Leveraging Manufacturing Capabilities to Overcome the Challenges of Orthogonal Direct Connector Architecture

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I. Abstract

A recent design by Acorn Product Development involved a large scale chassis system featuring the Molex Impact Orthogonal Direct Connector. This provided substantial challenges for low cost, high volume manufacturing due to the need for reliable module interconnectivity without a mid-plane.

The primary challenge involved the chassis backbone which simultaneously dictated chassis alignment and structure while maintaining an open framework for airflow. Through an effort to reduce cost and drive down assembly time, a die cast structure was conceived. Working closely with manufacturers, major hurdles were overcome to achieve tolerances necessary for module alignment resulting in a cost efficient, 4Sigma design.

II. Introduction

Acorn Product Development is a product design firm with offices in the Silicon Valley, Boston, Dallas, and Dongguan China, providing comprehensive product engineering services for leading companies around the globe. Our areas of expertise include turnkey product development, engineering analysis, materials cost analysis, and manufacturing cost reduction. Our primary intent is to supplement innovative thinking with timely engineering analysis to ensure robust designs that are manufacturable, reducing design spins and therefore time to market.

Due to the demanding nature of the clients served, Acorn is constantly exposed to new challenges that require novel thinking and problem solving. One recent project involved a large form factor modular network switch with a need for reliable, high speed interconnectivity. The switch was a high powered solution using software defined networking (SDN) and development and operations (DevOps), supporting port speeds of up to 40Gbps. To match the speed requirements, Molex Orthogonal Direct connectors were selected as the connector of choice. Removing the necessity for a backplane allowed for the high speed connections required while simultaneously allowing adequate cooling for the dense electronic layout.

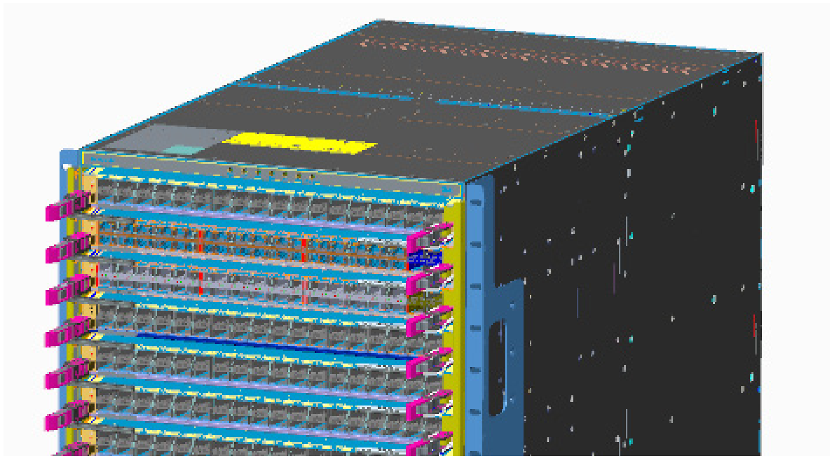

Figure 1: Frontal Profile of Modular Switch.

The switch features six different module types installing from both front and rear.   The modules include the Line Card, Fabric Module, Supervisor, SC, Fan Module, and PSU. High speed connections were required between the sixteen Line Cards (LC) and the six Fabric Modules (FM).

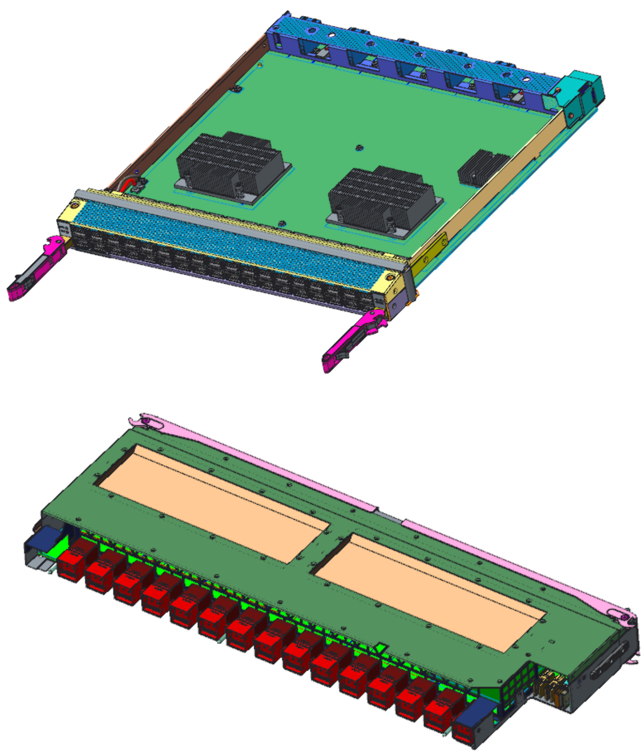

Figure 2A: Line Card (LC) assembly; Figure 2B: Fabric Module (FM) assembly

Due to the modular nature of the chassis, one crucial design criteria was that all installed LC modules would be able to communicate with all installed FM 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.

