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These circuits bend where boards cannot

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The circuit board, coiled to show its flexibility, was made from six layers of a low-outgassing material for a medical device.

Unusual circuits call for unusual materials

Some flex circuits work in medical environments so tough that standard materials just won't do. Here's how one design team selects materials for unusual jobs.

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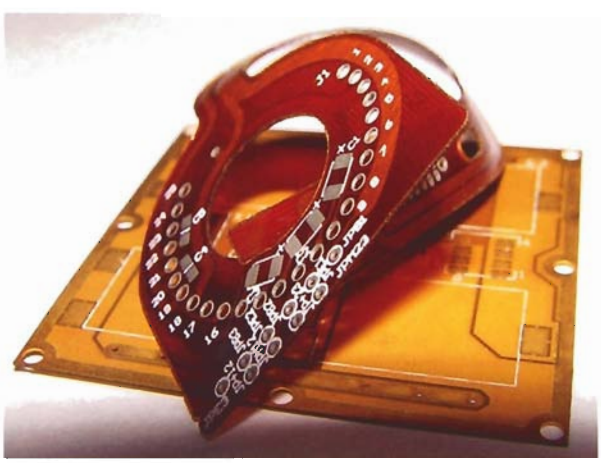
General-purpose flexible circuit "boards" have electronic components that can bend to fit in tight spaces. Most are just one or two layers thick and are meant for "flex-to-install" applications because they tolerate only a few flex cycles. They are found in a variety of medical and consumer products.

More complex flex circuits have three or more layers and are based on specifications that require, for instance, high flex cycles or must be bent or flexed to fit into unusual packaging. Electrical engineers are getting so creative that many new flex circuits have unusual features and take a little research and experimentation before they are confidently manufactured in quantity.

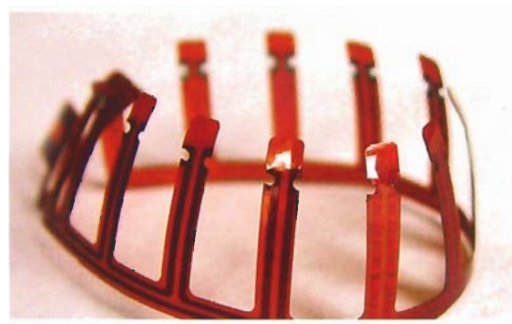
What's possible

Most people think of a flex circuit as a board with conductors sandwiched between layers of insulating material. Although true, the description fits many types of flex circuits. A few that we have built show what is possible. For example:



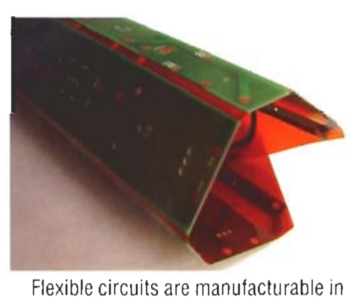
A single-sided circuit

- Single-sided flexible circuits have one conductive layer of copper on a dielectric (insulating) material. These simple circuits could be used in a hinge on a laptop computer or on the hinge of a flip-open phone and endure many flex cycles. These are built by a number of fabricators.
- Double-sided circuits place copper on both sides of the dielectric. Applications are similar to those mentioned above but where more interconnections are required in a small space.



A double-sided circuit places copper on both sides of the dielectric.

- In flexible circuits with several layers, each is registered to the other layers and bonded together with a layer of cured adhesive. The layers are electrically connected by plated through-holes.
- Sculptured flexible circuits are single or double sided with thicker copper to allow connections such as fingers or pads as rigid extensions of the flexible conductors. These circuits have thicker copper plating on exposed areas where conductors could be inserted into mating connectors.



Flexible circuits are manufacturable in several layers.

A double-sided circuit places copper on both sides of a dielectric layer.

