad requirements down there and not knowing that making a double-sided clad is a lot different than making a single sided clad. The materials are vastly different, too.

These are the sort of things that provide us feedback, outside of when people call to complain that something is underperforming. So how do you bridge the gap? Maybe this could be a way to do that. Then you could say, "What are the actual requirements for performance in the system?" Not "This is what we're using and it works, so those are the requirements."

What does an antenna feed line need to be? What do the dielectric properties need to be? What does the flux performance need to be? What do digital interconnections need to be? Where can you get away with ED versus RA? Where can you get away with a lower performing polyimide or different system?

Shaughnessy: Mark, what do you think?

Finstad: Well, I'd like to address what Jonathan said. One of the biggest issues that a lot of people don't understand is that all of the flex dielectrics that have low dielectric constant and low loss require really high-temperature lamination. With the LCPs, DuPont DK, pretty much all of them, you have to laminate around 300°C. Not a lot of flex suppliers have presses that go up that high, so you really limit your

vendor base. And I know that the first time that I looked at LCPs I was talking to a guy from Rogers and he specifically said, "Don't try to do this without having us involved because it's a real bear to work with. It's a thermoplastic so things don't stay put where they're supposed to and so there's a lot of challenges." And I don't know if the price has come down recently, but it used to be outrageously expensive

and if you had multiple layers of the stuff you could have anywhere from \$50-\$100 or more per square foot in material costs before you start doing anything with the material.

It really made it tough to make commercial applications with that material because price-wise it was off the charts. That's a big problem with the LCPs. Now I know that there's some new lower temp materials coming out that have a dielec-

tric constant in the 2.8 range. I think when that comes out it would be good to stay in touch with the manufacturers to have the trials that verify that the end products are electrically and mechanically good but also that the materials are easier to process. Because having something that does everything you need electrically and mechanically on the final circuit doesn't do a whole lot of good if nobody can work with it to get to that final product.

Weldon: I want to echo Mark on that point. Because you look at the LCPs for instance, right? You're really paying for that loss tangent number which is .001-.002 and it's a bear, or you can just sacrifice and go with an epoxy which can process easier, it's cheaper and much better to work with. And all you do is go from .001" and .002" up to .002" to .003". I'm going to go through all this trouble for that extra 0.001 loss tangent number? I think that's kind of the key, right? Are people looking at that?



Mark Finstad

Finstad: Right, I think a lot of that gets up into the super-high frequencies. You start looking at 10 gigs and higher, that's where you get some people that are really sensitive to that. I've got one right now where I said, "Are you running anything with high speed?" and they were looking more in the 10+ gig range. They said, "We can't have the polyimide and the thermosetting adhesive properties at 10 gigs, even though the transmissions lines are very short."

Sometimes I wonder if it's an electrical engineer who's looking too much at the numbers and not at real life, because anyone who's designed flex knows that that's your whole life. If you get the electrical engineer and the mechanical engineer together in the same room, they're speaking opposite languages. Everything that makes a flex better electrically makes it worse mechanically and vice versa.

And there's always a compromise. You rarely get everything you want. If you make it perfect and pristine from an electrical standpoint, but as soon as you bend it your conductors crack, it doesn't do you any good. There's always that balancing act and most of the time both sides have a little bit of give and take. They can handle a little bit less in impedance to get a little bit thinner, so you can still bend it; you may not get as thin as you want but it will be acceptable.

There's always that balance on what you need, and sometimes I wonder if some people designing the front-end stuff, they're so wrapped up in just the numbers they don't realize that you probably could get by with something that doesn't perform at the level of an LCP and it will work almost as well. You get 90% of what you needed and people can actually build it.

Shaughnessy: Do they over-constrain it because they're worried about it?

Finstad: Yes, unfortunately a lot of engineers come out of college and they don't know squat about printed circuits. No one teaches flex circuits in college. You learn electrical theory. All you've got are a bunch of numbers and you're learning the leading-edge stuff there and so when you get dumped in the industry, it's kind of the school of hard knocks. That's how you figure things out, by learning what actually works and what doesn't, and getting push-back from manufacturers on what can and can't be done.



Scott McCurdy

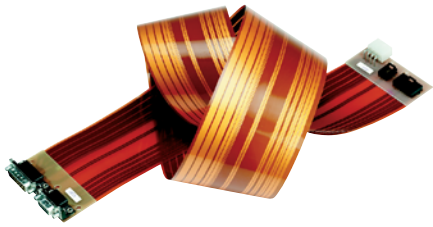
Shaughnessy: Scott or Scott? Either of you want to chime in here?

McCurdy: Well, I've got a couple of things. I spent two days last week at the CES show in Vegas. And you walk around that 2.7 million square feet and you see it all. You see a glimpse of the future, and I can see where the flex business is going to have way more applications in the future in a lot of areas like robotics and things, and

certainly automotive is going to suck up so many different interconnect things. And coming from the design world now, I think the designers need to kind of come to grips with maybe they haven't had flex experience before but I think there's more coming.

So being able to understand more about the design for manufacturability. It's not just a rectangle anymore that you put six up on an 18 x 24 panel. They don't understand the panelizations and the fact that when they get to manufacturing, they're not rigid. You have to be thinking about different arrays, different ways of interlocking boards to get the maximum amount of panel. I mean, there's just a lot of that that is just kind of out of the norm of what most circuit board designers are used to.

The designers aren't necessarily choosing the materials, but they're trying to make sure

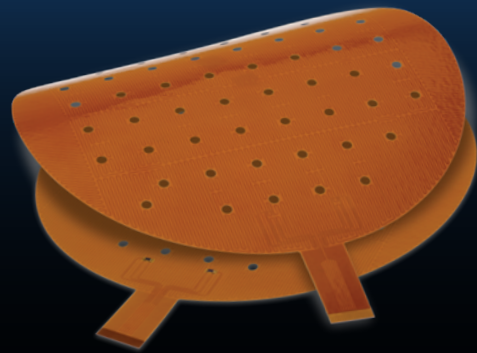
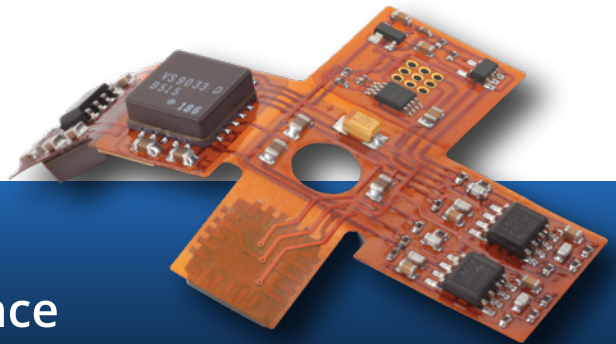


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that it's not just connect the dots, but there's mechanical things that they need to understand more about bend radius and stuff like that but they just haven't had a lot of experience.

Finstad: I would like to second that. All the differences between rigid and flex are important. It's just there are so many designers that have only done rigid and they just come in and think, "Well, I'll just use the same rules for flex." And you must coach them that there are a lot of differences. There's more differences than similarities between rigid and flex circuits.

McCurdy: We recently did a project for a headset that the engineers at the company had come up with and wanted to do in rigid-flex, and by the time we got through the project it ended up being so expensive. There are tradeoffs there with trying to connect two things together that maybe a piece of flex between two rigid boards in a consumer device would have been a better solution. And understanding those tradeoffs would have saved them a lot of money. They went down the wrong trail.

Miller: Yeah, I would say, too, that IoT has had a big influence on the use of flex and especially from the application of direct attach to flex for components, again it's the DFM issues, but the designers just are not thinking about it in terms of robustness and the application. They're using flex typically for a reason and that flex puts stresses on solid joints that aren't normally there. So again, it's the melding of electrical design and mechanical design on steroids at the PCB and flex design level.

