Basic Designs Of Flex-Rigid Printed Circuit Boards

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Flex-rigid boards allow integrated interconnection between several rigid boards. This technology helps to reduce the number of soldered joints and plug-in connections and also the number of wires and cables, thus improving quality and reliability. For this reason the flex-rigid board has now become firmly established in many sectors of industry. We take a look at the basic stack-up methods for flex-rigid boards, as well as an innovative variant, the Yellowflex circuit board.

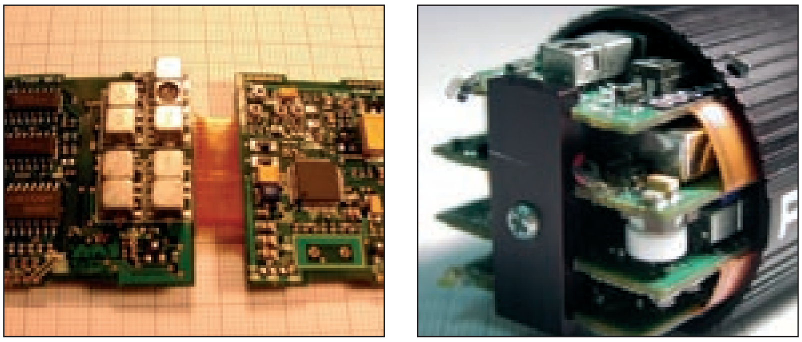


Figure 1 - A flex-rigid board with components assembled (left) and a flex-rigid board after assembly (right)

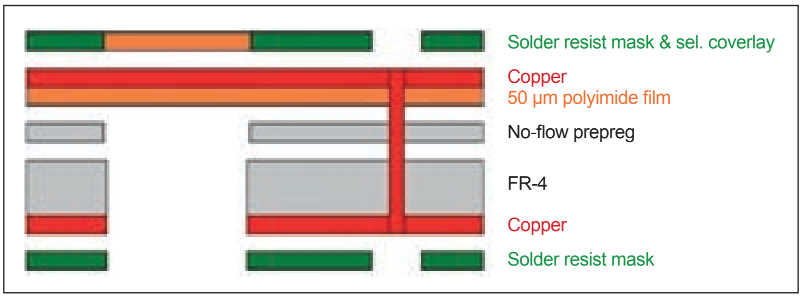


Figure 2 - Basic build-up of an asymmetrical Multiflex board with two layers

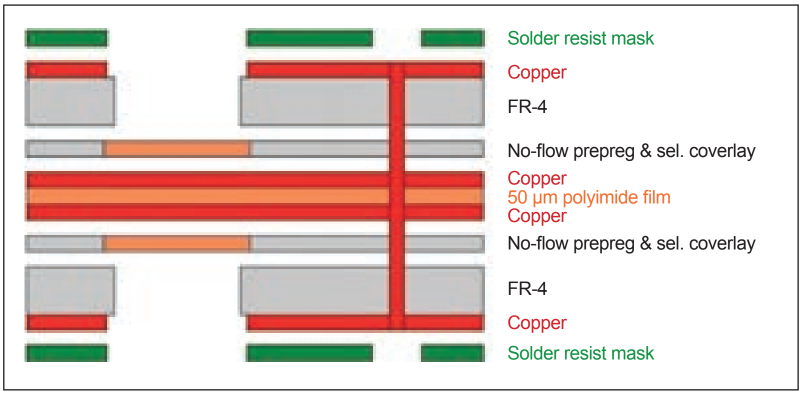


Figure 3 - Basic build-up of a symmetrical Multiflex board with four layers

Modern-day electronic systems are characterised by high functionality and relatively compact construction. The amount of space that device designers make available for the electronic equipment is always limited and therefore needs to be utilised in the best possible way.

For these reasons, circuit boards need to have a high interconnection density and layer count. Many electronic devices are fitted with several rigid boards that need to be interconnected to form a compact module. Additionally, connections to peripheral elements such as controls and displays and external connections are usually required, and these can be wires, cables, flat ribbon cables, jumpers, plug-in connection systems, etc. Such connections have to be set up during the automatic component insertion process or made and tested with a high outlay in subsequent work steps.