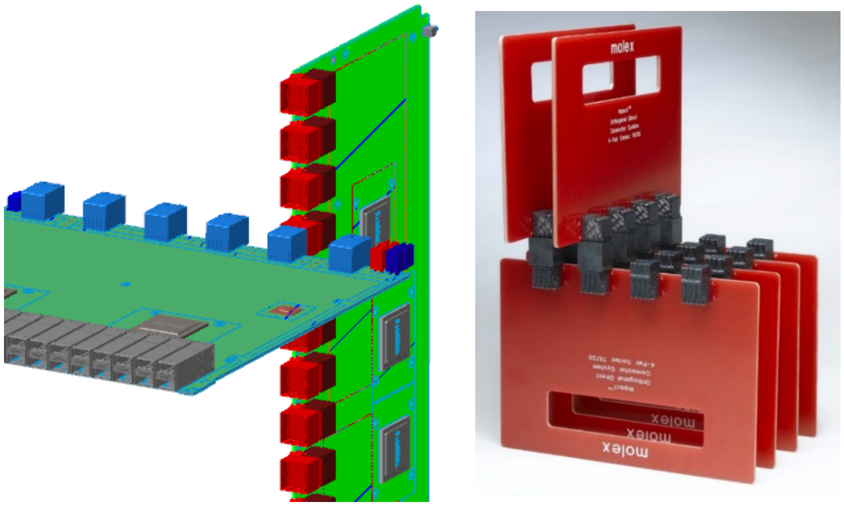

Figure 3A: Board to Board connection using OD Architecture. Figure 3B: Molex Orthogonal Direct Connectors. (www.molex.com)

While this resulted in an elegant architecture for module communication and signal speed, it proposed a severe challenge with connector alignment and mating. The Molex OD connectors had only 1.5mm of lead in each and to mate an FM 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. This article recounts the process of how this monumental problem was systematically tackled, the role that a crucial component played in resolving it, and how it evolved and took shape through working with suppliers and statistical data to create the most cost efficient and manufacturable solution without compromising on performance.

III. Early Design

The first question tackled in the design process was to study the feasibility of achieving reliable connector mating without binding. For one module to align with sixteen simultaneous required an acute alignment scheme with a small window for success. The endeavor to achieve alignment at this scale produces a potential for binding that increases as alignment features are tightened. Due to this, as the chassis structure was developed, a sizable effort in tolerance analysis was concurrently undertaken in an effort to minimize the tolerance stack-up that accrued through the chassis. As a result a large portion of the chassis design and assembly reflected the results of the tolerance analysis. Further compounding the challenge was the system wide paradigm that focused on ease of assembly. With designs from Acorn, the use of external fixtures for alignment is generally undesirable, as they add to assembly time and process. As much as possible, 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 was able to achieve the required tolerances with zero fixturing required. Due to the addition of an intermediary board through later generations, the current chassis requires the use of one fixture.

Tolerance Stack Up Analysis

Loop ID Number	LCBB-CS-BX
Loop Name	LC Binding with Vertical Bus Bar in X. Aligned by CS.
Revised Date	6/1/2013
Reason for Analysis	
Failure Condition	
Possible Mitigation	