Matties: From a designer's point of view, are there component issues that they need to be aware of when dealing with flex?

Miller: Well placement, location, proximity to the bends, those are things that you need to be aware of as they're going to be a stress put on that area.



Scott Miller

Shaughnessy: It sounds like what all of you are saying is that there are a lot of questions about flex. There's a lot of uncertainty at each level of the process with flex.

Finstad: Yes, absolutely. Even the SMT stuff. I was in Boston meeting with a customer last week and he asked, "How close can I put the component to the edge of the board? And how close

can I put it to the flex rigid transition area?" I gave him the numbers that I felt comfortable with. He wanted even closer. You're always getting pushed. They're trying to use up every square millimeter of space and they don't want to leave anything open.

Shaughnessy: In what markets do your flex typically wind up? What segments of the industry?

Finstad: The first 27 years it was all military, avionics, aerospace, implantable medical, and now it's high-end commercial, cameras, cell phones and headphones are full of flex now. It's going everywhere; GPS, anything that's handheld is going flex. It's probably easier to tell you what doesn't have flex in it than what does. As I said, when I worked at Minco, everything we did was Class 3. I don't know if I ever saw a drawing in 27 years that said Class 2 on it. If it did, you still got Class 3. It was more difficult and expensive to try to segregate a single run and run it to a Class 2 than just run it at Class 3.

FCT never competes against Minco because we do Class 2 virtually across the board. Once in a while we'll do a little bit of Class 3, but rarely. The long and short is, anybody who can build in Asia is going to build in Asia, and

so that's all the Class 2 products. Class 3 stuff is the military, avionics, aerospace, implantable. That's all going to stay in the United States.

In automotive you're going to have shock and vibration, you're going to have extreme temperatures, both high and low, things like that where you wouldn't see that in a cell phone. Cellphone is going to be experiencing pretty much room temperature and unless you drop it there's not going to be any shock and vibration. It's a completely different animal between those two. Another thing for automotive is cost. They are trying to shave off everything they can, whereas in high-end commercial they've got a little bit more space because they're providing a premium product and people are willing to pay for the newest electronic widget out there. When you start getting pressed for cost, then you start looking at less expensive materials that can affect the end performance, which you're trying to keep up on the top end also.

Matties: So, the strategy for cost is really important.

Weldon: That's a good point about the requirements, because the requirements are different, but there are even standards that are different, right? So automotive might use IEC. A guy who uses software might use IPC. With automotive, you don't have to have UL. There are certain things that are very different. If you're new to automotive, making flex, this is what you need to know. Build according to these specs or these specs. These are things you need to be worried about. These are things you don't need to be worried about. I really like that point, thank you.

Matties: When we look at design, I know we talked about PCB designers, but how involved is the system designer in this process? How much influence do they have over the actual parameters?

Finstad: Seems like really often the flex is the last thing that gets designed into the system.

They get everything else put together but now they've got to hook it up and make a bunch of flex to do it. You end up trying to work with the available space that's left over after everybody else got their portion of the volume.

Matties: We hear frequently that things are just thrown over the wall and you have to hammer it in. Freedom CAD probably knows that the best, correct?

McCurdy: We see that same thing. It's pretty accurate. I think, too, what we see at times is the use of flex for power applications, and that's probably something that has its own uniqueness because it's done for different reasons but having copper poses a different problem.

Finstad: I agree with that. We've looked at replacing a lot of wire harness and cable in automotive with flex and cost is the primary issue but even getting down to what thickness of copper do you use to replace those high current power lines. You're talking 12 volts and 20 amps. That's a big copper trace. And with a cable that's braided it's not much of an issue, but you try to turn that into a flex circuit, what do I do? Do I use two ounces of copper that's three inches wide? What the heck do I run here and then how do I build a circuit around it and make that even remotely cost effective? It gets even more interesting when they say, "Let's run a couple of differential lines right next to it." And, of course, they say that every time.

Matties: I think we're pretty close to wrapping up. Andy, is there anything else that we need today?

Shaughnessy: I think we covered it. Thank you all for your time.

McCurdy: Thanks, everyone. FLEX007

Experts Discussion with **John Talbot**, Tramonto Circuits



Feature Interview

BY THE I-CONNECT007 EDITORIAL TEAM

For this first issue of *Flex007 Magazine*, we interviewed John Talbot, president and owner of Tramonto Circuits. Headquartered in metro Minneapolis, Minnesota, Tramonto manufactures flexible and rigid PCBs for a variety of industry segments. Editors Andy Shaughnessy, Patty Goldman and Stephen Las Marias asked John to discuss the challenges and opportunities in the world of flexible circuits, and some of the trends he's seeing in this market.

Andy Shaughnessy: John, what trends are you seeing in flex this year?

John Talbot: I think wearables will be a big topic for the next three or four years. We're seeing a lot of interest in aerospace and automotive right now. Assembly is something near and dear to my heart; even though the flex industry has been around for a long time, it's still a really small part of the overall industry, and we still have customers who are not comfortable with the assembly portion of flex circuits.

Shaughnessy: Do you all offer flex assembly and design?

Talbot: Yes, we build bare circuits and we do assembly and design. We still don't see a whole lot of customers that are looking for design help. They tend to design the circuits as they would a printed board, and then get some help from us to just adjust it or revise it to make it manufacturable in the flexible circuit world.

Patty Goldman: How much of your design work is for flex?

Talbot: Maybe 10% are designed from the bottom up. Everything else is at least a design put in front of us and then we help them adjust it.

Goldman: So that 10%, do they just say, "Here, design something for us please?" Or are they just throwing up their hands and saying "We don't even know how to design this"?

Talbot: Not quite. It's more like they don't have the time, or they've designed circuit boards for a long time, but now they're starting to get into flexible circuits and they just need some help figuring things out, typically with the standards. For years and years,





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we all know what the printed circuit board industry likes about trace widths and spaces and drill hole sizes, annular rings, and solder mask clearance; all that kind of changes a little bit when it comes to the flex industry. So, 90% of what we get is people who are comfortable with circuit board standards but not so much with the flexible standards.

Shaughnessy: Are flex standards keeping up with the industry, John?

Talbot: Not entirely—not for a company like ours anyway. We’re still an etch company. We are still removing copper and I think that we are seeing a pattern for several years now, of things getting smaller and tighter—smaller holes, smaller traces, and that sort of thing.

Stephen Las Marias: You mentioned earlier that some of the companies are still not comfortable with the assembly of flexible circuits. Why do you think that is so?

Talbot: It’s probably two-fold, Stephen. One reason would be because they’re very comfortable with printed circuit board assembly, and two because you can’t simply put a flexible circuit through the SMT line the way you would a circuit board. There are more fixtures and more carriers; there’s more planning and more tooling required to do it.

Las Marias: Does that mean that you have to sort of customize your assembly line when you’re working on flexible circuits?

Talbot: Yes, on almost every product. Let me give you an example: If you panelize a circuit board, and you put the traditional mouse bites in that we use to hold the circuits into the panels, that panel will stay nice and rigid all the way through



the screening process, the pick-and-place, and the oven. Now, if you panelize a flexible circuit, the tabs are not the same. We don’t have mouse bites necessarily. We have literally just a tab of material left open. So, handling that panel, even if you’re using fixtures and carriers, sometimes just handling the panel out of the packaging will break the tabs, and now you’ve got floppy circuits. You’re trying to screen very small patterns into a paste, and then also trying to hit it with the pick-and-place machine as well. This causes a little more of a problem than the traditional circuit board would.

Shaughnessy: What are some of the segments driving flex now? What about automotive?

Talbot: We’re seeing some automotive right now, and we’re still seeing a lot of aerospace, and medical is very high. Another topic that I would add to this is very long circuits.

Goldman: Which of the industries has the greatest influence on change or keeping you at the highest level of technology?

