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Flexible Circuits

Design and Applications

Steve Gurley

FLEXIBLE CIRCUITS

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Preface

This book was written to provide basic guidelines relative to the design, application and manufacturing considerations of single-sided and double-sided, plated-through hole flexible circuits which are commonly used in both static and dynamic applications.

The book will help solve problems involving packaging and costs in multiplant interconnection situations. The objective of the book is to inform packaging, electrical, and mechanical engineers of the most economical choices relative to the design and specification of the flexible circuit interconnect. Another objective is to provide sufficient information concerning the interconnection of electrical/electronic systems, so the lowest cost systems approach can be easily chosen.

One element of the flexible circuit market that has not been covered in depth is flexible multilayer and rigid-flex multilayer circuits. The reason for this is twofold. First, most multilayer and rigid-flex applications are manufactured in small quantities and are for defense or military applications requiring a completely different set of guidelines. Second, flexible multilayer circuits are not really flexible but flexible materials are used for space and weight reduction. When many layers are fabricated from a group of flexible films, adhesives, and foils, they become a fairly rigid piece of material when all laminated together.

Steve Gurley

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1.1. DESCRIPTION OF FLEXIBLE CIRCUITS

1.1.1 IPC Definition

Flexible printed wiring, sometimes called flexible printed circuitry can be defined as a random arrangement of printed wiring, utilizing flexible base material with or without cover layers. This definition, along with many other printed circuit terms and definitions can be found in the publication *ANSI/IPC-T-50B*, published by the Institute for Interconnection and Packaging Electronic Circuits, revised in June 1980.

1.1.2 Identification Features

Identification features can be easily drawn from the definition of the product. It is necessary to develop an almost automatic recognition of flexible circuit characteristics since there are relatively few manufacturers of this product. Much confusion occurs when manufacturers of similar products are solicited to supply flexible circuits when in fact, they don't manufacture them.

1.1.3 Interconnect Look-alikes

Interconnection systems which are similar to, and confused with, flexible circuits are called flat cable, collated cable, ribbon cable, and sometimes wiring harnesses. The basic differences among all of these interconnection products are the types and forms of conductors, and the types and forms of insulating materials used. The most significant difference between flexible circuitry and "look-alikes" is the random arrangement of conductors, that is that all conductors are not parallel to each other. This factor is generally dictated by the arrangement of electrical/electronic components which are to be interconnected on one or more position planes.

Interconnection look-alikes, which sometimes appear to be flexible circuits but which are really wiring harnesses, woven cables, or other types of insulated flat or round conductor cables are shown in Figure 1.1.

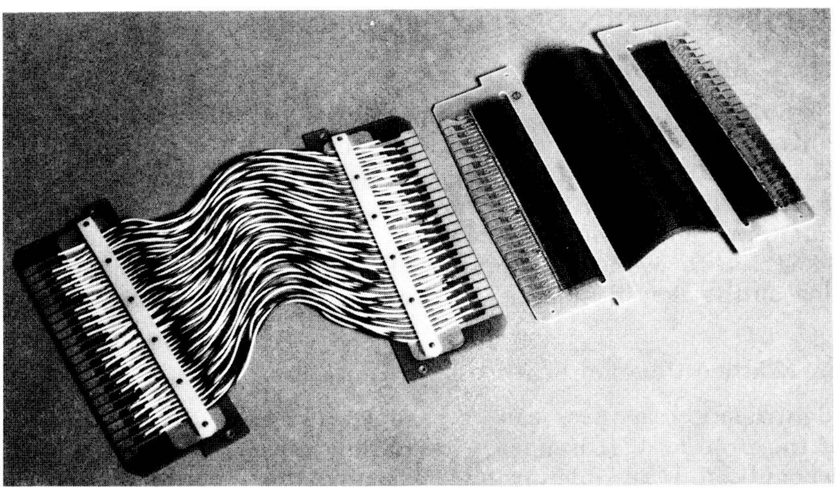

Figure 1.1 Interconnection look-alikes. Flexible cable and flat cable, which sometimes look like flexible circuitry. (Courtesy of Rogers Corporation, Chandler, Ariz.)