These conventional interconnection systems take up a considerable amount of the limited space available, and are therefore not always the best solution. PCBs that can be assembled three-dimensionally can offer great advantages. Flexible boards are one possibility, but the most reliable technology is offered by the flex-rigid circuit board.

Flex-rigid circuit boards

Flex-rigid boards have a special advantage: they consist of two or more rigid areas that are electrically interconnected by flexible areas, thus obviating the need for separate interconnections with the rigid boards. The flex-rigid board can then be packaged with minimal waste of space (Figure 1).

The interconnection technique used for flex-rigid boards has very high reliability factor because many plug-and-socket connections and soldered joints - a well-known source of faults - can be dispensed with. High-cost production steps, such as the soldering of flat ribbon cables to connect the rigid boards, plus testing, are also eliminated. The design engineer prepares only one layout including the interconnections. Only one set of drawings is needed and only one article is purchased and kept in stock.

Flex-rigid boards are used nowadays in numerous applications and are to be found in virtually all industrial segments, notably automotive, telecommunications, medical, sensor technology, mechanical and aeronautical engineering and military electronics. In the consumer goods industry they are used on a large scale for computer equipment, digital cameras, flat-panel displays and mobile telephones.

There are two kinds of flex-rigid boards. One is the low-cost Semiflex board, where the flexible - or bendable - areas consist of, for example, thin FR-4. These are highly suitable when only a small number of bends are needed during component insertion and board installation. The other is the Multiflex board, in which the flexible layers normally consist of a polyimide film that covers the whole surface of the board, including the rigid areas. These are suitable for applications where very small bending radii can occur, or for those involving dynamic bending loads.

The Multiflex board

Flex-rigid boards that comprise flexible films such as polyimide are known as "Multiflex" circuits. These are the traditional flex-rigid boards that have been produced on an industrial scale for more than 30 years.

Distinguishing features

Boards such as the Multiflex are known as hybrid designs, as they are made up of both rigid and flexible substrates. The electrical interconnections between the individual layers are made through metal-plated vias, the plated-through holes, which normally go through the rigid and flexible layers, or microholes using the sequential build-up method.

The flexible base material, usually flexible polyimide film, covers not only the flexible area but also the entire rigid area of the board. Stack-up techniques also exist in which the flexible base material is only used selectively in the flexible area. However, this production method is still very complex and therefore not used very often.

The design of a flex-rigid board should not be confused with that of the single- or double-layer flexible boards with reinforcing strip. These are sometimes also termed flex-rigid boards, but do not match the performance features of a true flex-rigid boards which, for instance, enable components to be assembled on both sides of the rigid areas.

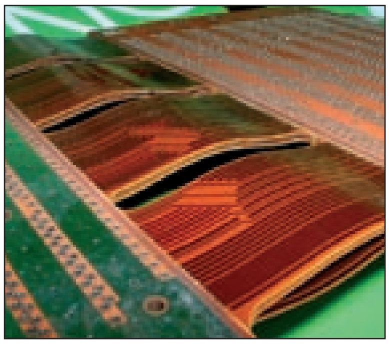


Figure 4 - High-layer-count Multiflex board

Multiflex boards can be characterised as flex-rigid boards with at least two conductive pattern levels. The flexible and rigid layers are electrically connected by plated-through holes in the rigid area, can be automatically equipped and soldered, and are suitable for press fitting and bonding. The flexible area can be bent tightly many times, and even dynamic bending loads are possible.

