Overview of Rigid Flex Technology

Joseph Fjelstad
Flexible circuits have seen explosive growth in recent times owing to their numerous advantages as an interconnection medium.

Presently nearly every imaginable type of electronic product employs flex.

The technology requires understanding in order to assure successful deployment.

This is especially true for rigid flex variants.
Rigid Flex Advantages

- Rigid Flex interconnection technologies enable design freedom unmatched by more traditional rigid interconnection methods and the applications are rapidly expanding.

- Integrating more technology into less material and space is a key technological objective but it has many other benefits.

- Newer materials, structural concepts and manufacturing processes will open doors to future products that will improve our communications, entertain, transport, protect and inform us but could also redefine medical technology and aid in scientific discovery.

- Flexible electronic Interconnections will play an expanding role in the future of electronics and rigid flex will have an increasing role.
Rigid Flex Issues

Several approaches have been used since the 1970s for rigid flex.

Rigid flex can reduce overall complexity and increase reliability.

However, the cost for rigid flex is greater than for either rigid or flex due to a number of factors:

- PI flex materials are more expensive than FR4 laminates (~3X)
- Low flow adhesives normally are more costly than epoxy prepreg
- Coverlayers and flexible cover coats also cost more than standard solder masks
- Design and process planning are often engineering time intensive
- Manufacturing is labor intensive, some equipment is unique and rigid flex is not readily adapted to automation.

Still from a system perspective, rigid flex can save time and money.
Rigid Flex Constructions
Origins...
Rigid Flex... Nearing 50 Years of Use

Nov. 5, 1968

V. F. DAHLGREN ET AL

3,409,732

STACKED PRINTED CIRCUIT BOARD

Filed April 7, 1966

FIG. 2.

FIG. 3.

INVENTORS:
VICTOR F. DAHLGREN
SIDNEY K. TALLY
THOMAS H. STEARNS

BY

THEIR ATTORNEYS
Rigid Flex Applications
Rigid Flex Circuit Applications

Rigid flex circuits were developed largely to replace bulky and heavy wire harnesses but have since migrated to many new areas of application:

- Clam shell type mobile phones
- Mobile phone camera modules
- Missiles and weapons systems
- Camera monitoring systems
- Electrical test equipment
- Lap top computers
- Digital cameras
- Hearing Aids
- Satellites
A Few Rigid Flex Examples
CCD Detector

Source: University of Texas
Hand Held Key Board Assembly

Source: Interconnect Systems, Inc.
LCP Rigid Flex
COB on Rigid Flex

Source: University of Pennsylvania
Representative Rigid Flex Constructions
Exemplary Rigid Flex Constructions

Traditional Rigid Flex Structure

Coverlayer extends over all Internal circuitry
Exemplary Rigid Flex Constructions

Short
Coverlayer
Rigid Flex
Construction

Coverlayer does not extend over Internal circuits
Exemplary Rigid Flex Constructions

Hybrid Laminate
Rigid Flex Construction

Copper foil covers lapped rigid and flexible materials
Exemplary Rigid Flex Constructions

Surface Flex
Rigid Flex
Construction

Flex circuit on outer surfaces only
Exemplary Rigid Flex Constructions

All Rigid Material Rigid Flex Structure

Rigid laminate material routed to thickness that will bend using suitable radius. Flexible coverlay normally needed.
Reinforced Flex Construction

(Not a rigid flex)

Flex circuit bonded to rigid stiffener
The Basic Process

1. Double-sided flex is built with coverlayer but no holes

2. Rigid caps are scored for later removal and laminated to flex using bondply or pre-preg

3. Circuit is drilled and processed like standard multilayer circuit. After routing the scored areas are removed to allow circuit to flex

Note: Conceptually representative only… Many steps are missing
Other Solutions and Issues

- Thin or thinned FR4 circuits can be bent.
- Semi-rigid laminates with non woven reinforcement materials and lower modulus thermoplastic resins (e.g. PTFE, polyester etc.) have been explored and could be revisited.
- The rub is that when it comes to assembly, used of high temperature lead-free solders will be cause for continuing concern to the industry owing to the higher Z axis CTE inherent with more commonly used design and manufacturing approaches for rigid flex structures.
Tacky Carrier for Flex SMT Assembly

- Metal carrier plate can be cut to size
- Adhesive is a tacky high temperature silicone
- Lead-free solder capable
- Durable withstanding multiple reflow passes
- Provides ESD protection
- Easy removal after assembly
- Can be cleaned and reused
- Can be modified for two side SMT assembly
Flex SMT Assembly Aids
Flex SMT Assembly Fixture
Rigid Flex Assembly
Rigid Flex Assembly
Rigid Flex Assembly
Bulkhead Connector Assembly

Tiered pins with trimmed flex soldered to connector in sequence.