1.2 CONSTRUCTION OF FLEXIBLE CIRCUITS

The construction of flexible circuits is generally thought of in two- or three-component part systems. In the two-part system, base insulator materials are joined to the conductor foil without an adhesive system, either by additive processes such as electroless and electrolytic plating or by mechanically screening an image onto the insulator surface with conductive epoxy. Another two-part system is to use resins in the base insulator system to bond the copper in the original laminating cycle. The three-part system is composed of a separate adhesive system which is usually coated onto the base insulating film and then nip-rolled together with the conducting foil to produce the laminate. Figures 1.2 and 1.3 show screening and laminating operations, respectively. Figure 1.4 shows a typical roll of finished laminate.

1.2.1 Films and Other Base Insulations

From a visual standpoint, flexible circuits look very much like printed circuit hardboards unless they are viewed after being formed into a multiplane interconnect system. Some of the confusion surrounding the design and application of flexible circuits seems to be based on the fact that flexible circuits in a single flat plane have an appearance often mistaken for their hardboard cousins.

The major difference between the two products is that flexible circuits are usually fabricated using conductive foils of extremely ductile copper, which are glued to extremely thin, flexible substrates with a number of adhesive choices. Most of these thin substrates are in the film family, although some are base insulators manufactured using a combination of strengthening fiber, in either a random or mat form held together with a resin. In such cases the resin itself acts as the adhesive for the conductive foil layer and the product is manufactured in a two-part form rather than the more common three-part base adhesive and conducting foil configuration.

Polymide

The most popular insulating base material is the polyimide film, popularized in the electronics industry by E. I. du Pont de

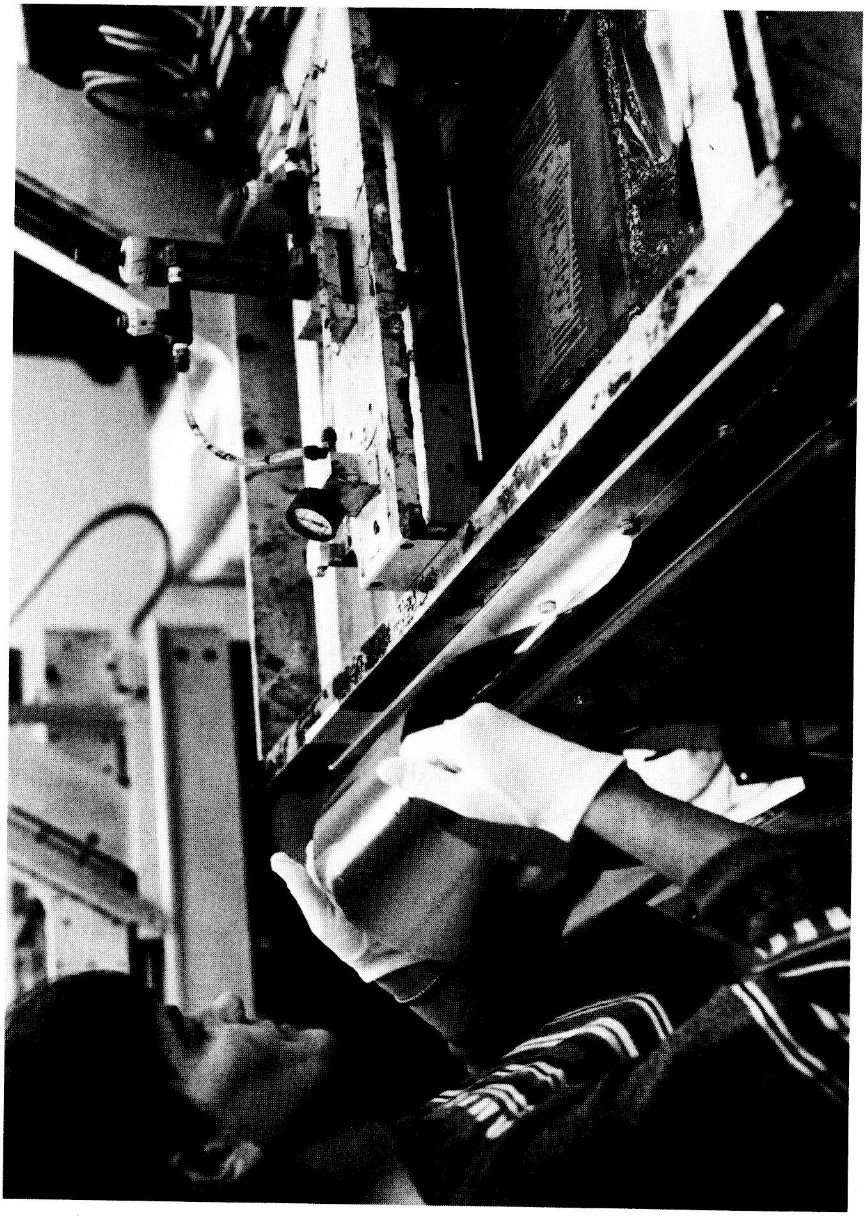

Figure 1.2 An example of the screening process. (Courtesy of Sheldahl, Inc., Northfield, Minn.)