Basic stack-up techniques

The Multiflex board offers a number of stack-up possibilities and gives the design engineer wide freedom in the design and selection of materials. Yet

Figure 5 - 3-layer board with two layers in the flexible area (left); 3-layer board with one layer in the flexible area (right)

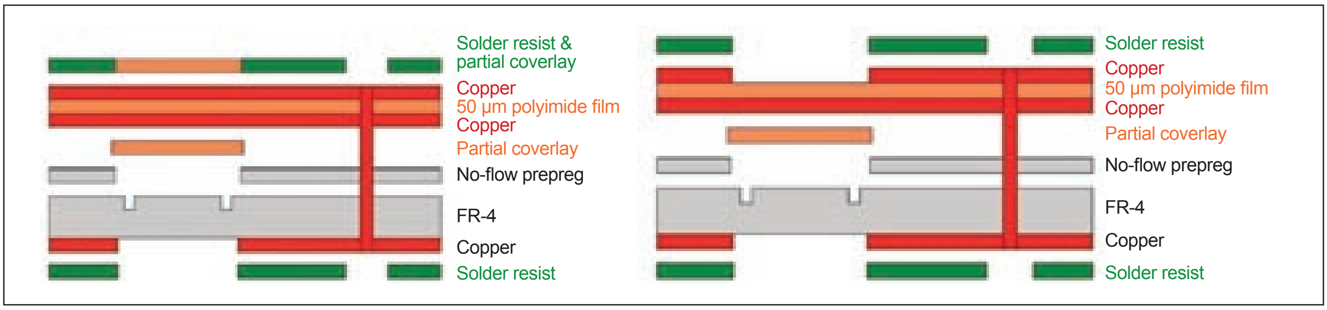


Figure 6 - 4-layer board, symmetrical with two layers in flexible area (left); N-layer, symmetrical board (right)

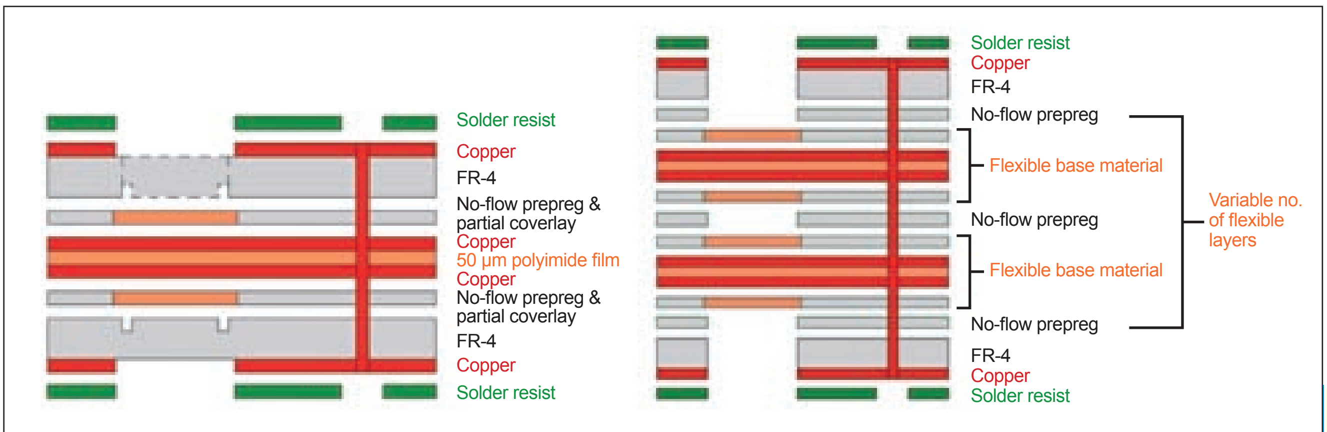



Figure 7 - Multiflex board with non-bonded flexible area

all stack-up techniques of Multiflex boards derive from two basic designs: the asymmetrical and the symmetrical build-ups (Figures 2 and 3).

The asymmetrical layer build-up is the simplest form of Multiflex board. The flexible base material is located on one outer side and the rigid material forms the second side of the flex-rigid board. In the case of the two-layer asymmetrical Multiflex board shown in Figure 2, the flexible material need not be registered to the rigid material. The two base materials are usually bonded with NoFlow prepreg, which has a very low resin flow. The future flexible areas of the board are left free of NoFlow prepreg so as to avoid bonding of the flexible base material with the rigid material. The coverlay, used to protect the conductors on the flexible substrate, is generally applied selectively. Using the asymmetrical layer build-up method, Multiflex boards can be produced with several flexible and rigid layers. As shown, the built-up technique is not limited to two layers.