Label	Element Name	Nominal	±Ti	PDF	Effective Process Variation	Normal SD	Z	Cp	Sigma^2	%Contrib
B1	Crown Clip Connector Feature Tolerance		0.1270	T	0.050800	0.0423	2.50	0.83	0.002581	4.2%
B2	Conn Crown Clip Tab Tolerance		0.0635	T	0.025400	0.0212	2.50	0.83	0.000645	1.0%
B3	GAP - Crown Clip Tab to PCB Slot		0.1100	U	0.062857	0.0367	1.75	0.58	0.003951	6.4%
B4	PCB Slot Edge to Centerline		0.0500	N	0.016667	0.0167	3.00	1.00	0.000278	0.5%
C	PCB Feature to Feature		0.1000	N	0.033333	0.0333	3.00	1.00	0.001111	1.8%
D	Mini Loop - LC Guide Pin Parallel to Board		0.3561	N	0.118714	0.1187	3.00	1.00	0.014093	22.9%
E	GAP - LC Guide Pin to CS Edge	0.5000								
F1	CS Hole Radius		0.0500	N	0.016667	0.0167	3.00	1.00	0.000278	0.5%
F2	CS Hole to Edge		0.1500	N	0.050000	0.0500	3.00	1.00	0.002500	4.1%
G0	CS Edge to ESW SM - Surface to Surface	0.0000								
G1	ISW Form to Form from ESW Surface		0.3810	N	0.127000	0.1270	3.00	1.00	0.016129	26.2%
H	Bus Bar Tolerance From Drawing		0.3000	N	0.100000	0.1000	3.00	1.00	0.010000	16.2%
I	Bus Bar Thickness Tolerance		0.3000	N	0.100000	0.1000	3.00	1.00	0.010000	16.2%
J	Crown Clip to Bus Bar Gap	0.75								
						0.0000				
	Nominal Gap	1.250	**Z Predicted**	**Alpha (Single Sided)**	**DPPM**	**Percent Defects**		**Total Standard Deviation**	0.248124	100.0%
	Upper Spec Limit	100	397.99	0.000000	0	0.00%				
	Lower Spec Limit	0	5.04	0.000000	0	0.00%				
				Total DPM	0	0.00%				
				Effective Z	5.04					

Figure 4: Acorn Tolerance spreadsheet. Acorn uses a method of statistical tolerance analysis similar to RSS, but incorporates variables for process capability.

The first half of the challenge was the ability to mate the modules reliably in the wipe direction. The Molex OD connectors are especially challenging in this respect, with short pin lengths. This resulted in a very short wipe distance.

The tolerance loop for wipe contained over thirty contributors. Because physical parts weren't available for measurement, 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 major tolerance contributors such as sheetmetal bends.

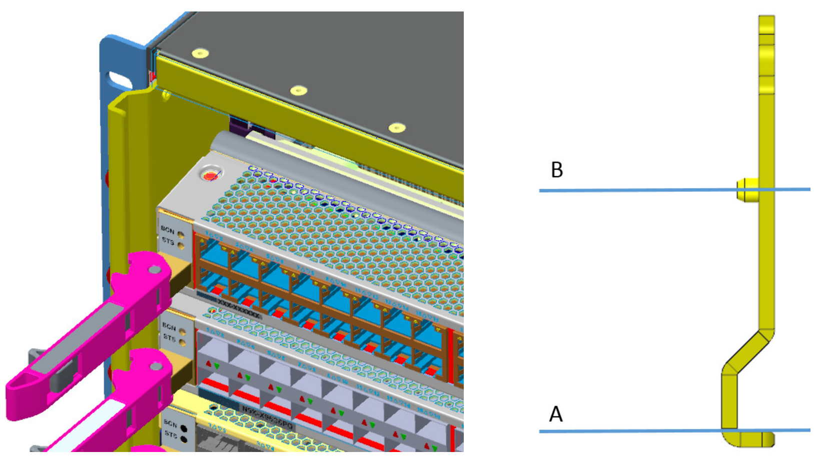

Figure 5A: Snapshot of LC ejector bar in chassis. Figure 5B: Snapshot of LC ejector bar top view. A crucial dimension in the wipe direction is indicated by point A and B. Normally this dimension passes through 3 sheetmetal bends. The part was fixtured after sheetmetal forming and the locating hole for the guide pin was machined using Surface A as the primary datum to ensure a tight dimensional tolerance.

When these features were unavoidable, secondary machining operations were employed to minimize the tolerance stack up through those features. An example of this is shown in 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.

The second half of the challenge lay in determining how the connectors would gather. 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. This would have incurred large drawbacks in overall system cost and airflow restriction. Due to this a guide pin system independent of the connectors was conceived. The new strategy allowed for each module to align while only requiring three guide pins, resulting in a reduction in material cost, assembly complexity, and airflow occlusion.