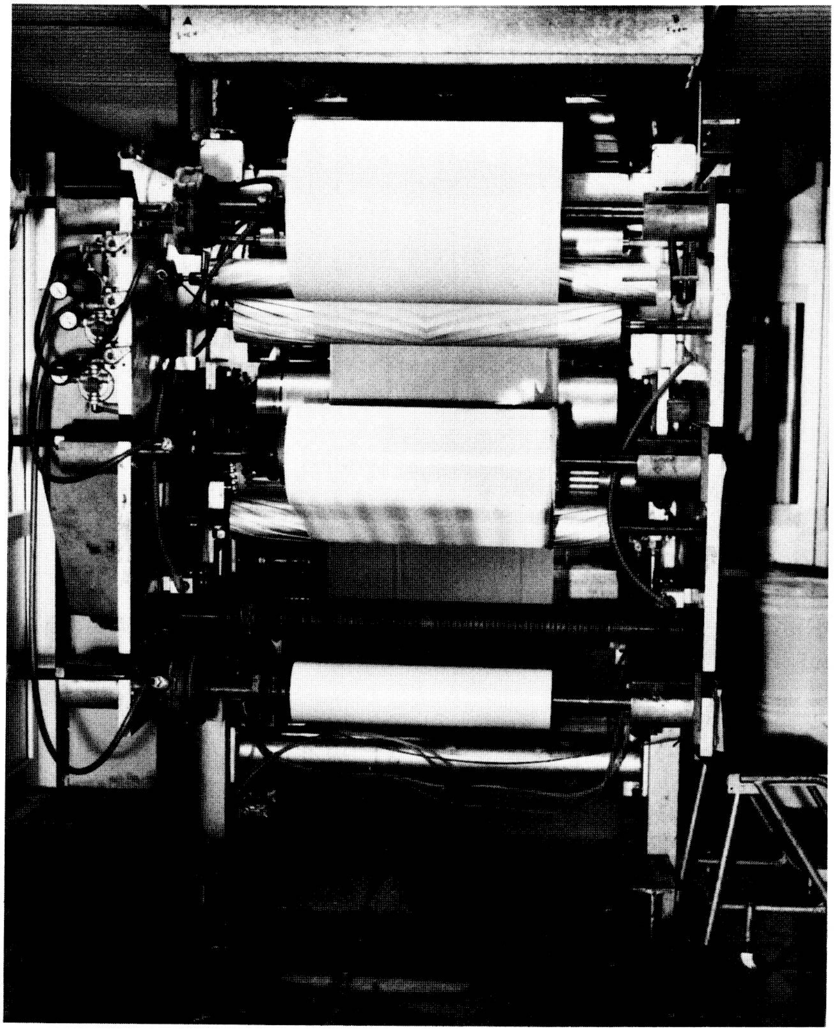

Figure 1.3 An example of the laminating process. (Courtesy of Sheldahl, Inc., Northfield, Minn.)