It has to be borne in mind that the outer layer is flexible, which means that when the plated-through hole is made a further Copper deposit is applied to the Copper of the flexible base material. This layer of Copper normally loses its original properties and is therefore not quite as flexible and elastic as in its untreated state. Flexibility is therefore dependent on the ductility of the deposited Copper from the through-hole plating and conductor electroplating processes. It is sufficiently good for many applications.

Multiflex boards with asymmetrical layer build-up are relatively easy to make at low cost. Component insertion and assembly work is also non-critical, and the boards can be supplied in soldering frames or based on the snap-out technique to facilitate further processing.

If the flexible base material is located between two rigid substrates, this is known as a symmetrical layer build-up (Figure 3). The flexible base material is then an inner layer and can be prefabricated accordingly. The conductive patterns of the flexible layers are selectively protected by coverlays in the flexible area of the board. The dimensions of the rigid coverlays must if necessary be made to match the conductive patterns of the flexible inner layers. A good registration of rigid layers to flexible layers is important. NoFlow prepreg is generally used for bonding the complete layer stack-up.
As long as the flexible layers inside the stack-up are not through-plated, high flexibility and bending loadability of

Figure 8 - Snap-out technique (left); snap-out parts before removal (right)

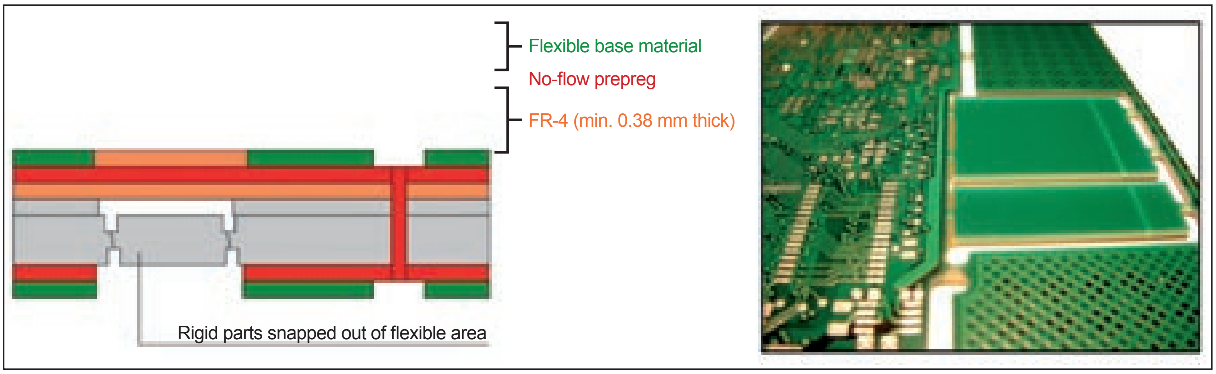
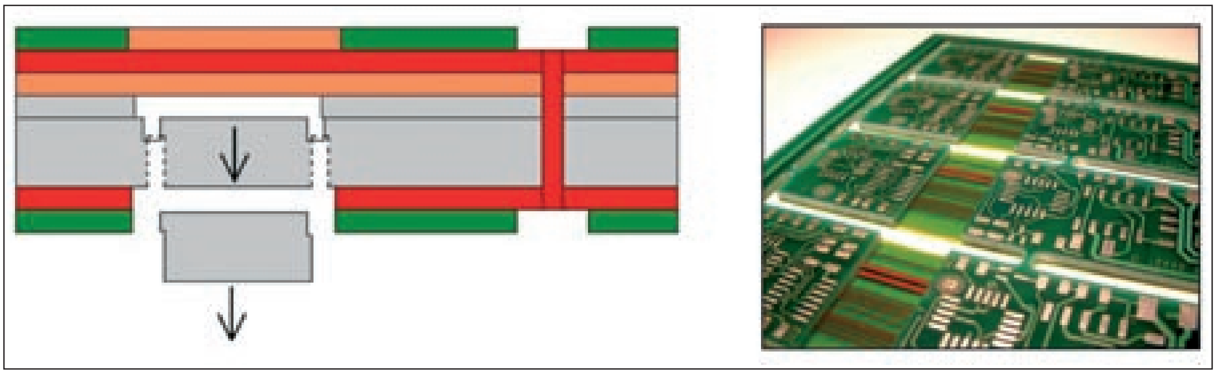