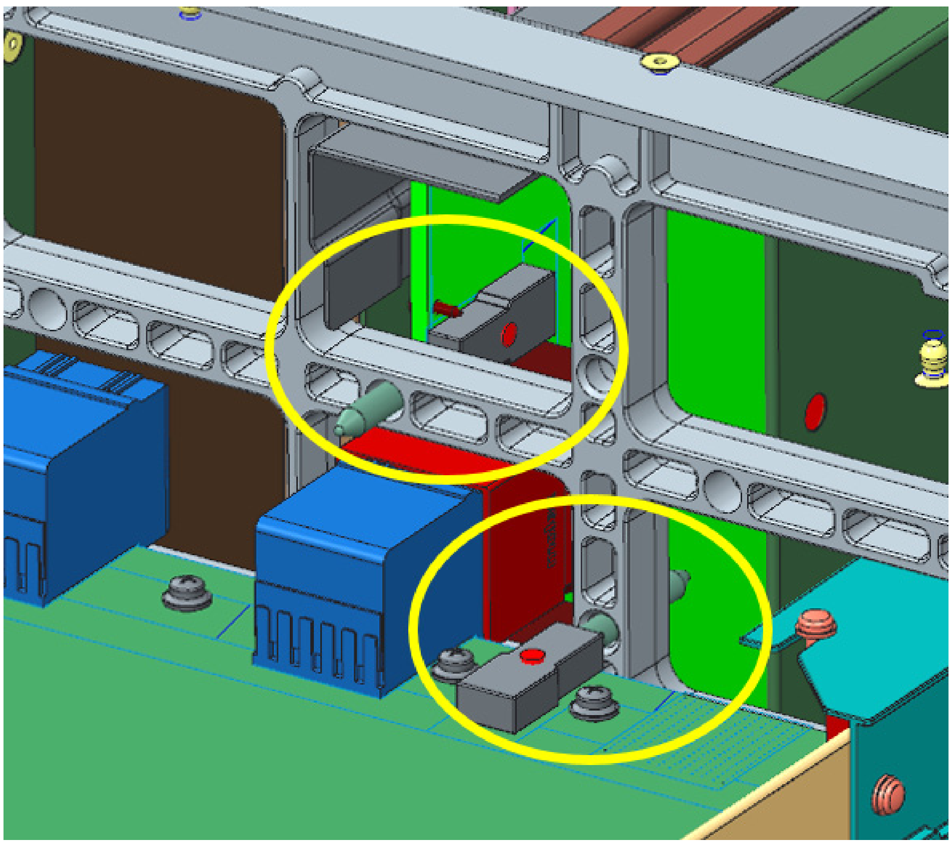

Figure 6: Acorn module alignment pins mated to center structure. The center structure serves as an intermediary alignment fixture.

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

IV. Center Structure Development

The center structure was originally conceived as a sheetmetal assembly. Cost was the driving factor in this design but it created issues for the suppliers. The tight tolerances required by the design resulted in intricate features that were difficult to manufacture. The convoluted assembly of the sheetmetal center structure compounded this fault and the original sheetmetal concept was rejected for something more manageable.

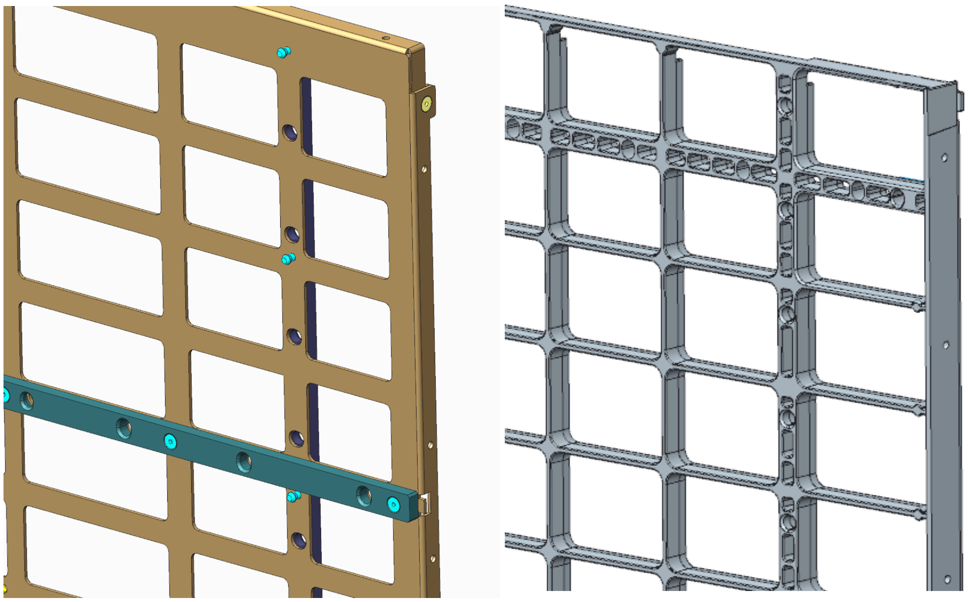

Figure 7A: Initial conception of Center Structure featured sheetmetal base construction with extruded aluminum features for alignment. (Left) Figure 7B: Final Center Structure with hybrid die cast and CNC construction. (Right)