Pins untrimmed and each layer of interconnect soldered sequentially. Clearance holes provided on each layer for non interconnecting pins.

Flex circuit lap soldered to connector pins.

Flex for layered connections.
Integral Connections

Supported Edge Connection

Unsupported Edge Connection

Lapped Edge Connection

Fitted with Connector Elements

Crimped Pin / Socket Connector

Staked Pin Connector

Straight or Formed Pin Connector

Commercial Mated Pair Connector
Solder Alloy Free Electronics (SAFE)
Rigid Flex Options
The Punishment of Sisyphus
Soldering Fishbone Diagram

Source: Interphase Corporation
Question:

Is Solder Necessary for Electronic Assembly?
Base Material
Machine, Mold or Etch Cavities
Place Components in Cavities
Coat with RCC or Alternative
Prepare Flex Circuit and Bondply
Laminate Assembly
Drill Through Holes and Vias
Plate Assembly and Thru Holes
Image and Etch
Alternative Methods Possible
Expose Flex By Design
Form Circuit
Molded Solderless Rigid Flex Assembly Type I

Tested and burned in components are positioned for assembly on a flexible film.

The components are seal bonded on bottom and at least partially encapsulated on film. Optional support carrier can be used to facilitate processing. However, component side can be plated and sealed with metal for ESD, EMI or heat spreading if desired.

Holes are drilled (e.g., by using a laser) to access contacts on packages and components.

Plating and imaging processes create circuits and interconnection to contacts. Steps may be repeated to create additional circuit layers as needed.

Cover layer is applied to top final circuit layer to protect conductors.

Carrier if used, is removed and the flex circuit can be bent into desired shape.
Molded Solderless Rigid Flex Assembly Type II
Over Molded RigidFlex Assembly Type III

1
2
3
4
5
6

7
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9
10

Patents Pending
Metal Rigid Flex Assembly (1)

Assemble components to substrate to create modules for product

Encapsulate assembly

Singulate modules
Metal Rigid Flex Assembly (2)

1. Place modules (or discrete components) into machined aluminum carrier

2. Cure adhesive

3. Laminate flexible material and create vias to access lands
Metal Rigid Flex Assembly (3)

Additively create circuits to required layer count needed for design

Laminate converlayer

Machine (or chemically mill) excess aluminum
Metal Rigid Flex Assembly (4)

1. Apply etch resist
2. Etch exposed aluminum
3. Apply strain relief
Metal Rigid Flex Assembly (5)

Form to desired shape
Panel Processing View
Aluminum Core
Rigid Flex Processing
Components are preferably selected to all be of common thickness with leads on common pitch which facilitates both design and manufacturing.

Substrate (e.g. Al panel) can have components on both sides and can serve as a combination of heat spreader and ground layer.

Components are placed with leads facing up and held in place by suitable adhesive until encapsulated and ready for direct circuit build up avoiding the use of solder and its potentially damaging thermal effects.
Aluminum Core Rigid Flex Assembly
Solderless Redesign Exercise
Solderless Redesign Exercise
From Rigid to Rigid Flex

140 x 100mm 12 layer rigid board
442 FPGA 0.8mm pitch

6 layer Aluminum Rigid-flex Assy
~30mm X 40mm (when folded)
All components on 0.5mm pitch
50μm line/space with 50μm vias
• Design is ~70% smaller in terms of total area
• Folds into an assembly with footprint ~15% of original design with minimal increase in height.
• Though the density of aluminum is higher than FR4, (FR4=1.8 gr/cm³, Al=2.7gr/cm) the total weight of the assembly is projected to be ~55-65% less than the original.
• Rigid flex structure is amenable to the separation of digital and analog circuity and thus the potential for better control of the energy created by analog devices and power supplies.
Stretchable Rigid Flex Circuit
Out of Plane Stretching
Methods from the Past
Solderless Stretchable Rigid Flex Circuit Processing
Rapid Prototyping
With parts in hand, first prototypes could possibly be completed in hours rather than days, weeks or months.
Printing stretchable inks on elastomer bases is an option.
Solderless Assembly Benefits
No Printed Circuit Required