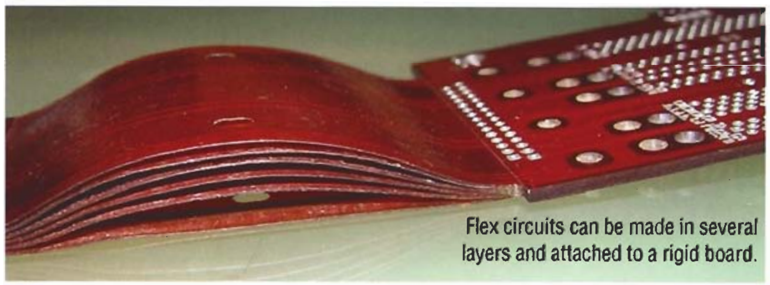
- Flex circuits can be thermally molded into simple shapes such as domes on a flexible circuit.
- Multilayer rigid flex is a rigid board with extending flex circuits. These boards are the most complex and connect two or more rigid or multilayer boards.

A few materials

As you'd expect, flex circuits are made from a range of materials. Each has its pros and cons, so the design trick is to find a material that meets most design or use needs. The most common flex material used today is **DuPont's Kapton®**. It is a dimensionally stable polyimide compatible with most printed circuit-board processes. It has high tensile strength, it's nonflammable, and has about the same coefficient of thermal expansion as copper. Kapton's® biggest downside is that it readily absorbs moisture. In any board, moisture makes manufacturing more difficult, causes delamination in boards, and would outgas in vacuums.

Mylar® or polyester films are also used in flex circuits. These materials are highly flexible, dimensionally stable, are relatively inexpensive, and absorb little moisture. However, polyester films don't tolerate soldering temperatures, so when the material is used, do not expect to repair the circuits should they need resoldering. Also, many flex circuits work as connectors and so have few components that carry heat.

Nomex®, an aramid material, is dimensionally stable, has good tensile strength, and can stand up to soldering temperatures. Its drawback is its propensity to pick up process chemicals and moisture.

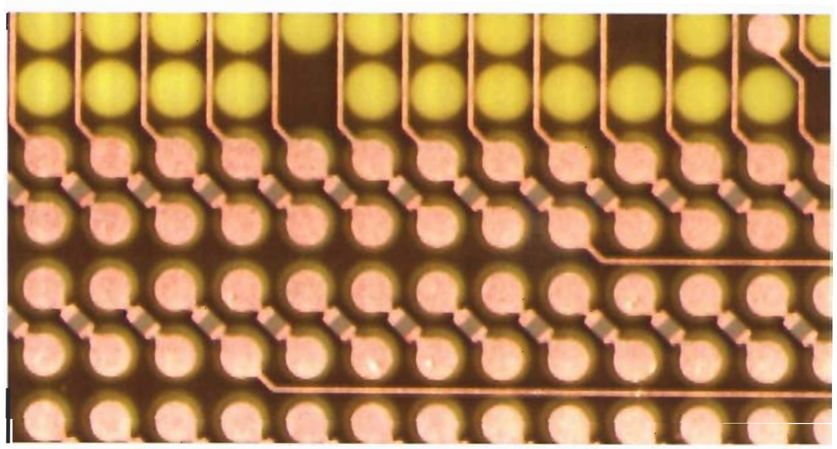


Flex circuits can be made in several layers and attached to a rigid board.

Embedded thin film resistors for medical electronics

The use of embedded passive components in the PCB industry has grown quickly over the past several years, primarily in demand for smaller, thinner, and denser circuitry. Demand seems greatest in medical electronics. The application here deals with an embedded passive material, OhmegaPly®, a thin-film resistor material manufactured by **Ohmega Technologies Inc**, Culver City, Calif., (*www.ohmega.com*).

The material, a nickel phosphorous alloy (NiP), is electroplated onto copper foil. This plated foil may then be bonded to various dielectric materials.



The slightly pink bars are termination resistors within five internal logic planes of a 14 layer FR4 glass-epoxy circuit board.

Conventional subtractive printing and etching allows making a single circuit layer of conductive copper foil traces connected to resistive elements. The circuit layer may be used as an inner layer for a multilayer printed circuit board, or as a surface layer in a conventional circuit. We have successfully bonded OhmegaPly® to PTFE (Teflon®), polyamides (rigid and flexible), FR-4 epoxy glass, along with several other exotic materials. OhmegaPly® comes in 0.5 oz. (18 μm) and 1-oz. (35 μm) copper foils. Sheet resistivities of 10, 25, 50, 100, and 250 Ω/sq. are available.