Upon scrapping the sheetmetal concept, a machined version of the center structure was developed. This concept performed exceptionally well and produced excellent results in terms of its ability to hold tight tolerances throughout the part, along with its simple assembly and construction. Despite its exceptional performance, the major drawback to the machined structure was cost. Ultimately a die cast structure with post operation machining was conceived. This solution combined the cost efficiency and simplicity of a die cast component with the tight tolerances available when CNC machining.

V. Center Structure Production Challenges

The concept assumed that we would be able to die cast a large aluminum component at NADCA standard tolerances. Any features that required tighter tolerances from what the die casting process could hold would require a secondary machining operation. There were several challenges that arose in making the transition from the CNC to die cast.

The large flat profile of the center structure resulted in significant part warpage, making it difficult to locate for machining. The flexible nature of the open lattice structure also had a tendency to move during machining, reducing the accuracy of the machining process. Solving this issue required detailed analysis of the part to break down critical features and their relationship. In the chassis body, the center structure is located by four tabs which position the component in Y and Z.   The accuracy of these tabs affect the alignment and mating of every module in the chassis.   The other critical features on the center structure were the guide pin holes that provided alignment for the LC and FM.   The diameter of these holes along with their directly affected the alignment of the LC and FM modules.   For the finished product to perform as needed, the most crucial tolerances to hold would be the location of the tabs to these guide pin holes.   Everything else could be held at looser tolerances and the parts around them designed to work with NADCA Standard tolerances.

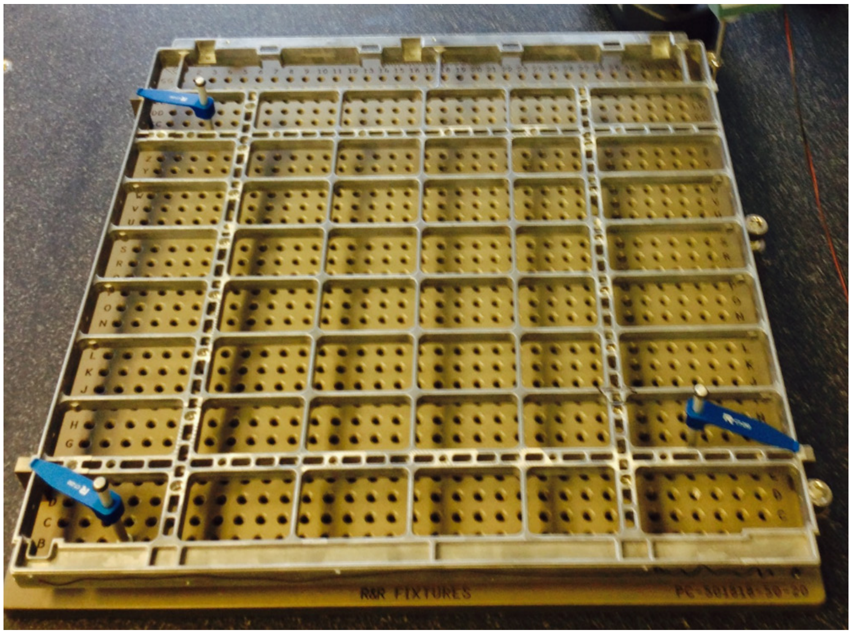

Figure 8: Picture of die cast center structure during first article inspection. The part is clamped down at three locating tabs which also define the machining datum.

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 it had been desired for the part to be machined 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 reversed 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 due to concerns with setup and machining costs and overall throughput.

Acorn worked with the vendor 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 this reduced the setup time and further drove the cost down.   The benefits of the updated die cast center structure were unparalleled, resulting in almost a 90% cost reduction from the machined part.

VI. 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 was laid out in this study but it was only one of numerous tolerance loops. 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.

It was only through the diligence put forth initially to break down the problem, identify a solution, and verify with engineering analysis, that a well performing design was able to be achieved. Subsequently it was also the close relationship and open communication with suppliers that allowed the chassis to be realized, both in performance and manufacturability.