



# Designing and Fabricating Rigid-Flex Assemblies for Durability and Performance

## Introduction

Rigid-flex circuit board assemblies offer a unique blend of durability and flexibility, making this hybrid PCB design invaluable in applications where space is constrained, and intricate bends, shapes or movement are required. By integrating rigid and flexible substrates, board assemblies satisfy both dynamic design requirements as well as solid structure where needed. The payoff is in enhanced reliability. Conventional circuitry can suffer from issues like wire fatigue or connector failure due to bending, movement, and high levels of vibration. Rigid-flex board designs mitigate these issues by minimizing or reducing potential points of failure, improving the overall robustness of the assembly.

Like pure-play flexible circuit boards, rigid-flex assemblies facilitate streamlined manufacturing processes. Their compact form factor reduces the need for bulkier wiring and connectors, simplifying and reducing final assembly costs. This efficiency is particularly advantageous in reduced space applications such as electronic equipment packages in missile systems, spacecraft, and avionic LRUs.

The flexibility of rigid-flex circuits enables designers to create custom shapes and configurations that would be unattainable with conventional rigid PCBs. This adaptability enhances design freedom, allowing for innovative solutions in compact or oddly shaped devices. Let's explore some of the key design and fabrication issues involved in building rigid-flex PCBs for rugged application environments.

## Harsh Environments and Rigid-Flex PCBs

Shock, vibration, and temperature extremes can significantly impact PCBs, affecting their performance, reliability, and longevity. When subjected to shock or vibration, PCB assemblies may experience physical stress, leading to solder joint fractures, component displacement, and discontinuities at connector-to-board terminations. High temperatures can cause material expansion, solder joint fatigue, and degradation of components, potentially resulting in malfunctions or permanent damage.

Rigid-flex circuit assemblies excel in environments with high vibration or shock, such as aerospace or military defense applications. Their ability to withstand mechanical stress without compromising functionality ensures uninterrupted operation in demanding conditions. Rigid sections provide structural support and stability, reducing the risk of component displacement or solder joint fractures during shock or vibration events. Additionally, rigid sections can better dissipate heat, helping to manage temperature extremes more effectively. The pliable sections of rigid-flex boards allow for greater flexibility and bendability, enabling boards to withstand tight bend radii packaging or dynamic operational flexing without compromising electrical connectivity or mechanical integrity. This same flexibility readily absorbs and dissipates mechanical stress caused by shock or vibration, reducing the likelihood of damage to the board or its components.



## Designing for Durability and Reliability

To maximize the durability and reliability of rigid-flex circuit assemblies, designers and manufacturers employ multiple design and fabrication techniques.

Firstly, careful attention is paid to the layout and routing of traces, ensuring that they are optimized for the specific mechanical and electrical requirements of the application. This includes minimizing the stress concentrations on the flexible portions of the board by avoiding sharp bends or too tight radii, as well as ensuring proper clearance between traces to prevent short circuits.

Additionally, designers may incorporate features such as stiffeners, coverlays, and adhesive fills to reinforce the flexible areas of the board and protect them from mechanical damage or environmental contaminants. Stiffeners are rigid materials (such as FR4 or polyimide) attached to the flexible sections to provide structural support and prevent bending beyond specified limits. Coverlays, typically made of polyimide or similar materials, are applied over the flexible circuit layers to protect the traces from moisture, dust, and other contaminants, enhancing their longevity and reliability. Adhesives are used to bond the different layers of the rigid-flex assembly together, ensuring mechanical stability and preventing delamination under stress.

During the fabrication process, manufacturers employ techniques such as precision drilling, controlled impedance matching, and thermal vacuum lamination to achieve high-quality rigid-flex construction. Precision drilling with X-ray capabilities enables the creation of fine vias with precise dimensions, allowing for dense interconnections between layers while minimizing the risk of damage to the flexible substrates. Controlled impedance matching ensures consistent signal integrity across the board, reducing the risk of signal degradation or electromagnetic interference. Thermal vacuum lamination techniques are used to bond the rigid and flexible layers together with uniform pressure and temperature, ensuring strong adhesion and preventing defects such as voids or delamination.

## Flex-to-Rigid-Flex Transitions

Smooth transitions between flexible and rigid sections are crucial for reducing stress risers and ensuring the long-term reliability of rigid-flex assemblies. This is because stress concentrations can occur with abrupt changes in geometry leading to mechanical failure or fatigue over time.

By ensuring smooth transitions, designers can distribute mechanical stresses more evenly throughout the assembly, reducing the likelihood of localized stress concentrations that could weaken the material or cause localized damage. Smooth transitions help to maintain the structural integrity of the flexible sections, preventing them from experiencing excessive bending, stretching, or tearing at the transition points.

Moreover, smooth transitions minimize the risk of delamination or separation between the rigid and flexible layers of the assembly. When there are abrupt changes in curvature or thickness, it can create points of vulnerability where the layers may peel apart or separate under mechanical stress, leading to reliability issues or electrical failures.



In addition to reducing stress risers, smooth transitions also facilitate the manufacturability of rigid-flex assemblies. They allow for more consistent and reliable fabrication processes, such as lamination and soldering, by ensuring uniform contact and adhesion between the different layers and materials.

Smooth transitions between flexible and rigid sections play a critical role in enhancing the mechanical integrity, reliability, and long-term performance of rigid-flex assemblies. Designers must carefully consider the geometry, material properties, and fabrication techniques to achieve smooth transitions that minimize stress concentrations and ensure the robustness of the assembly in demanding applications.