Reliability is of utmost importance for medical electronics. Resistive materials can enhance circuit board reliability by reducing or eliminating discrete resistors and the problems associated with fluxes, soldering, and washing. Also, reducing the area required for discrete resistors gives a smaller or thinner circuit board, or both. Another plus is that double-sided, surface-mount circuit boards can be reconfigured as single sided. Such resistive materials have been used extensively for more than 30 years in a variety of critical applications, repeatedly exhibiting outstanding long term reliability.

One particular medical application

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Comparing HyRelex® laminates

Material	Dk at 10 GHz	Thickness, mils	Thickness, mm
TF-260	2.6	0.0017, 0.0030	0.04, 0.08
TF-290	2.9	0.0023, 0.0035	0.06, 0.09

An application

Fermi National Accelerator Laboratory is home to the Tevatron, a 4-mile circumference, high-speed particle accelerator. The lab needed a flex circuit for an unusual application – a particle detector inside the accelerator. The circuit had to work as a controlled impedance board with a low-loss material because the circuit would be detecting low-amplitude or weak signals. Also, the circuit could not out-gas. Lab researchers didn't want the detector finding particles that were released from the circuit. In addition, the circuit had to be flexible enough to fold into a cramped enclosure, even though the design required four copper layers, two layers of signals and two for shielding. The circuit would also have to withstand soldering to make all the electrical connections.

All the common flex-circuit materials considered for the job had some shortcomings. The biggest problem was that most materials absorb water and chemical too easily. If a material picks up moisture or chemicals during manufacturing, it can then give off or out-gas those particles later. Polyester, however, looked as if it could meet the low out-gassing requirements because of its low moisture absorption.

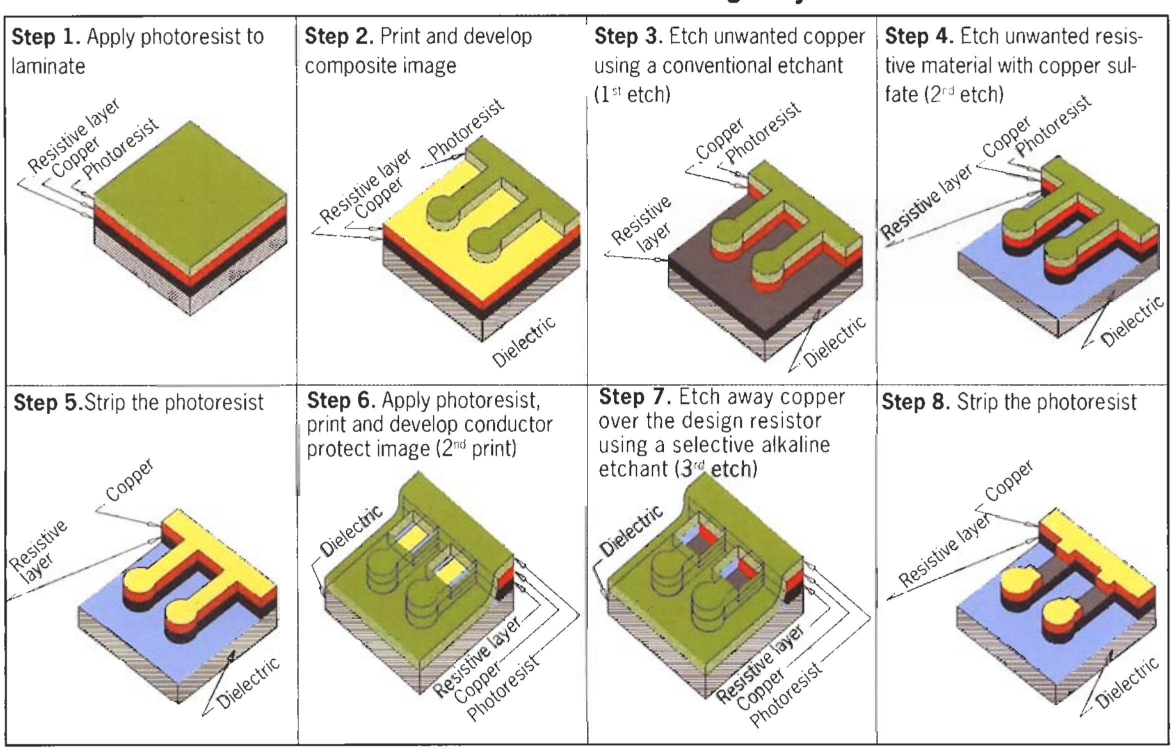
It presented a few challenges, however, first with trying to build a four copper-layer board and then with the soldering temperatures. So we expanded the material search.