Talbot: That’s a hard question to answer. Medical for sure, and I wouldn’t even know after that. Medical are the customers who give us the most challenges.

Goldman: I just wondered if it was automotive, but I wouldn’t see that as quite the same kind of challenge, right?

Talbot: No, automotive for the most part doesn’t. They’re not making things as small and tight as the medical industry does.

Goldman: That’s true. The medical industry makes everything tinier and tinier.

Shaughnessy: And medical you've got to go deal with FDA regulations; it's a whole different set of hoops to jump through.

Talbot: It is, and really the trick with medical is to get the design right and consistent. Once it gets approved it has to be that way for the life of the part. The main automotive challenges, I would say, involve record keeping. And for medical, whatever the process is, you have to stick with it for the life of the product.

Shaughnessy: In automotive they're also a little more concerned with cost, right?

Talbot: Medical is, of course. So is automotive. To be honest with you, Andy, right now we're only 24 days into the new year and nearly half of our customers are shopping all their products. This economy that we've had for about a year now seems to be booming and making everybody happy, and now we have a tax cut, and everybody is getting money in their pocket. That's increasing pricing because, for instance, in 2017, payroll increased 40% at Tramonto.

Shaughnessy: A lot of companies gave out raises and ended up having lower numbers for the 4th quarter because of the raises.

Talbot: And they're hoping that it's going to catch up, but the big push I'm seeing right

now is that by the end of 2018, you're going to hear a lot of manufacturers say that we're getting back to a situation where everybody is trying to save a nickel or a penny.

Shaughnessy: Have you had any orders that are using 5G?

Talbot: We don't have anything in-house that's a concern for high-speed right now. Even the LCP materials is legacy stuff, so we're not seeing any new stuff like that. And to be honest, we don't have a whole lot of communications customers. With the communications customers we do have, typically we're building them circuits for their racks, servers and that sort of thing.

Shaughnessy: Do your customers tend to work with you from the get-go starting at the design level?

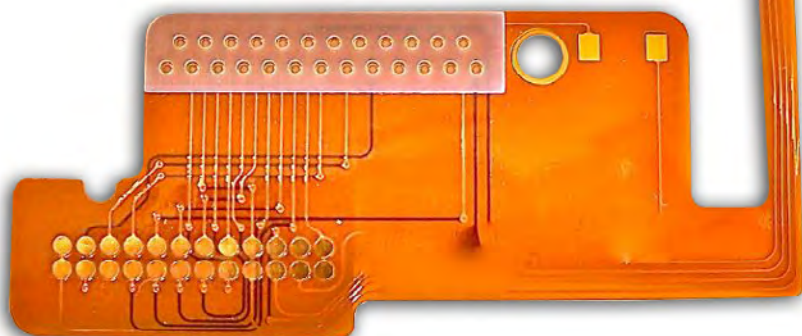
Talbot: Not all of them, Andy. Usually it's just if they have a problem, or if they think they might have a problem. We have lots of customers who have experienced designers, and we help when they have questions.

Shaughnessy: What kind of materials do you typically use for flex?

Talbot: Standard polyimide typically, some DuPont and some Rogers and some others.



But the dielectric properties tend to be generalized, I would say. We have a common dielectric constant that we use for impedance control type calculations, and of course when you get a design like that from an RF engineer or from a high-speed engineer, they're using different calculators than we are and typically they get



really close. The bigger problem that we have when we're talking about dielectrics and stack-ups for that sort of design is the thickness of materials that are built.

We have a standard line of thicknesses, and if the customer has designed it and put it through the calculator and maybe it says there needs to be 5 mils in between copper layers, and that's just not a common thickness for us. That's when we get into situations where literally we will go out and purchase special material just for that. Dielectric properties, though, are or have been historically basically generalized in our industry.

Goldman: I've heard that if you've changed your parameters or your temperatures, for instance, then the dielectric properties change and so you almost have to pick a point and go from there. Could that be why they're so generalized?

Talbot: I would assume so. For instance, in the summer when there is high humidity, we get a lot of moisture in the materials and that changes the dielectric properties as well. We've had to live with that for a long time, but the truth is if we stick to the normal typical standards and design a circuit around them, and adjust as necessary after measuring impedance

coupons, we see very little failures after that. And these are the general published numbers. Yeah, you're sort of just jumping in the middle and using those specifications, but they work well in the field.

Shaughnessy: You mentioned the very long flex. Do you guys do any of that?

Talbot: We do. Probably about 10% of the circuits that we build are outside of the standard length. We can go up to a meter pretty comfortably and have gone much longer than that for several others. The last one that we quoted for somebody, they wanted a 12-foot or 14-foot long circuit, and they wanted 5 mil traces and 5 mil spaces. And that's just not possible, for us, along that length.

Shaughnessy: How do you even know how to bid a job like that?

Talbot: We don't bid it. We can't. If we thought that we could build it with a yield better than 1 out of 10 we would. But if not, then the cost is enormous, and we can either bid it that way and take up a whole lot of time and effort, or just say no. This design just doesn't fit our capabilities well. We've had some customers who kept coming back to us because they couldn't find anybody else to quote it.

Shaughnessy: What do you think about the new technology at CES, like the drones and 3D viewers and virtual and altered reality that have flex inside.

Talbot: That's great. But there's one thing I haven't seen, Andy. Every year, the overall circuit industry publishes the amount of circuit boards that are built every year versus the amount of flex, and I haven't seen the amount of flex really increase much. It kind of hovers between 10 and 15% of the overall industry. When that gets up to 25% or 35% or something like that, we'll know that it's into a lot of products.

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Goldman: I would have expected it to be higher or to be increasing.

Talbot: Agreed.

Shaughnessy: I remember it was about 5% when I started writing about PCBs in 1999. Flex was so expensive then that you didn't use it unless you absolutely had to, and now a lot of people look to it first.

Talbot: As soon as that percentage starts increasing, then our material costs will go down and it will be more in line with circuit board costs, because we're still more expensive than circuit boards.

Goldman: Do you do anything else other than flex?

Talbot: We also do circuit boards. Everything we do is etched, though. We can put flex on different materials, polyimides and polyesters and that sort of thing, but we're still an etch company. We haven't started any sputtering processes or laser etching or anything like that.

Shaughnessy: What about rigid-flex?

Talbot: We do, and it's about 5% of our work.

Shaughnessy: What do you think is the biggest bottleneck for you as far as flex goes? Or for your customers?

Talbot: Materials as of late. You know, a year ago we went through a time when copper wasn't being sourced in as big of quantities as it was earlier. Copper prices go up and down all the time, but material costs too for a while made materials very difficult to get. Now it's not so difficult getting materials, but I think that's kind of cyclic. Right now, I would say our biggest challenge without question is labor. Labor would be number one.

Goldman: What do you mean exactly?

Talbot: Skilled labor. We actually have a training program at Tramonto for the assembly portion. We'll bring people in who have never assembled before and we'll run them through the IPC or the J-standard training program. The thing about bringing people into a training program is some of them have never been in manufacturing before. When they get into the environment, they may find out they don't like it. But trying to find skilled people right now is very difficult.

Goldman: I wasn't sure whether you meant dollars and cents, or if you meant like you said skilled and capable people.

Talbot: It's both. Like I said, last year our payroll increased 40%, which is a pretty big chunk. And this year we don't see that changing at all. To get the skilled people and retain them, it's going to take that. I've read there are 5 to 8 million men from the ages of 25 to 40 who are just sitting on the sidelines, and they're just not in the workforce like they used to be. That's a lot of people that are capable, trainable, and not available.



Shaughnessy: I've read that there are a lot of people who have kind of opted out. They're not even going to bother looking for another job.

Talbot: Right. I think another problem we're going to see in 2018 is going to be a squeeze on price. I've already seen it, and I think competition is going to be fierce.