Figure 9 - Removing the snap-out parts (left); the flexible area is visible after removal (right)



the flexible layers can be attained. The bending loadability is mainly determined by the quality of the Copper cladding (RA or ED) of the coverlay material and the bending radius.

Because of the symmetrical distribution of the materials, this build-up technique offers advantages over the asymmetrical build-up as regards the plane-surface structure of the board. Higher mechanical and thermal stability is attained because rigid materials are located on both outer layers. This stack-up technique allows very high-layer-count flex-rigid circuit boards to be produced (Figure 4).

Design possibilities

Practically any layer configuration can be built up from the two basic designs presented. Figure 5 shows the layer stack-ups of two asymmetrical Multiflex boards with a total of three conductive pattern layers. In the example on the left, the flexible area carries two layers, both of which are protected by selectively applied coverlay. The example on the right has only one layer in the flexible area, and the coverlay is needed there only once. Similarly to the production of multilayers, several layers in the rigid area can be prefabricated as modules and fitted together to make flex-rigid circuit boards.

In the production of Multiflex boards, the rigid, non-bonded areas ultimately have to be removed. This can done by making grooves along the contour lines of the flexible area. A depth-controlled countergroove made before routing the board contour will separate these rigid areas from the circuit board (Figure 6, left). The right side of Figure 6 depicts a Multiflex board with several flexible layers that are not bonded together in the flexible area. This measure provides for greater flexibility as compared to a full-surface bonded variant.

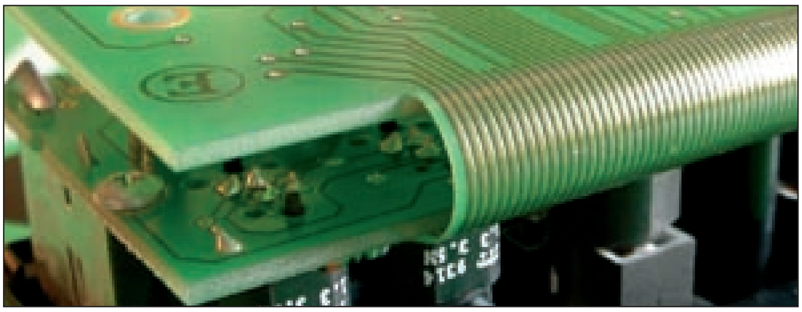


Figure 10 - Semiflex board

The Multiflex board can be used in conjunction with several flexible layers, thus allowing the production of transmission cables in place of coaxial cables to transmit radio frequency signals. Asymmetrical and symmetrical transmission lines can be made with characteristic impedances in the range of 50 - 130 ohms and tolerances of between ± 5% and ± 10%.

Snap-out technique

Multiflex boards do not have to be delivered as single parts for further processing. To facilitate equipping and soldering, they are very often delivered in a multiple printed panel in a soldering frame. This enables them to be processed practically in the same way as rigid boards or multilayers.