Taconic's Advanced Dielectric Division develops and produces woven glass PTFE (**Teflon®**) materials and laminates with dielectric constants (*Dk*) ranging from 2.1 to 10.2, and in thicknesses from 1.5 mils to over 0.5-in. Knowing a material's *Dk* allows calculating an etched line width to get an impedance needed for a particular material thickness. Taconic has grouped a few of its thinner PTFEs into a family of flex materials called HyRelex®. These come in two *Dk* values.

The engineering team compared the moisture absorption properties of the different laminates and additional properties of Kapton®, HyRelex®, and other polyimide films. The team chose a polyimide laminate and built samples to compare them to the PTFEs (HyRelex®). Taconic's TF-290 appeared the best to meet the electrical specs. Its *Dk* of 2.90 gave a line width and spacing to get the right impedance for the board.

The next step was to see if the polyimide or Taconic's TF-290 would meet the out-gassing requirements. Circuits made with Kapton® and other polyimide films failed the out-gassing test. But TF-290 has a moisture absorption of less than 0.02%, so we were confident the material would

How to manufacture a flexible circuit with OhmegaPly® resistors



HyRelex® TF laminates versus competitive materials

Film	HyRelex® TF260	HyRelex® TF 290	Kapton® HN	Kapton® KN	Kapton® KN	Apical®
Adhesive	None	None	Phenolic Butyral	Acrylic	Acrylic	Epoxy
IPC-4103 and 4204	/9	/9	/10	/1	/22	/2
Max operating temperature, C	160	160	105	NR	105	115
UL 94 flame class	V0	V0	VTM-1	NR	VTM-0	VTM-0
Peel strength, lb/in	8	8	5	11	10	8
After thermal shock, N/m	1,450	1,450	875	1,925	1,750	1,450
Dimensional stability, %	-0.02	-0.02	-0.07	-0.05	0.05	-0.07
Moisture absorption, wt%	0.02	0.02	2.5	2.6	2.6	1.4
Dielectric strength, V/mil	1,200	1,200	8,000	4,250	5,600	6,500
Dk	2.60	2.90	4.00	3.20	3.30	3.70
Df	0.0022 @ 10GHz	0.0028 @ 10 GHz	0.02 @ 1 MHz	0.011 @ 1 MHz	0.01 @ 1 MHz	0.028 @ 1 MHz
Thickness minimum, in.	0.001	0.0015	0.0012	0.0018	0.0018	0.0018

All values typical

THIN FILM RESISTORS

CONTINUED FROM PG. 37

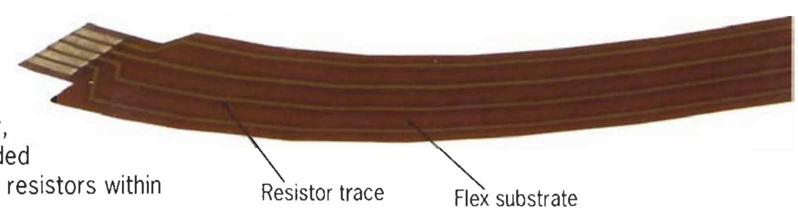
required a multilayered flexible circuit cable using the resistive film. We obtained a sample made of 0.5-in. copper with a 10 Ω/sq. resistive coating. We bonded the film to one side of a flexible Kapton® substrate in a press. The other side was laminated with conventional 0.5 oz copper foil.

Applying standard imaging and etching processes to both sides generated the needed copper foil traces on one side of the strip and a combination of copper and resistive traces on the other. Electrical tests verified compliance with the specs. A next step applied a protective coating to the resistive elements to prevent mechanical damage during handling and application. An additional resistance test verified the resistive films integrity and value.

Another application using resistive film involved a medical image memory controller, in which the film provided a series of termination resistors within five internal logic planes of a 14 layer multiplayer FR4 glass epoxy circuit board. Termination resistors were intended for close proximity to the integrated circuits to improve impedance matching and reduce propagation delay. Embedded resistors also reduce the EMI often associated with chip or through hole resistors.