- No procurement
- No testing required
- No inventory or shelf life concern
- No CAF concern
- No surface finish process durability issues
- No high temperature warp or board damage
- Lower overall material use
- All copper circuits created in situ
- Assembly is still edge card capable
No Soldering Required

- Eliminates many manufacturing process steps
- RoHS restricted material concerns eliminated
- No solderability testing or surface finish concerns
- No high temperature damage to devices
- Energy use is reduced (no bakes or reflow)
- No solder shorts, opens, micro voids, copper dissolution and the host of other common solder related reliability issues and concerns
- Limited post cleaning and testing concerns
# Traditional Process Steps

## Design PCB Assembly

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>1.</td>
<td>Create schematic</td>
</tr>
<tr>
<td>2.</td>
<td>Indentify components</td>
</tr>
<tr>
<td>3.</td>
<td>Layout circuits</td>
</tr>
<tr>
<td>4.</td>
<td>Validate signal integrity</td>
</tr>
<tr>
<td>5.</td>
<td>Validate design DfM</td>
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<tr>
<td>6.</td>
<td>Validate design DfR</td>
</tr>
<tr>
<td>7.</td>
<td>Validate design DfE</td>
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## Fabricate PCB (multilayer)

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<table>
<thead>
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<tbody>
<tr>
<td>1.</td>
<td>Drill (stack height varies)</td>
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<tr>
<td>2.</td>
<td>Desmear or etchback</td>
</tr>
<tr>
<td>3.</td>
<td>Sensitize holes</td>
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<tr>
<td>4.</td>
<td>Plate electroless copper</td>
</tr>
<tr>
<td>5.</td>
<td>Clean and coat with resist</td>
</tr>
<tr>
<td>6.</td>
<td>Image and develop resist</td>
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<tr>
<td>7.</td>
<td>Pattern plate copper</td>
</tr>
<tr>
<td>8.</td>
<td>Pattern plate metal resist</td>
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<tr>
<td>9.</td>
<td>Strip plating resist</td>
</tr>
<tr>
<td>10.</td>
<td>Etch base copper</td>
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<tr>
<td>11.</td>
<td>Clean and coat with soldermask</td>
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<tr>
<td>12.</td>
<td>Image and develop</td>
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<tr>
<td>13.</td>
<td>Treat exposed metal (options)</td>
</tr>
<tr>
<td>14.</td>
<td>Route to shape</td>
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</tbody>
</table>

## Assemble PCB

<p>| | |</p>
<table>
<thead>
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<tbody>
<tr>
<td>1.</td>
<td>Procure components</td>
</tr>
<tr>
<td>2.</td>
<td>Verify RoHS compliance</td>
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<tr>
<td>3.</td>
<td>Verify component solderability</td>
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<tr>
<td>4.</td>
<td>Verify component MSL number</td>
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<tr>
<td>5.</td>
<td>Kit components</td>
</tr>
<tr>
<td>6.</td>
<td>Procure PCBs</td>
</tr>
<tr>
<td>7.</td>
<td>Verify RoHS compliance</td>
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<tr>
<td>8.</td>
<td>Verify PCB solderability</td>
</tr>
<tr>
<td>9.</td>
<td>Verify PCB High Temp capability</td>
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<tr>
<td>10.</td>
<td>Design solder stencil &amp; purchase</td>
</tr>
<tr>
<td>11.</td>
<td>Develop suitable reflow profile</td>
</tr>
<tr>
<td>12.</td>
<td>Track component exposure (MSL)</td>
</tr>
<tr>
<td>13.</td>
<td>(Rebake components as required)</td>
</tr>
<tr>
<td>14.</td>
<td>Position PCB &amp; stencil solder paste</td>
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<tr>
<td>15.</td>
<td>Inspect solder paste results</td>
</tr>
<tr>
<td>16.</td>
<td>(height and skips)</td>
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<tr>
<td>17.</td>
<td>Dispense glue dots (optional)</td>
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<tr>
<td>18.</td>
<td>Place components</td>
</tr>
<tr>
<td>19.</td>
<td>Inspect for missing parts</td>
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<tr>
<td>20.</td>
<td>Perform hand assembly as required</td>
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<tr>
<td>21.</td>
<td>Clean flux from surface and under</td>
</tr>
<tr>
<td>22.</td>
<td>Verify low standoff devices</td>
</tr>
<tr>
<td>23.</td>
<td>Test cleanliness</td>
</tr>
<tr>
<td>24.</td>
<td>Underfill critical components</td>
</tr>
<tr>
<td>25.</td>
<td>X-ray inspect soldered assembly</td>
</tr>
<tr>
<td>26.</td>
<td>Identify shorts, opens, voids, missing</td>
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<tr>
<td>27.</td>
<td>Electrically test</td>
</tr>
<tr>
<td>28.</td>
<td>Rework and repair as needed</td>
</tr>
<tr>
<td>29.</td>
<td>Package</td>
</tr>
<tr>
<td>30.</td>
<td>Ship</td>
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</table>
Reduced Component Concerns

