ENGINEERING BRIEF

Building Tolerance

Orthogonal Direct Connector Architecture

Module Interconnectivity Meets Low-Cost Manufacturing

Charged with designing a large-scale SDN-based switch using the Molex Impact Orthogonal Direct (OD) Connector, Acorn Product Development tackled the challenge of creating affordable, reliable module interconnectivity without a midplane.

While the benefits of midplane-less OD connector-based design are compelling—unrestricted airflow opens the door for higher powered modules and direct module interconnection improves signal integrity—the approach is also challenging. To develop a chassis family with tight structural and alignment tolerances that perform as well as traditional midplane-based designs, we began with in-depth engineering analysis.

Using advanced analytical modeling, we vetted an array of new construction techniques. In parallel, we worked closely with manufacturers to ensure mass-production goals and product performance requirements could be achieved. Innovative design coupled with vigorous analysis and supply chain collaboration produced a robust, cost-efficient 4Sigma design that met the tolerance requirements for reliable module alignment.

Novel thinking leads to faster, more affordable solutions

When a trailblazing solution is required, we begin by conducting ideation sessions on high-level challenges. A seasoned team of engineers participate, bringing deep expertise from a number of disciplines to the table. Not only do the sessions yield a wide range of potential solutions, but our think-tank approach reduces the likelihood that a promising idea is overlooked—one that could make the difference between bringing a superior or inferior product to market.

Analysis pays off every step of the way

With a variety of chassis solutions on the table, we used engineering analysis to determine if a viable solution was possible, and to identify the most promising concepts for further development. Working in parallel with the manufacturer, we developed a feasible concept—a solution that was backed up by engineering analytics that gave our client confidence in its viability.

> The challenge was to develop a midplane-less chassis family that provided structure and alignment tolerances equivalent to that of a traditional chassis.

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Weighing design alternatives with upfront analysis

Due to the modular nature of the chassis, all installed LC modules need to be able to communicate with all installed FM modules regardless of their slot positioning and regardless of module population.

Designing the switch

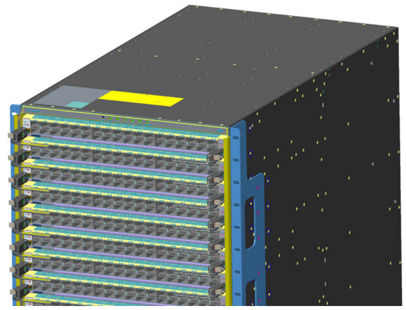

Figure 1
Frontal profile of modular switch

The switch features six different module types, installed from both front and rear. The modules include line cards, fabric modules, redundant power supplies, and several system management modules. High-speed connections, provided by the OD connectors, were required between the sixteen line cards (LC) and the six fabric modules (FM).

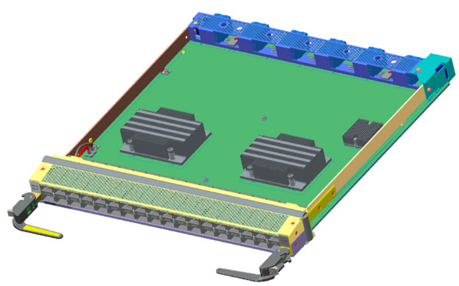

Figure 2A
Line Card (LC) assembly

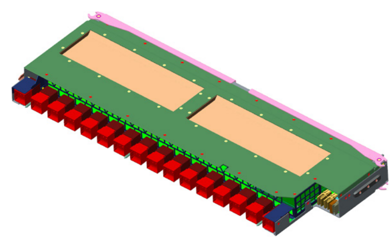

Figure 2B
Fabric Module (FM) assembly

Due to the modular nature of the chassis, all installed LC modules need to be able to communicate with all installed fabric modules regardless of their slot positioning and regardless of module population. Due to this, every LC was populated with six OD connectors to communicate with each FM and every FM was conversely populated with sixteen OD communicate with each LC.