Goldman: More and more people are getting into flex, that's for sure. Whether or not they're good at it remains to be seen.

Talbot: We'll find out, right? Because the companies that have been out there for a long time doing this, if they're losing customers to the newcomers, and then they start seeing those customers come back, we'll know if they're good at it or not. It's not the easiest thing in the world to do.

Goldman: Everybody can do a couple. Everybody could do a few prototypes.

Talbot: Right, it's the production that's another story.

Shaughnessy: How did you wind up doing this for a living?

Talbot: I came from the developer side of the fence. I'm an electrical engineer by trade and I've developed hardware and software, and back in the day I was developing for UL and the FCC, so I've been on the other side of the fence. I know the problems, questions and challenges that people have when they say, "This is the board we want to build but our supplier can't build it this way," so we have to adjust it here and there and whatever. That's why we coined the phrase "design for application" as opposed to design for manufacturing.

Shaughnessy: How about IoT? Does IoT figure into what you guys do?

Talbot: We're starting to see more and more of it these days. Even in the manufacturing world,

we're actually thinking about putting a system into our factory just to follow a product along. We've toyed with the idea of having a way for our customers to log in to our website and follow their product around so they don't have to call and get updates or they don't have to get the system updates. They can just log in at any time and see if they're on time, see if they're behind schedule, and so forth.

It really just didn't work well because people wouldn't use it, because it was easier for them to just call or send an email than to log in and find their password, log in, check on their product, know exactly what order number they're talking about. We're toying with another idea that would actually fit into the IoT and send updates through an app to a cellphone.

Customers could get regular updates, and they'd consistently know as the product moved to the next stage, how many days were left. At a glance they'd know how their product is going. We feel comfortable doing that because it's one of our key progress indicators and it's one of the things that we track regularly every year. I don't know if anybody else does it, but we publish our on-time delivery results and our RMA results every year. We feel comfortable putting in a system like that for our customers.

Shaughnessy: As an EE, did you ever design flex yourself?

Talbot: I didn't. When I was designing hardware and software it was all going on rigid circuit boards at the time. I kind of stumbled into flex almost accidentally, and have been there now nearly 20 years. I've spent about half my career in the flex industry and half my career in the engineering world, on the other side of the fence.

Shaughnessy: Well, we appreciate your insight here, John. Thanks so much for your time.

Talbot: Thank you, Andy. FLEX007



Field Trip: CID Class Sees How Flex is Made at **Streamline Circuits**

by **Kelly Dack, CID+
EPTAC**

I've been designing PCBs and flexible circuits for decades now. I've heard a lot of advice over the years, but what really sticks in my mind are the wise words of a mechanical engineer I worked with back in the '80s. He was an older guy named Clarence. One day, Clarence and I were doing a design review, and he gave me some sage advice: "Kelly, never design something that can't be built."

I got a chuckle out of his statement. Well, duh! Of course, it must be manufacturable. Every designer knows that, right?

But as the years went by, I engaged with more designers, design teams and manufacturing stakeholders. (In my view, the stakeholders are anyone with "skin in the game." We don't want to let down any of our fellow stakeholders.) I soon realized that Clarence's words were a prophetic warning for my future career path as a PCB designer. While I was thinking "duh," I had only begun to start reaching out to suppliers and manufacturers in the PCB industry.

As I spoke with these manufacturing stakeholders about what they need from a designer to make successful circuit boards, I heard woe-filled tales of PCB designs that were unmanufacturable. Some designs had lines that would etch away, or via pads that would be obliterated if over-drilled to allow for plating. Multilayer PCB stack-ups would often need to be a quarter-inch thick to achieve the specified impedance requirements. It was as if these PCB designers had never set foot inside a fabrication facility before. And that turns out to be the case more often than you might think; many designers have never visited a board shop.

After many years, I'm still designing rigid PCBs and "flexitos," and I'm still reaching out to PCB manufacturing suppliers and making queries to find out what designers can do to help our manufacturing counterparts be successful. And you know what? I'm am hearing Clarence's words echoing from an entire industry of fabricators: "Never design something that can't be built."

If you are a PCB designer, are you surprised? Maybe you are responding "Duh," as I did 30

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years ago. In the spirit of Clarence, I'm here to warn you that "duh" is an inadequate response. Unmanufacturable designs are still prevalent in the PCB industry, on a worldwide scale.

To help alleviate this issue, I'm trying to convince designers that they need to visit a board shop every now and then. I recently had the opportunity to take a group of designers on a tour of Streamline Circuits, a rigid and flex fabricator in Santa Clara, California.

As a design instructor for EPTAC, I was teaching an IPC Certified Interconnect Designer (CID) class in Santa Clara. This four-day class drew a group of five PCB designers, all hoping to achieve their CID certification by the end of the week. During the segment of the course materials that covers the importance of reaching out to other PCB process stakeholders, I always ask the class if anyone has visited a PCB fabrication supplier to see the process up close. I am constantly amazed that a very small percentage of designers have ever done so.

During this class, I had learned that the training facility that EPTAC uses in Santa Clara is a block away from Streamline Circuits. Streamline does a lot of military and aerospace work, as well as communications and industrial electronics. The company manufactures quite a bit of multilayer flex and rigid-flex circuits, in addition to rigid boards. This would make a great field trip for my CID class!

I had already preached the story about Clarence and his admonition to never design something that can't be built. Then I asked how many designers in the class had toured a flex manufacturer, or even a rigid PCB shop. The answer was none.

I asked our class if they would like to take a lunch break the day before our test, off the class clock, to visit Streamline Circuits. The response was unanimous. Absolutely!

I called Streamline with my idea, and Applications Engineer Randy Thompson said he'd love to host a tour of their facility. Fabricators



Figure 1: From left to right: Jeremy Dunn, instructor Kelly Dack, Lakschmi Chaturbhuj, Yuebin (Victor) Ma, Terry Child, Streamline Applications Engineer Randy Thompson, and Dugan Karnazes. All CID students passed the exam and are now CID-certified.



Figure 2: Lakschmi Chaturbhuj inspects circuitry during the Streamline tour.

generally love to host tours to educate designers about the fab process and their own unique capabilities. They host tours in the hope that the designer will become more in touch with the materials, processes and people involved with the process and, well, design better!

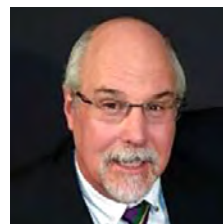
We ended up spending hours at Streamline. Randy proved to be quite the tour guide. The designers were able to smell, touch and observe flexible circuits as they were being manufactured. The class learned that there is much more to flex manufacturing, and therefore flex design, than they could have imagined.

The best reason to take a board shop tour: Designers get to use senses that don't usually come into play while working on their CAD systems in their offices. These CID students were able to smell, touch, and see flexible circuits and rigid boards in the process of being built, something which can only happen during an on-site tour.