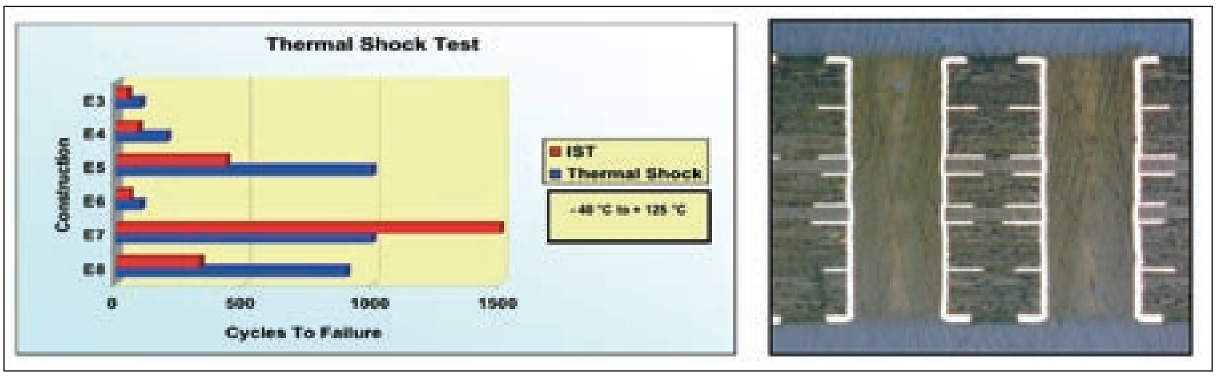
The snap-out technique is also a form of delivery in which the flex-rigid boards are “artificially” kept in a rigid condition for ease of handling when the board is being assembled. With this method, the rigid, non-bonded areas are not removed during contour milling of the circuit board, but remain connected to the board with a few tabs. These snap-out areas can easily be removed by the OEM or EMS prior to assembly after component insertion and testing (Figures 8 and 9). In the case of symmetrical Multiflex boards, the snap-out parts should all be on one side otherwise the flexible material could be damaged when the parts are broken out.

Reliability

Flex-rigid circuit boards based on flexible polyimide film have proved successful for decades in applications (aeronautical and military) with high reliability requirements. Nowadays, the automotive and the telecom industries also set very high quality and reliability standards for PCBs. The resistance to cyclic temperature stress with extended temperature limits and a higher number of cycles, in particular, constitute a great challenge for every type of circuit board.

In the design of Multiflex boards, such requirements need to be considered in the early design stage. Due to the relatively high coefficients of thermal expansion involved in flexible adhesive systems, such systems should, if pos-

Figure 11 - Results of thermal shock tests (left); micrograph after 2500 cycles (right)



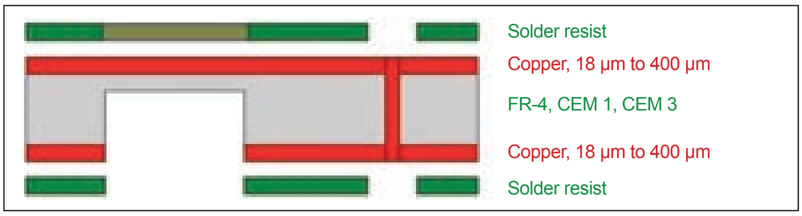


Figure 12 - Basic layer build-up for a Semiflex board

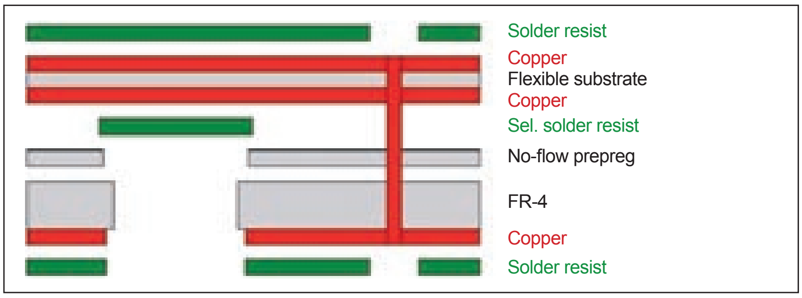


Figure 13 - Basic layer build-up for a Type II Semiflex

sible, not be used in the layer stack-up. The plated-through holes in the rigid areas especially should be free from adhesive systems. Where special reliability standards are required, adhesive-free flexible base materials are to be favoured and coverlays should always be applied selectively to the flexible area.

Furthermore, NoFlow prepreg normally has a lower glass transition temperature (Tg) compared to conventional prepreg. For the FR-4 grades, the Tg of NoFlow prepreg is in the range of 105°C, some 30°C lower than that of the standard prepreg.