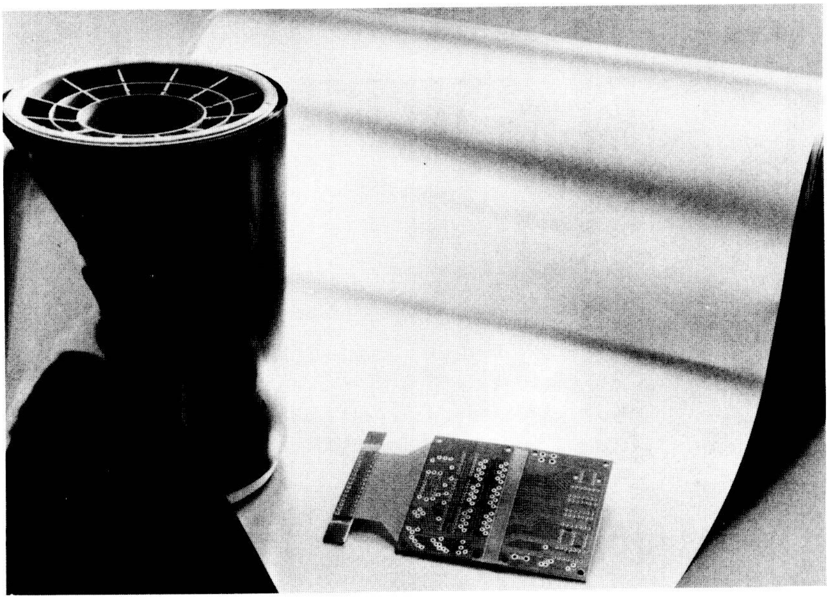

Figure 1.4 A typical roll of finished laminate for flexible circuits. (Courtesy of Rogers Corporation, Chandler, Ariz.)

Nemours and Co. and manufactured under the trade name of Kapton.

According to Du Pont, Kapton® polyimide film possesses a unique combination of properties previously unavailable in circuit materials. The ability of Kapton to maintain excellent physical, electrical, and mechanical properties over a wide temperature range has proven especially useful when used in flexible circuit applications involving high temperatures, such as those created in soldering applications. Kapton is synthesized by a polycondensation reaction between an airomatic and dianhydride and airomatic diamine. There is no known organic solvent for this film and it is infusible and flame-resistant. Besides being used for flexible circuits, Kapton film is used in other electrical and electronic applications, such as insulating wire and cable, as slot liners in motors, and for transformer insulation.

Although Kapton is available in several different types, the type H material is the most popular for flexible circuit use and is provided in thicknesses of 0.001, 0.002, 0.003, and 0.005 inches. It is also available on special order in 0.0005 inches for circuit applications requiring extreme thinness and flexibility. When the best dimensional stability is needed, type V Kapton is available, however, it is available only in 0.002, 0.003, and 0.005 in. thicknesses. Table 1.1 and Figures 1.5 a-d show the physical and chemical properties which give this film its outstanding characteristics.

Table 1.1 Typical Properties of Kapton Type H Film 25 μm (1 mil)

PHYSICAL	Typical Values **78K (195°C)**	 **296K (23°C)**	 **473K (200°C)**	**Test Method**
Ultimate (MD) Tensile Strength, MPa (psi)	241 (35,000)	172 (25,000)	117 (17,000)	ASTM D-882-64T
Ultimate (MD) Elongation	2%	70%	90%	ASTM D-882-64T
Tensile Modulus, GPa (MD) (psi)	3.5 (510,000)	3.0 (430,000)	1.86 (260,000)	ASTM D-882-64T
Tear Strength — Propagating (Elmendorf), g	—	8	—	ASTM D-1922-61T
Tear Strength — Initial (Graves), g(g/mil)	—	510 (510)	—	ASTM D-1004-61

MD — Machine Direction

THERMAL	**Typical Values**	**Test Condition**	**Test Method**
Zero Strength Temperature	1088K (815°C)	.14MPa (20 psi) load for 5 seconds	Du Pont Hot Bar Test
Coefficient of Linear Expansion	2.0×10^{-5} m/m/K (2.0×10^{-5} in./in./°C)	259 to 311K (−14°C to 38°C)	ASTM D-696-44
Flammability	94 VTM-O		UL-94 (1-24-80)
Limiting Oxygen Index	100H-38		ASTM D-2863-74

ELECTRICAL	**Typical Value**	**Test Condition**	**Test Method**
Dielectric Strength 25 μm (1 mil)	276 v/μm (7,000 v/mil)	60 hertz 1/4" electrodes	ASTM D-149-61
Dielectric constant 25 μm (1 mil)	3.5	1 kilohertz	ASTM D-150-59T
Dissipation Factor 25 μm (1 mil)	.0025	1 kilohertz	ASTM D-150-59T

CHEMICAL		
Chemical resistance	Excellent (except for strong bases)	
Moisture Absorption 25 μm (1 mil)	1.3% Type H 2.9% Type H & V	50% Relative Humidity at 296K (23°C) Immersion for 24 hours at 296K (23°C)

Source: Courtesy of E. I. du Pont de Nemours and Co., Wilmington, Del.