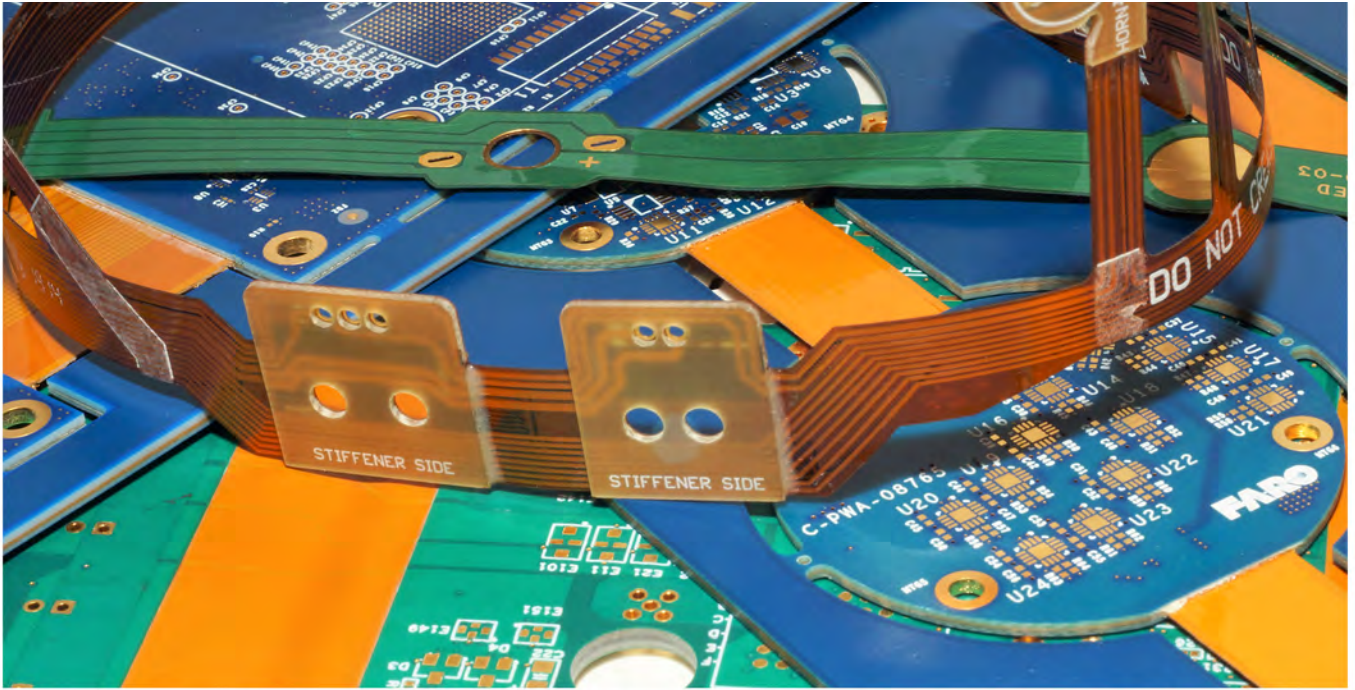
Later, I asked the class for their thoughts on the CID class, and Dugan Karnazes, a brand-new CID-certified designer, seemed to speak for the group.

"Even though I've been designing boards for years, I found the course to be pretty valuable and informative. I would recommend CID training for anyone looking to gain a bit more knowledge about how PCB manufacturing works," said Karnazes. "There's an incredible amount of perspective that comes with understanding how upstream design decisions affect the end manufacturability, reliability, and price of a PCB assembly. This certification is not just for designers anymore; engineers need to know these processes as well. PCBs are only getting more complex."

It's hard to argue with that! I hope to take more of our CID classes on tours of board shops in the future. Where else can designers smell, touch, and see rigid and flexible circuits being manufactured? **FLEX007**



Kelly Dack, CID+, is an IPC CID instructor for EPTAC. He has over 30 years of PCB design experience.



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

Feature by Dave Lackey and Anaya Vardya
AMERICAN STANDARD CIRCUITS

Designing Flex Circuits for First-Pass Success, Part 1

The design process is arguably the most important part of the flex circuit procurement process. The decisions made in the design process will have a lasting impact, for better or worse, throughout the manufacturing cycle. In advance of providing important details about the actual construction of the flex circuit, it is of value to provide some sort of understanding of the expected use environment for the finished product.

The electronics industry serves several different markets that do not always share the same product acceptability or reliability expectations. For this reason, the electronics industry, through IPC and other standards organizations, has developed a classification system that specifies what is expected of products for different classes. The system of classification is not intended to be a measure of quality. Rather,

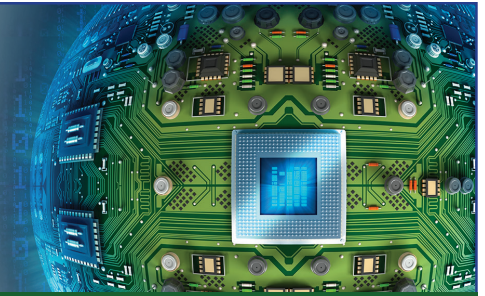
quality is a matter of conformance to a set of established requirements for a product in a given application. Therefore, quality products can be created in each of the classifications within the system. It is generally accepted that there are three classes of product. These have been defined by IPC standards as follows:

Class 1 – Consumer products and products for non-critical applications where cost is normally the primary driver.

Class 2 – Higher-order products in terms of quality and reliability expectations, including telecommunications, computers and general industrial.

Class 3 – High-reliability applications including military, aerospace, automotive and medical products.

By defining the class of the product being designed, the purchaser is letting the manufacturer know what added controls to apply to the manufacturing process and the level of care they will need in the inspection process to



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ensure that the customer gets the product that is best suited to the application.

The following are discussions on matters of high importance to achieving first-pass success in securing quality flexible circuits from a flex circuit vendor.

It is important to provide some information about the operational requirements for the flex circuit, especially if the circuit is to be used in a dynamic flexing application, such as for a disk drive read/write head assembly. The reason for this is the circuit vendor needs to provide a plan for proper layout strategy for manufacturing; a plan which accounts for the grain direction of the copper foil during the manufacturing process. This is because there is a measurable difference in terms of flexing performance between the machine and transverse directions of the copper foil.

Fabrication Specification Details

After the basic circuit design layout is completed, the next most important piece of information required is the fabrication specification. This document communicates to the fabricator all the pertinent details for the physical construction of the circuit and what is needed and expected in the final product. If this information is incomplete or inaccurate, or if a customer has requirements that cannot be reasonably met by a competent manufacturer, time will be unnecessarily lost, at a cost to both the customer and the vendor. For this reason, it is vitally important that the fabrication specifications are checked and rechecked before putting them out for bid. In the sage words of the master carpenter, "Measure twice, cut once."

Manufacturing Tolerances

Manufacturing system operators need not only the dimensions of the part they are to manufacture, but also the tolerance for the important features of the product. With flexible circuits, this is something that must be done with thought, care, and consideration of the realities of flexible circuit materials.

With some features, design tolerances may be critical for the performance, fit, or further processing of the product (line widths, spaces,

hole sizes, physical separation of features, positional accuracy, etc.). In these cases, the manufacturer can often employ methods to deal with the requirement on a localized basis. In the case of other features, the tolerance may be less critical, significantly less critical, or even non-critical. An important thing to keep in mind is that flexible materials are not as dimensionally stable as rigid materials, and while local features may be held in tight tolerance relative to each other, features from end to end may be less predictable. Given that flexible circuits are normally installed in some 3D form after assembly, the tight tolerances on planar measurements are often not necessary. If there are questions about a tolerance callout, the designer should contact the manufacturing engineer. It is always best to solve the problem before it becomes a problem.

Unclear Layer Designation (Rigid or Flex)

The purpose of a product specification is to provide clear, unambiguous instructions on the product's construction. In the case of a multilayer circuit design, this is vitally important. The relationship of internal circuit layers relative to one another has become increasingly important in not only assuring that correct interconnections are being made, but also in product performance, especially with controlled impedance designs and signal integrity issues. Several different systems have been developed over the years to help assure that there is no uncertainty in the order of the circuit layers in the final construction. The fabricators engineering staff can provide recommendations if needed. Note the thickness and construction of each core in Figure 1.