Because of the different materials used, thermal cycling causes considerable stress and strain in the flex-rigid build-up. The plated-through holes are particularly affected by these loads. Cracks in barrels and at junctions can cause breaks in interconnections. The materials to be used for applications with high thermal cycling loads therefore need to be selected with care.

The thermal expansion coefficients in the x, y and z directions as well as the modulus of elasticity need to be taken into account and matched to the coefficients of the materials used in the build-up. If the values differ too much, the internal stresses would be too high after laminating. The chart in Figure 11 shows that Multiflex boards with a suitable stack-up survive high thermal shock stress perfectly well.

In addition to FR-4, almost all materials available on the market for the production of multilayers can be used for the build-up of flex-rigid boards. As alternatives to the polyimide film, films made of LCP (liquid crystalline polymer) and PEEK are suitable.

The Semiflex board

The vast majority of flex-rigid circuit boards are not subjected to continuous dynamic bending when in operation. In many applications, the flexible areas are bent only a few times during assembly and possibly for refinishing and repair. In such cases it is not necessary to use a flexible base material such as polyimide film. Bendable material is often adequate (Figure 10).

Build-up and production of the Semiflex board

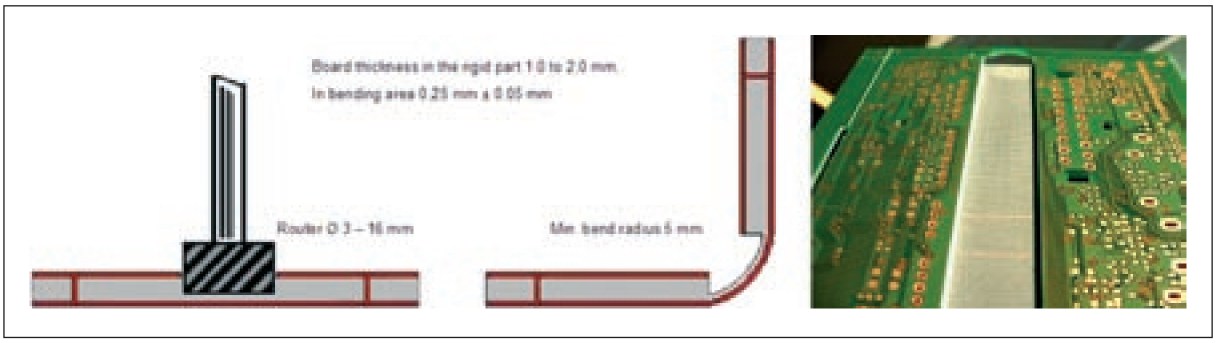
Semiflex boards (Figure 12) are made of the same conventional base materials used for multilayers and double-sided PCBs. The production method consists of reducing the thickness of conventional multilayer materials selectively until the material is flexible. This is achieved by depth-controlled routing in the areas that have to be bent. This is the only additional manufacturing step (Figure 14) compared to the process for double-sided circuit boards and multilayers.

For technical reasons, a few restrictions apply to the use of Semiflex boards: only a few bending cycles are allowed (up to 10 cycles); the bend radius is limited to 5 mm minimum; the maximum length of the bending area should not exceed 16 mm; and only one conductive pattern layer is possible in the bending area.

Semiflex Type II

Where bending requirements are higher than those allowed by the original Semiflex technique, there is a variant, Type II, which was developed on the basis of the production process for Multiflex boards (Figure 13). In place of flexible polyimide film, bendable materials can be used. The suitability and flexural strength of the materials are very different, and if necessary should be checked for the appli-

Figure 14 - Depth-controlled routing to thin down the rigid material (left); depth- routed Semiflex board (right)



cation in question. Figure 15 provides an overview of the bending loadability of various laminates (bend radius is 1mm and bending angle 180°). Lam 8 and Lam 9 are laminates made of very thin non-woven aramide. The new Yellowflex technology is also show. The other materials are glass-fabric reinforced bendable laminates.