OhmegaPly® sheet resistivity

Sheet resistivity Ω /sq.	Material tolerance, %
10	3
25	5
50	5
100	5
250	10

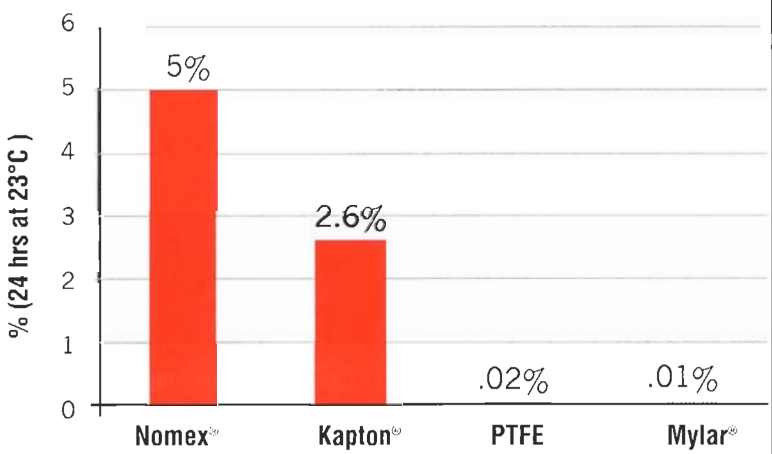


A medical application required a multilayered flexible circuit cable using a resistive film. The prototype is made of 0.5-oz copper with a 10 Ω/sq. OhmegaPly® resistive coating. Film is bonded to one side of a flexible Kapton® substrate. The other is laminated with conventional 0.5 oz copper foil.

OhmegaPly® RCM properties and specs

Sheet resistivities	10	25	50	100	250	Comments
Material tolerances, %	±3	± 5	± 5	± 5	± 10	
Load life cycling test (ΔR%)	<0.4 after 1,000 hr	<5	<5	<5	0.5 after 1,000 hr	Mil-Std-202-108I, Ambient temperature: 70C, On and off cycle: 1.5 hr each in 10,000 hr test
Current noise index, dB	<-16	< -15	< -15	<-15	< -15	Mil-Std-202-308, Voltage applied: 53.2 at 10 Ω/sq; 5.6 at 25 Ω/sq, and 7.9 at 100 Ω/sq
Short time overload, ΔR%	0	0	0	0	0	Mil-R-10509 Method 4.6.6 Power: 2.5 x rated for 5 sec
Resistance temperature						
Characteristic, PPM/C	13	50	60	100	100	Mil-Std-202-304 Hot cycle: 25, 50, 75,125C Cold cycle: 25, 0, -25, -55C
Humidity test, ΔR%	0.3	0.5	0.75	1	2	Mil-Std-202-103A, At 40C and 95% relative humidity for 240 hr.
Thermal shock, ΔR%	0.1	-0.5	1.0	1.0	1.0	Mil-Std-202-107B 25 cycles, hot and cold temperatures: 125C and -65C
Hot oil, ΔR%	-	0.1	0.25	0.5	0.75	IPC-TM-650 Method 2.4.5 Immersed for 20 sec at 260C
Solder float, ΔR%	0.2	0.5	0.75	1.0	0.5	Mil-Std-202-210D Immersed for 20 sec at 260C
Resistance to solvert, ΔR%	NA		NA	NA	NA	Mil-Standard-202-215A Immersed for 15 min.
Toluene 1-1-1		0.2				
Trichloroethan		0.0				
Acetone		0.2				
Freon		0.0				
Capacitance, pF at 5 Hz	~0	~1	~1	~1	~1	
Inductance, nH at 5 Hz	< ~0.6	<~0.6	<~0.6	<~0.6	<~0.6	

Moisture absorption for several materials



not pick up moisture or plating chemicals during processing. The material also meets NASA requirements for out-gassing in space applications.

Although we had the right material, we still had to make a board with four copper layers flexible enough to meet the bend requirements. The original design, with solid ground planes on the outer layers, made the board too stiff.

The team solved the problem by making the outer ground planes a cross hatched pattern. This made the board more flexible. And while it eliminated almost half the copper on the outer layers, it did not affect the board's electrical integrity. The boards were built and shipped on time, tested and installed, and are working in the accelerator at Fermi National Labs.