Cover Layer Requirements Not Properly Called Out or Defined

Coverlayer and cover coat are terms normally reserved for flexible circuit constructions and they are by default a defining structural element of both flex and rigid flex circuits. Coverlayers serve as a flexible solder mask of sorts, protecting the delicate circuits from damage and potential wicking of solder

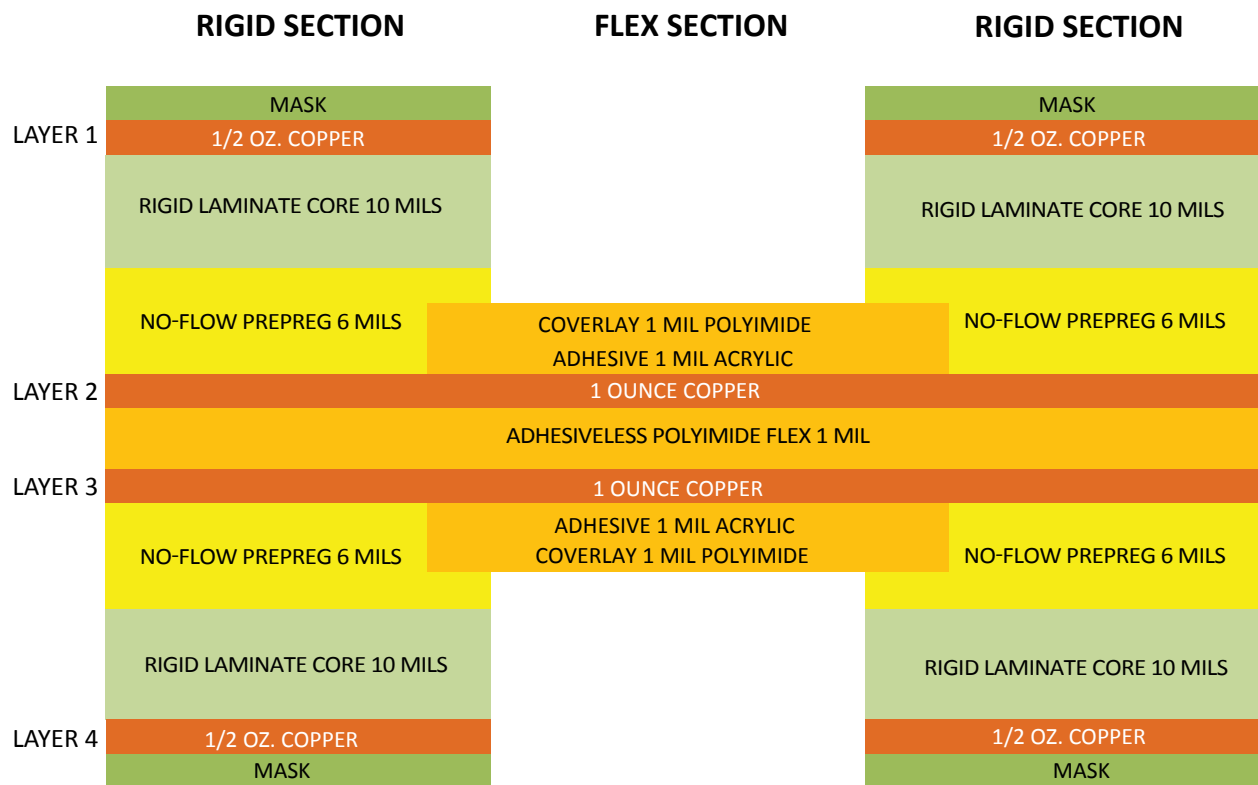


Figure 1: Example of four-layer flex construction.

along circuit traces, while leaving open access to design features where interconnections are to be made to components by soldering. It is important to determine the thickness of a coverlayer to allow for maximum flexibility when desired, and ensure you have chosen a coverlayer with a sufficient amount of adhesive on it to accommodate the copper weight. Coverlayers are also of importance in the design of areas where the circuit is to be bent either just one time, intermittently, or dynamically, millions or even billions of times over its useful life. The latter case, the dimensions and make of the flexible circuit coverlayer is critical. In dynamic flex circuits, there is need to balance the amount of flexible materials on the sides of the conductors where flexing is to occur.

It is important to know and understand that there are different types of materials available for use as coverlayer materials, and that there is no single, ideal solution. These material choices include: materials that are laminated to the copper circuits using heat and pressure; materials that can be laminated and then pho-

toimaged, like solder mask, to define points of connection; and materials that are simply screen printed on to seal traces, while leaving open features of interest for further processing or for making interconnections.

Number of Flex Layers

The clear majority of flexible circuits have just one or two metal layers. However, an increasing number of high-performance products now require high layer counts and high-density interconnect (HDI) design techniques. As layer count increases, so does the need for control in design generation to accommodate manufacturing process realities. It is also worth noting, while on the topic of layer count, that stiffness increases as a cube of thickness. That is, if one doubles its thickness, the stiffness goes up eightfold ($2^3 = 8$), and thus small increases in thickness due to increases in layer count can greatly decrease circuit flexibility. The converse is also true, of course. The following are some key concerns to be understood and addressed in the design process relative to flex layer count.

As is the case with any multilayer construction, core thickness must be provided with the assumption that copper is clad on at least one surface. The core thickness is generally understood to be the thickness of the dielectric material between the copper layers. The core mate-

rial can be a simple single-sided piece of copper clad polymer, or it can be clad with copper on both sides. Many different core thicknesses are commonly available for flexible circuits, but the most common is 75 mm, typically comprised of 25 mm of base polymer (e.g., poly-

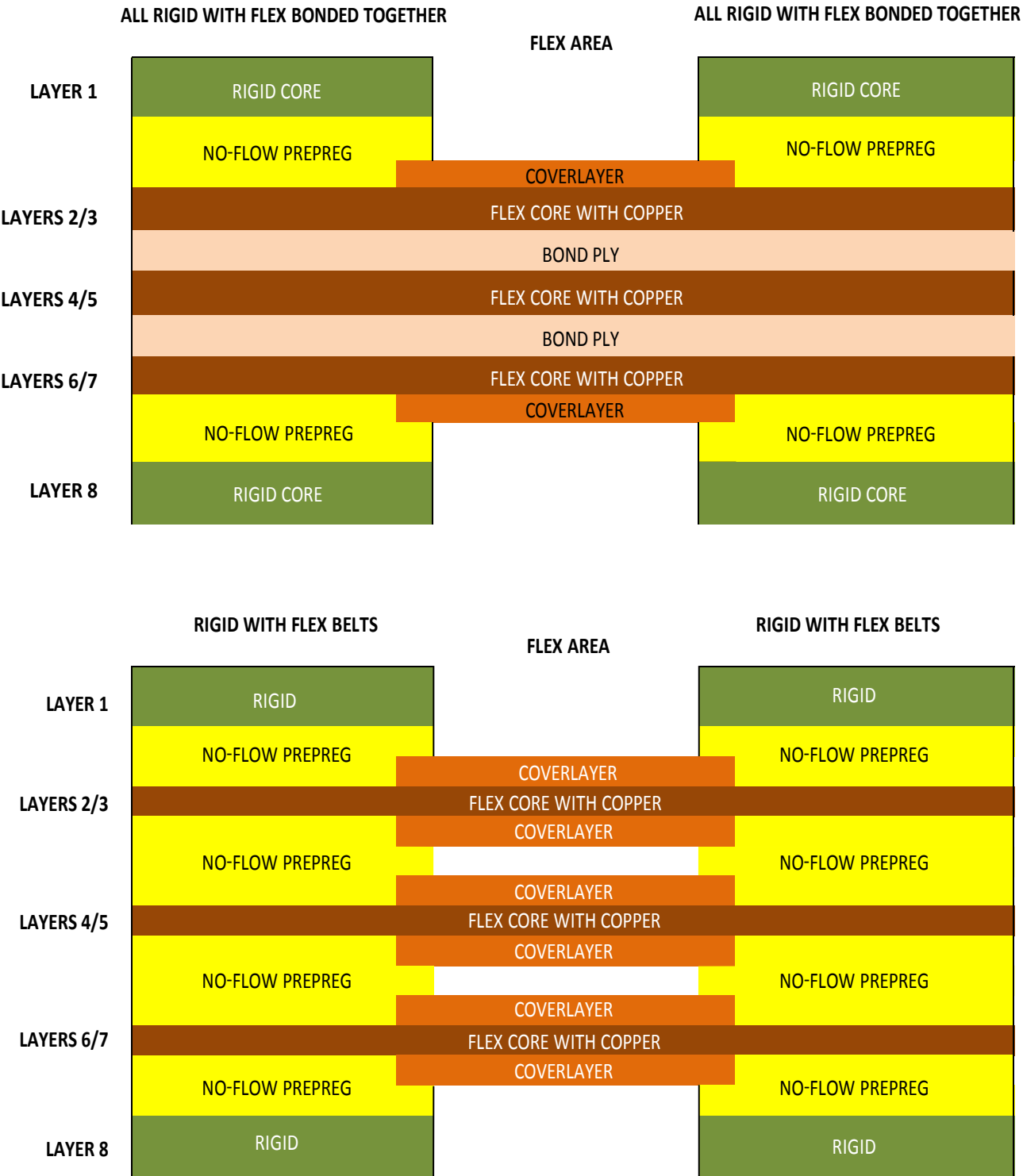


Figure 2: Bonded vs. unbonded flex.