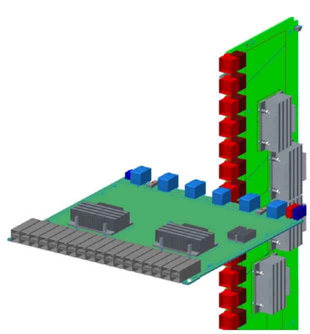

Figure 3A
Board-to-board connection using OD architecture

Figure 3B
Molex Orthogonal Direct Connectors (www.molex.com)

While this resulted in an elegant architecture for module communication and signal speed, it proposed a severe challenge for connector alignment and mating. The Molex OD connectors have only 1.5 mm of lead-in in each direction. To mate a fabric module in a fully populated chassis required the simultaneous alignment of sixteen connectors in sixteen different modules along with a set of backplane and bus bar connectors. An undertaking of this scale had not been attempted before.

Exploring the design process

For one module to align with sixteen others simultaneously, an acute alignment scheme with a small window for success was required. To achieve alignment at this scale, the potential for binding increases as alignment features are tightened. As the chassis structure was developed, extensive tolerance analysis was undertaken concurrently in an effort to minimize tolerance stack-up throughout the chassis. As a result, a large portion of the chassis design and assembly reflected the results of the tolerance analysis.

Achieving assembly goals

Further compounding the challenge was the requirement for ease of assembly. At Acorn, we minimize the use of external fixtures for alignment to keep assembly time down. The critical components in the chassis were designed to be self-aligned using slot and tab features or half-shear features to locate the parts. The assembly of the initial chassis achieved the required tolerances with zero fixturing required.

Label	Element Name	Nominal	+-TI	PDF	Effective Process Variation	Normal SD
A	LC-CPM Conn CL to LC PCB Surf		0.1270	N	0.042333	0.0423
B	LC PCB Surf to Guide Pin CL		0.1000	N	0.033333	0.0333
C	LC Guide Pin CL to Edge Radius		0.0500	N	0.016667	0.0167
D	LC Guide Pin to CS Hole Gap	0.40				
D1	CS Hole Radius		0.0500	N	0.016667	0.0167
E	CS CNC Hole to Hole		0.1000	N	0.033333	0.0333
F	CS Hole Radius		0.0500	N	0.016667	0.0167
G–I	Mini Loop - CPM-CS Hole Y		0.1938	N	0.064602	0.0646
J	CPM-LC Conn to LC-CPM Conn Offset	0.05				
	130716–Offset for 2 CS		0.1414	N	0.047140	0.0471

			Z Predicted	Alpha Single Sided	DDPM	Percent Defects
	Nominal Gap	0.450				
	Upper Spec Limit	100	938.85	0.000000	0	0.000%
	Lower Spec Limit	0	4.24	0.000011	11	0.001%
				Total DPM	11	0.001%
				Effective Z	4.24	

Figure 4

Acorn uses a method of statistical tolerance analysis similar to RSS, but incorporates additional variables for process capability.

Achieving alignment goals

Mating the modules reliably in the wipe direction, particularly with short pin lengths, was especially challenging. The tolerance loop for wipe contained over thirty contributors. Because physical parts weren't available for measurement at the time, statistical process capability data from major manufacturers was used to establish the standard for manufacturing capability for different processes. Specific care was taken to avoid features that became major tolerance contributors, such as sheet metal bends.

Tolerance analysis in parallel with chassis design

The assembly of the initial chassis was able to achieve the required tolerances with zero fixturing required.

Designing for manufacturing and assembly with parts not yet available

Because physical parts weren't available at the time for measurement, statistical process capability data from major manufacturers was used to establish the standard for manufacturing capability for different processes.