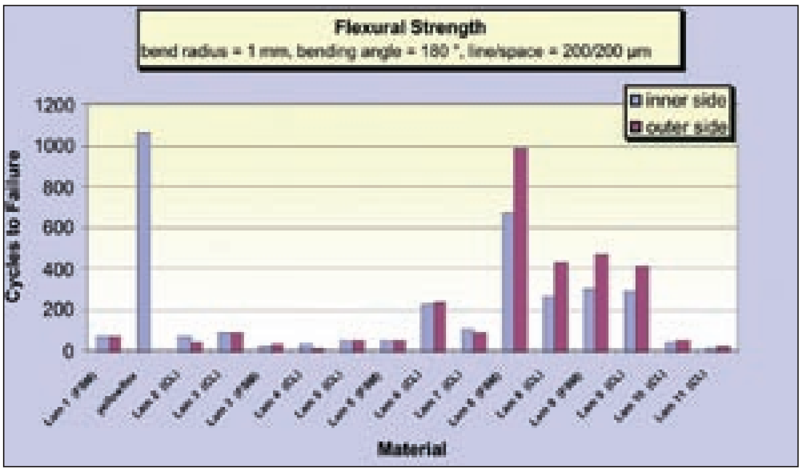


Figure 15 - Flexural strength of bendable laminates

The Yellowflex board

The Yellowflex circuit is a new technique enabling production of cost-effective flex-rigid boards that are suitable for applications with small bending radii and several bending cycles. However, this technology was not developed for continuous dynamic bending loads.

Build-up technique for the Yellowflex board

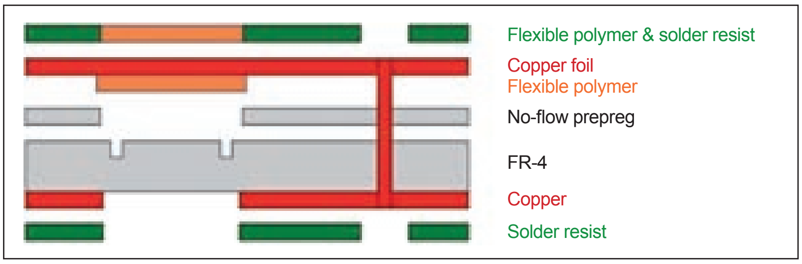


Figure 16 - The Yellowflex technique

Flexible or bendable base material is not needed for the Yellowflex process. Instead, a Copper foil is selectively coated with a flexible polymer material. The coating is applied to the treatment side of the Copper foil with the shaping of the flexible areas of the circuit board. The coated foil is subsequently laminated in the normal way to the rigid material (Figure 16).

The Yellowflex board is normally made of FR-4 materials. In the rigid area, this build-up does not differ from that of the double-sided boards or multilayers. The Yellowflex board can hence be produced using entirely conventional methods and processes. Further processing of the Yellowflex board is absolutely compatible with FR-4 materials. Drying before component insertion and soldering is not necessary. In contrast, the flexible polyimide films used in conventional flex-rigid boards are hygroscopic. As such, these boards should be dried before the components are inserted, to avoid delamination by steam formed during the soldering process.

Compared to the bendable laminates available on the market, Yellowflex boards attain distinctly higher flexural loadability values (see Figure 15). At a bend radius of 1 mm and a bending angle of 180°, the first conductor shorts will occur only after 1000 bending cycles. Furthermore, as the flexible material is only applied to the flexible area of the board, this technology reduces use of valuable raw materials and is environment-friendly.

A technique for every application

The Multiflex circuit board represents the highest level of rigid-flex PCB technology. It meets the highest quality and reliability requirements and can be used for highly dynamic bending loads. The Semiflex and the new Yellowflex techniques are alternatives that can be used in low bending load applications. Neither technique uses flexible polyimide film and processinging is practically the same as for rigid boards. The Yellowflex board is also suitable for semi-dynamic bending applications and, by selective use of the flexible polymer material, is an environment-friendly process.

Figure 17 - A Yellowflex board