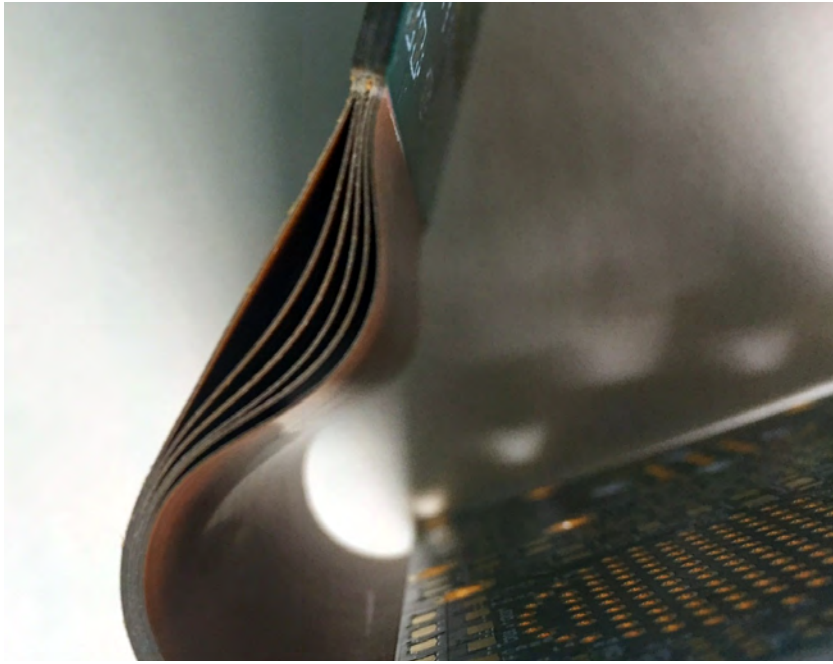


Figure 3: Completed PCB flex belts separated.

imide, polyester) with 25 mm of adhesive (e.g., acrylic, modified epoxy) on either side to bond copper foil to the surface of the base polymer. Thinner and thicker core materials can be procured both with and without adhesive. It is recommended that designers check with their flex vendors for both their recommendations and the availability of the chosen material.

While the discussion so far been limited to flexible circuit core material, rigid materials are employed in the fabrication of rigid-flex circuits. Of course, any of the myriad core materials used in rigid multilayer circuits are also available to make rigid-flex circuits. However, once again, it is advisable to check with the flex manufacturer for advice as to what options are most common and readily available.

Separation Distance Between Flex Circuit Cores

When a product requires two or more cores, there is a need to define in the specification what the spacing requirements are between cores. The spacing can impact product performance (physical and electrical) and, most obviously, thickness. In some designs, the spacing between flex circuit cores may be filled with dielectric material, but with other designs the dielectric between flex cores in the flex area may be omit-

ted to assure maximum flexibility (Figure 2).

If the core layers must be unbonded, this should be noted in the documentation. Those areas where bonding is to be avoided should be identified in the design artwork package. The unbonded areas must have a coverlayer applied to each exposed side (Figures 2 and 3). In laminated areas, it is not required and arguably a liability when plated through-hole reliability through the assembly process is considered. Obviously, in areas where interconnection is required between multiple layers of internal circuits, a dielectric is required as shown in Figure 2.

In the next installment we will continue this three-part series by addressing circuit layout symmetry, designing for bending, and controlled impedance. **FLEX007**



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



Anaya Vardya is CEO of American Standard Circuits.

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APCT Moves into **Rigid-Flex** with Cartel, Cirtech Acquisition

Feature Interview by Andy Shaughnessy
I-CONNECT007

When I spoke with APCT President Steve Robinson a year ago, he said he was interested in adding flex and rigid-flex capabilities. With the recent acquisition of Cartel and their subsidiary Cirtech, APCT now has a flex and rigid-flex facility, along with military and aerospace certifications. At DesignCon 2018, I asked Steve to discuss these acquisitions and what they mean for APCT and their customers.

Andy Shaughnessy: Steve, good to see you again. Now, as the top guy at APCT...

Steve Robinson: I'm the head janitor. I clean up all the messes [laughs].

Shaughnessy: That's right. Steve, give us a quick background on APCT.

Robinson: APCT was founded in 2008. It was Advanced Printed Circuits before that. This will

be the 37th year of that facility and that operation. When I left Merix, I acquired this operation and we've been focusing on a high level of advanced technology and high engineering support for over eight years now. Business has been great, and we've been very fortunate. I think we picked the right market segment and the right business model that we gleaned at the time. We just had a nice start to 2018 with another acquisition.

Shaughnessy: Tell us about this acquisition.

Robinson: We acquired two business entities. First, Cartel Electronics, run by Bruce McMaster in Orange County, California is a rigid medium-to-advanced technology manufacturer, a high-mix commercial factory. Then we acquired an affiliate of theirs, Cirtech, which has a market niche: defense aerospace, military-focused, with high-level certification, and flex and rigid-flex as well.

One of my charters in 2017 was to provide a solution for our customers in the flex and



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rigid-flex arena. And I was happy to get this deal done; we started on it in August 2017 and finally closed in January 2018. It's nice to have the additional capacity and depth from the Car-tel team, along with the additional offering of the flex and rigid-flex. The defense and aerospace certifications of Mil-P-55110 and 31032 were high-value targets, and to be honest, it was easier to acquire than it was to implement them in my current operations. So, we chose that path.

Shaughnessy: So you don't have to train anyone...

Robinson: Yes, you don't have to change the culture of your specific factories either. One is a high-reliability facility, a little bit more meticulous with its focus, while the other facilities are more advanced technology-focused and speed-focused. Stopping to complete 20 pages of paperwork every other day is kind of cumbersome to our task of quick turn, but both strive for high reliability.

And I'm really excited to introduce our quick-turn culture into those arenas. In the initial month, I've been meeting with customers, especially the flex and rigid-flex. Even in the defense and aerospace segments, the technologies are evolving very quickly, and there's a shortage of suppliers. So when you have our established, high-reliability factory and now you introduce our advanced technology, quick-turn capabilities, our meetings have been pretty

eye-opening. Customers now know that they have a source that they can go to that offers a broader range of technology for them. Because they're being pressured, the defense industry is the same as ours—smaller, thinner, lighter, faster, more economical, more affordable, and more efficient. And so that's driving smaller, tighter lines, smaller features, everything that embraces the advanced technology space that APCT has niched itself in.

So far the feedback's been tremendous, and the customer interest is through the roof compared to what we expected. So it's really good. We're really excited about it, looking forward to the rest of 2018 and working with it. As I said before, as with any acquisition, you don't buy a company; you buy the team. I'm excited about the depth of the team, and the experience they have. Many of these people have been building printed circuit boards in their industry niche for 20–30 years, so it adds tremendous depth to APCT. It still is just people working with people, so to have a huge surplus of industry veterans is something special.