### **The Importance of “Keep Out Areas” in Rigid-Flex Circuit Design**

"Keep Out Areas" in rigid-flex circuit design serve several critical purposes that contribute to the overall functionality, reliability, and manufacturability of the assembly.

Firstly, these designated areas help prevent interference between components, traces, and mechanical features. By defining specific regions where components or traces should not be placed, designers ensure that critical components are adequately spaced to prevent electrical short circuits, signal interference, or mechanical conflicts. This is especially crucial in densely populated assemblies where space is limited, and components are closely packed.

Keep Out Areas also aid in maintaining structural integrity and preventing mechanical issues. By delineating regions where components or traces should not overlap with mechanical features such as mounting holes, connectors, or folding areas, designers can prevent physical stress, bending, or tearing of the flexible portions of the board. This helps ensure that the assembly can withstand mechanical forces, vibrations, and flexing without compromising its functionality or reliability.

Additionally, Keep Out Areas facilitate the optimization of signal integrity and electrical performance. By avoiding placing components or traces in specific areas prone to electromagnetic interference (EMI) or crosstalk, designers can minimize the risk of signal degradation and ensure consistent electrical performance across the board. This is particularly important in high-speed or high-frequency applications where signal integrity is critical for the overall functionality of the system.

From a manufacturing perspective, Keep Out Areas streamline the fabrication process and reduce the likelihood of errors or defects. By clearly defining areas where components or traces should not be placed, designers ensure that assembly processes such as soldering, lamination, or routing can be executed efficiently and accurately. This helps minimize the risk of manufacturing errors, rework, or delays, ultimately improving the overall yield and reliability of the rigid-flex assembly.

### **Bend Radii and High-Layer Count Assemblies**

While minimum bend radii standards are provided by organizations like the IPC for different flex circuit stack-ups, designers may consider additional factors when designing rigid-flex assemblies for dynamic flex applications, especially in the context of multi-layer assemblies.



In dynamic flex applications where the flexible portions of the circuit will undergo repeated bending or flexing during operation, adhering to the minimum bend radii defined by standards may not always be best practice to ensure or extend the service-life of the assembly. Designers do in fact consider their real-world experience regarding the mechanical properties of the common materials, the number of layers in the assembly, and the specific requirements of the application to determine practical bend radii limits.

One critical consideration is the fatigue resistance of the flexible materials. As the number of layers increases in multi-layer rigid-flex assemblies, the overall thickness and stiffness of the flexible portion also increases. This can affect the material's ability to withstand repeated bending to bend radii limits without experiencing fatigue or mechanical failure. For this reason, designers must carefully select materials with appropriate flexibility and fatigue resistance for a given number of layers to ensure the assembly can withstand the expected number of bending cycles without degradation.

Rigid-flex designers also consider factors such as operating temperature, environmental conditions, and expected service life when defining bend radii limits for dynamic flex applications. Extreme temperatures, moisture, or chemical exposure can accelerate material degradation and increase the risk of mechanical failure, necessitating more conservative bend radii limits to ensure long-term reliability. On the other hand, more benign application environments may allow for a less conservative approach, pushing allowable bend ratings to higher levels.

## **Trace Routing and Via Placement**

In rigid-flex circuit assemblies, trace routing and via placement is one of the more critical aspects of the design process, one that directly impacts the performance, reliability, and manufacturability of the assembly. Here are some formal best practices followed at Glenair for trace routing and via placement in rigid-flex circuit assemblies:

- Employ symmetrical traces routing as much as possible in the flexible sections of the circuit to minimize impedance variations and signal skew. Symmetrical traces help maintain signal integrity and reduce the risk of electromagnetic interference (EMI).
- Minimize trace lengths to reduce signal propagation delays, reduce signal distortion, and improve overall electrical performance. In addition, optimize routing to reduce the number of vias and trace segments, particularly in high-speed or high-frequency applications.
- Avoid Sharp Bends or tight corners in trace routing, especially in the flexible sections of the circuit. Sharp bends can increase mechanical stress, strain, and the risk of material fatigue, leading to reliability issues over time.
- Optimize via placement to minimize signal distortion and impedance mismatches. Use via stitching techniques to provide a low impedance return path for high-speed signals and reduced ground bounce. Avoid placing vias near high-speed signal traces to prevent signal reflections and crosstalk.



- Carefully consider layer stacking sequence and via structures to optimize signal integrity and impedance matching. Use blind or buried vias where necessary to reduce signal propagation delays and minimize signal distortion.
- Maintain signal isolation to ensure proper signal isolation between different signal traces, power planes, and ground planes to prevent interference and crosstalk. Use shielding techniques such as ground planes or guard traces to minimize electromagnetic interference and improve signal integrity.
- Perform signal integrity analysis, such as impedance calculations and signal simulations, to validate the performance of the design and identify any potential signal integrity issues. Adjust trace routing and via placement as needed to optimize signal integrity and minimize signal distortion.

By following these best practices and the other issues discussed in the whitepaper, Glenair designers can optimize the performance, reliability, and manufacturability of rigid-flex circuit assemblies, ensuring they meet the requirements of their intended application while minimizing the risk of signal integrity issues and reliability problems. For more information on our rigid-flex-circuit board capabilities, contact the Glenair SuperFlex team.