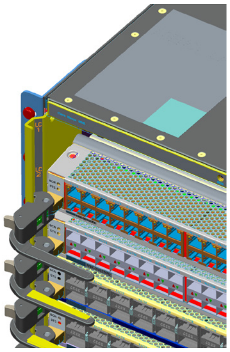

Figure 5A

LC ejector bar in chassis

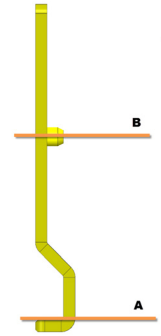

Figure 5B

Top view of LC ejector bar

When these features were unavoidable, secondary machining operations were employed to minimize the tolerance stack up through those features (Figure 5). Ultimately the care taken in the early design stages paid dividends as a 4Sigma confidence was achieved in connector wipe between the LC and FM.

Determining how the connectors would gather presented another challenge. For alignment purposes, Molex provides off-the-shelf alignment pins and shrouds for their OD connector line. Initially, considering the tight schedule, leveraging Molex's off-the-shelf alignment scheme looked appealing; however, several shortcomings became apparent. Because the alignment pins were tied into individual connector bodies, every connector would be required to carry a guide pin to ensure alignment in every module configuration—drawbacks included overall system cost and airflow restriction. Instead, a guide pin system—independent of the connectors—was conceived. The new strategy allowed each module to align while only requiring three guide pins, reducing material cost, assembly complexity, and airflow occlusion.

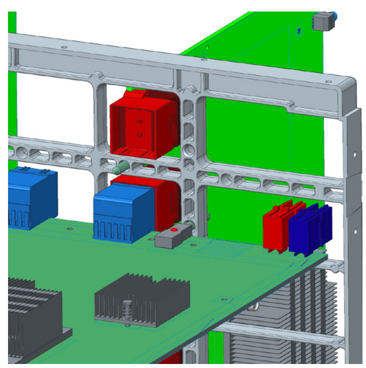

Figure 6

Acorn module alignment pins mated to center structure; center structure serves as an intermediary alignment fixture

The feasibility of this alignment scheme relied on an intermediary feature within the chassis to which the LC modules and FM modules could individually align. This feature became known as the center structure which simultaneously served as the primary alignment attribute and as a major structural element within the chassis.

Developing the center structure

The center structure was originally conceived as a sheet metal assembly; however, the tight tolerances required by the design resulted in intricate features across three dimensions that were difficult to manufacture.

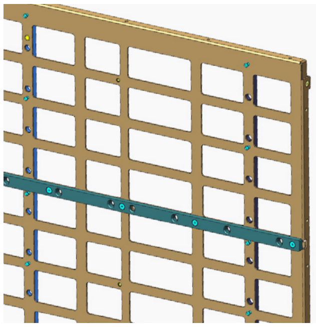

Figure 7A

Initial center structure concept; sheet metal base with extruded aluminum features for alignment

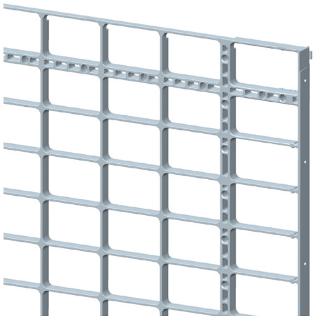

Figure 7B

Final center structure with hybrid die cast and CNC construction

Ultimately, a die-cast structure with post operation machining was developed, combining the cost-efficiency and simplicity of a die-cast component with the tight tolerances available with CNC machining. Due to long die-cast tooling lead times, initial center structures were fabricated by CNC machining aluminum plate.

The challenges of producing the center structure

The concept called for a large aluminum component to be die-casted to meet NADCA-standard tolerances. Features that required tighter tolerances would undergo a secondary machining operation. The transition from CNC routing to die-casting proposed several challenges.

The large, flat profile of the center structure produced significant part warpage. The flexible nature of the open lattice structure caused movement during machining, reducing accuracy. To rectify the problem, we analyzed part warpage and its affect on critical features. During production, four tabs are used to locate the center structure within the chassis body and position components on the Y and Z axes. As a result, tab placement affects the alignment and mating of every module in the chassis. Guide-pin holes were used to align LC and FM modules—the diameter of these holes had a direct affect on alignment. For the finished product to perform as needed, the location of the tabs as they relate to the guide-pin holes were the most crucial tolerances to hold. Everything else could be held at looser tolerances, with surrounding parts designed to meet NADCA-standard tolerances.