- Only fully tested and protected components used
- No solder balls or lead frames (preferred)
- Fewer component types needed (LGA & QFN)
- Smaller component libraries possible (Pkg types)
- Leadless components = No co-planarity issues
- No solder build up on tester/socket contacts
- Lower cost (simpler) & higher yield on devices
- No MSL issues or popcorning concerns
- Improved routing for area array IC packages
Circuit Design Advantages

- Components can be placed closer together
- Components can be placed beneath (atop) each other
- Increased routing capability
- Improved design security potential
- Integral heat spreader redefines placement rules
- Assemblies can interconnected in X, Y & Z planes
- Vertical bussing protocol opportunities
- Adaptable to optoelectronics
BGA Routing Advantage
Registered Package Thicknesses

- Low (L): 1.7 - >1.2mm
- Thin (T): 1.2 - >1.0mm
- Very Thin (V): 1.0 - >0.8mm
- Very Very Thin (W): 0.8 - >0.65mm
- Ultra Thin (U): 0.65 - >0.5mm
- Extra Thin (X1): 0.5 - >0.4mm
- Super Thin (X2): 0.4 - >0.3mm
- Paper Thin (X3): 0.3 - >0.25mm
- Die Thin (X4): < 0.25mm

US Dime

Extremely Thin (X)
Packaging Range
One Grid Pitch or Many?
“Bite Sizing” the Challenge
Reliability Improvement

- Simple structures with fewer elements
- Lower temperature processing avoids thermal damage caused by high temperature soldering
- Components are fully encapsulated increasing shock and vibration immunity
- Hermetic structure possibilities (plated metal jacket)
- Total EMI and ESD protection possibilities
- Integral heat spreader improves device life
What about Testing?

- Testing is believed to be critical… Why?
- Most testing is predicated on the anticipation of manufacturing related defects and faults
  - Shorts and opens are accepted as facts of life
  - Lead-free assembly damage to assembly components
- Current assembly technology has limits
- Simpler processes should yield higher
- The ultimate test is assembly turn on
- Can time and money for test be better allocated?
Future of Rigid Flex

- Integration of rigid and flex should see increased use and application in the future
- Each technology has intrinsic benefits and the synergy of the combination is highly compelling
- New structures will offer and should provide significant opportunities and improvements over current generation solutions.
- Unfortunately the crystal ball has not yet been perfected so the rate of adoption cannot be predicted.
Summary

- Rigid flex circuits are varied and versatile and continue to rise in importance in the realm of electronic interconnections.
- Because of the greater levels of engineering required, the cost for more complex structures will be higher but on a system level, the circuits will often prove a more cost effective solution.
- The product designer must understand both electrical and mechanical issues for success.
- New concepts for manufacture of rigid flexible and stretchable circuits have been presented for consideration and it is believed that the economics are compelling.
- While legacy components can be used, the structures are most easily realized using low profile components of common height.
- It is paradoxical that achieving simplicity in design often requires more discipline than complexity.
- Change is inevitable but adapting to, managing and controlling change is a choice.
“A mind, once stretched by a new idea, never returns to its original dimensions.”

Oliver Wendell Holmes
American Philosopher and Jurist