Bruce McMaster has been one of the top leaders of our industry for years, since the DDI days. John Stein is running our Cirtech operations, and he has many years in the design and manufacturing of flex and rigid-flex. I thought my team was the strongest team in the industry prior to this, so it's really exciting for me. As CEO, my job is team building, right? I put the best players on the field and have a good game strategy, and then execute with a good team. I am about to roll the PCB Patriots into the circuit board industry.

Shaughnessy: You talked before about how you want to reach the designers and design engineers on the front end to do high-reliability and the high-tech work.

Robinson: Absolutely. Because as you go to the advanced HDI space, there are still a lot of struggles in the design stages. They don't yet understand the critical steps to have high reliability and predictability in advanced technology builds. It requires balanced constructions, looking at what you can do, and making it



achievable for manufacturers to be successful.

That holds true for the flex and rigid-flex space as well. That industry is evolving, and designers are still struggling to do it right. Our core focus is still engineering at APCT, and that's what we are. We're a service company. We happen to build circuit boards, but this acquisition is still the same. We are a services business. We're working with designers, and we're working with engineers, helping them develop a concept, and then we build the solution for them. And that starts with early involvement, helping them through the design aspects of it. And it's fun. It's been exciting.

We grew 40% last year in that model, which was a big year of growth for us. I think we've found an area that has value, and there is a need. With any business model where you find value and a need, if you don't mess up the execution, you should have a successful opportunity. This is what we're seeing now.

Shaughnessy: And now you have flex and rigid-flex. The last time we talked, you said flex was on your radar screen.

Robinson: Right, we had no flex or rigid-flex. That was really my goal in 2017, to bring that opportunity. You want to diversify your offerings, but you also want to provide something your customers are asking for, and most of my customers were asking me for that. In 2018 we are going to try to perfect that, and now we've got customers asking for new technologies. They're talking to us about some of the thermal conductive materials out there, especially in the automotive and the lighting industries. How do we develop that for them and work on that?

As miniaturization has gone to levels even beyond our capabilities of 40 micron or less trace and space, we're being pushed for more. Our engineering team is now looking at the additive process, buildup processing, and some of those new technologies that are coming out and just starting to emerge. We will continue to chase those processes, as long as there is market behind it. I don't want to chase them just to prove that it can be done; I want

to chase them because there is some value and customers need it and there is a market.

Shaughnessy: I've talked to a couple of people here who say it's hard to find somebody who can build their flex the right way. One company owner told me that the worst things they have had to deal with is the assembly of flex, because with all the fixturing, it's almost like starting over from scratch.

Robinson: It's different. You know I have a few people on my team who have familiarity with that processing. I think you learn two things in that industry. Number one, you don't see many rigid and flex facilities combined. They've all pretty much abandoned that strategy; you see flex-dedicated or rigid-dedicated factories. Flex requires a little different mentality and a different thought process. I've learned that the upfront engineering and the time associated with developing a plan for flex is a lot more comprehensive than with advanced HDI or other tough technologies we can get on the floor in a couple hours or a day or so. With flex, it takes a few days to coordinate that.

The challenges we see are cycle time, along with miniaturization. You know it's going that route as well. How do you do it right? How do you do design? That's why I am excited about having design guys on my team that are at the early stage with the flex. This gives us an opportunity to lay the board out in the right way. It's all about how you lay your circuitry with the way that product is bending.

Shaughnessy: Do you have some flex designers now?

Robinson: We do, at the Cirtech facility, and they supply designs to customers as well. And the other piece is assembly. We're looking at putting some of that down there, too. Most reputable flex or rigid-flex facilities have some type of assembly in-house as well. We'll look at that maybe for that region. I've never embraced the assembly aspect of it because it is a conflict with a lot of our customers, and I don't want to create that. But with the flex and

rigid-flex, it's a little different model. So we'll see. It's kind of new, so we'll go with it and play with it for a while and see where it takes us. It's exciting—super busy. We had already completely filled our capacity for Q1 in the first two weeks of selling it. That tells me the interest is very high.

Shaughnessy: That's good. So what's the big hole in your capabilities now?

Robinson: We don't really have one. My sales guys love to tell me it would be nice to find a low-cost solution. You know, a really competitive low-cost solution. I'm not sure that's feasible anymore, in North America at least, to try to have that operation that can still sustain itself. There is still a significant need out there for 2-, 4-, 6-, and 8-layer low-tech stuff that is low-cost competitive. That's what the Advanced Circuits of the world have captured.

They own that. Some of the Internet-based model businesses have that and they are thriving on it, and I think you've got to allow them to be in that space. I don't think that is going to change.

We consider our global business a program management business, not a cost-driven business. But more people come to us to manage the recipe and manage the program. I think that will be my next focus area—to try to expand that and align that with more of the demand we are seeing. We've added some distribution in central U.S. so we can support the United States with it. It's a fun model to work with, because its capacity has no limits. So it's really the right program and the right customer partnerships that really look to us for the NPI and the recipe and manage the program for them.

As far as technologies, it's the same. You know, I think we've gone beyond the standard PCB manufacturing techniques. We have everything that you can do it with now, with the additive I think will be our biggest thing

we will look to improve. That process is probably the newest emerging. If you're going to get down to 10 to 15 microns trace and space, we've got to get creative with that. I think that's probably what we are going to focus on in a limited basis now.

Then the other aspect is the cycle time, to continue to focus on reducing our cycle times where we can do multiple lamination cycles. We are currently building three to four lamination cycle products in five to six days. That's from 10 to 12 two years ago, so we have really reduced that cycle time and the demand out there for that. Reducing cost and reducing cycle times of the advanced technology I think is one of my big focuses for 2018 along with the additive. I think that is something my engineering team is going to have to come to me with. Connecticut is already embracing the thermal conductive materials, so we are probably going to roll that out in that operation.

We have a significant automotive and lighting business out of that facility already, so it makes sense for that site to do it. And you know, other than that, you work on the culture and the integration of the new families we now have in Southern California. We'll be bringing them up to speed with the way ACPT does business and what is important to us, and how we focus on our customers. We want to enhance the culture at the new facilities and capitalize on them, and do some of the things always necessary early in the process of an acquisition.

Shaughnessy: Very good. Is there anything else you want to talk about?

Robinson: I think that's it. We'll talk again, I'm sure. Thanks for the opportunity.

Shaughnessy: Thank you, Steve. Great talking to you. FLEX007





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PUBLISHER: **BARRY MATTIES**
barry@iconnect007.com

SALES MANAGER: **BARB HOCKADAY**
(916) 608-0660; barb@iconnect007.com

MARKETING SERVICES: **TOBEY MARSICOVETERE**
(916) 266-9160; tobey@iconnect007.com

EDITORIAL:

MANAGING EDITOR: **ANDY SHAUGHNESSY**
(404) 806-0508; andy@iconnect007.com

TECHNICAL EDITOR: **PETE STARKEY**
+44 (0) 1455 293333; pete@iconnect007.com

MAGAZINE PRODUCTION CREW:
PRODUCTION MANAGER: **SHELLY STEIN**
shelly@iconnect007.com

MAGAZINE LAYOUT: **RON MEOGROSSI**

AD DESIGN: **SHELLY STEIN, MIKE RADOGNA ,**
TOBEY MARSICOVETERE

TECHNOLOGY SPECIALIST: **BRYSON MATTIES**

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EDITORIAL CONTACT

Andy Shaughnessy
andy@iconnect007.com
+1 404.806.0508 GMT-5



mediakit.iconnect007.com

SALES CONTACT

Barb Hockaday
barb@iconnect007.com
+1 916 365-1727 GMT-7



www.iconnect007.com