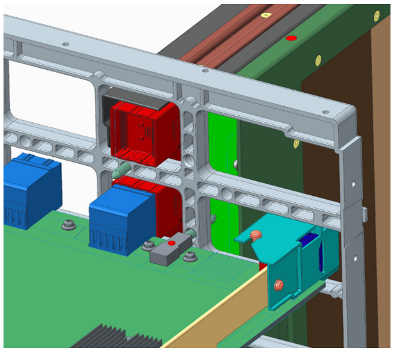

Figure 8

Acorn module alignment pins mated to center structure; center structure serves as an intermediary alignment fixture

Designing for tight tolerances in three dimensions

Ultimately a die cast structure with post operation machining was developed, combining the cost efficiency and simplicity of a die cast component with the tight tolerances available with CNC machining.

Working with suppliers from around the world to achieve design goals

Close relationships and collaborative communications with global suppliers, enabled the chassis to be designed for manufacturability and reliable performance.

About the author

Michael Zhang
Acorn Product Development

A mechanical engineer and project manager at Acorn, Michael's primary area of expertise lies in layout and development of rack mount servers for enterprise and military applications. He also has experience in high-speed switches, consumer electronics, and industrial equipment. Michael holds a BS in Mechanical Engineering and a BS in Biomedical Engineering from the University of Southern California.

About Acorn

Founded in 1993, Acorn Product Development is based in Silicon Valley with design centers in Texas, Boston, and China. We provide comprehensive product engineering services—from turnkey product development, subassembly development, and engineering analysis to materials cost analysis and manufacturing cost reduction—for leading companies around the globe.

To achieve accurate tolerances from the tab features to the guide pin holes, an initial machining pass was made to create one surface of the locating tabs. During machining, the part was clamped down to define the datum from which to take dimensions. Originally, the goal was to machine the part in a natural unclamped state because clamping would distort the part. Accurate machining tolerances could be achieved when clamping the part to remove warpage, however the critical dimensions would be altered upon release, as the part reverted to its natural shape. While this process made the most sense in terms of achieving the best tolerances possible, it was ultimately rejected after discussions with suppliers revealed concerns with setup and machining costs and with overall throughput.

Acorn worked with the suppliers from around the globe to establish a set of achievable tolerances based on the new process. These tolerances were once again fed through the extensive array of tolerance loops to ensure that the updated values didn't affect our 4Sigma design and hinder performance. To further reduce costs, the machining features were implemented in such a way that all passes, after the initial cut to define the first datum, would occur from one direction. By doing so, setup time was reduced, driving costs down further. The benefits of the updated die-cast center structure were unparalleled, resulting in almost a 90% cost reduction from the machined part.

Conclusion

Bringing this switch design from concept to fruition took over a year's time, including engineering design, prototyping, and production DFM and release. The primary architectural challenge in this brief was only one of numerous challenges requiring extensive tolerance loop analysis. Loops that ranged from module to module, module to backplane, and module to bus bar, the implications of which were all intertwined throughout the chassis.

By diligently breaking down the problem, identifying a solution, and verifying it with engineering analysis, a design was achieved that met both the performance and cost objectives. Finally, close relationships and collaborative communications with global suppliers, enabled the chassis to be designed for manufacturability and reliable performance.

Questions or suggestions?

If you'd like to learn more about our approach to DFM, share your ideas, or discuss this brief, please contact us—we'd welcome the opportunity to talk with you.

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Acorn Product Development
39899 Balentine Dr., Ste 161
Newark, CA 94560
P 510-249-9699
E sales@acornpd.com

www.acornpd.com

Michael Zhang
Mechanical Engineer and Project Manager
Acorn Product Development

510-743-9699 x2212
mzhang@acornpd.com

Barry Braunstein
Vice President
Business Development and Marketing
Acorn Product Development

617-475-1541
bbraunstein@acornpd.com