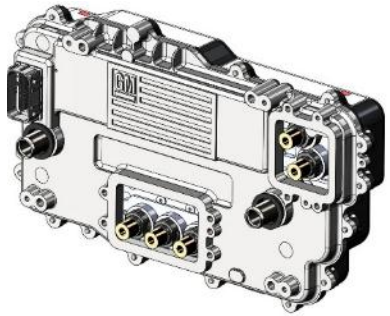
2014 DOE VEHICLE TECHNOLOGIES ANNUAL MERIT REVIEW

Next Generation Inverter

Project ID # EDT040

Presenter: Zilai Zhao
General Motors
June 10, 2015



GENERAL MOTORS

OVERVIEW

Timeline

- Start - October 2011
- Finish – January 2016
- 85% Complete

Barriers

- Cost
- Efficiency
- Performance and Lifetime
- Mass and Volume

Funding

	DOE	GM
Budget	**$6.0M**	**$10.6M**
FY12	$0.80M	$1.97M
FY13	$1.70M	$3.43M
FY14	$1.80M	$3.31M
FY15 (thru March)	$0.30M	$0.91M
Actual (thru Mar-15)	**$4.60M**	**$9.32M**

Partners

- Lead – General Motors
- Tier 1, 2, & 3 Suppliers - Hitachi, Delphi, Infineon, HRL, Panasonic, AVX, Kemet, and VePoint
- Collaborations - National Renewable Energy Laboratory, and Oak Ridge National Laboratory

RELEVANCE

- **Research Focus Area: Inverter**
  - Modularity/Scalability
  - Components – power module, gate drive, capacitor, current sensor and control card
  - Supplier development
- **Objective**
  - Develop the technologies and product design for a low cost highly efficient next generation inverter capable of 55kW peak/30kW continuous power.
- **Addresses Targets**
  - Cost: $3.30/kW produced in quantities of 100,000 units
  - Power Density: 13.4kW/l; Specific power: 14.1kW/kg
  - Efficiency >94% (10%-100% speed at 20% rated torque)
- **Uniqueness and Impacts**
  - Technology Co-development with the Tier 1, 2, and 3 suppliers
  - Detailed knowledge of vehicle application and ability to understand and assess vehicle impacts to make necessary materials and technology trade-offs.

MILESTONES

Month /Year	Milestone or Go/No-Go Decision	Status
June 2012	Power Inverters Based on Conventional, Transfer Molded, and Encapsulated Power Module Technology Delivered for Evaluation	Complete
Jan 2013	Initial Technology and Production Cost Assessment Complete with Report	Complete
Jan 2014	Concept Design Review – DOE “Go/No-Go” Decision	Complete
Sept. 2014	Critical Design Review (original scheduled for June 2014)	Complete
Aug. 2015	Demonstration of Inverter Performance	On track
Sept. 2015	Final cost estimation (originally scheduled for Sept. 2014)	On track
Dec. 2015	Preliminary reliability study	On track

ACCOMPLISHMENT: HIGH POWER DENSITY

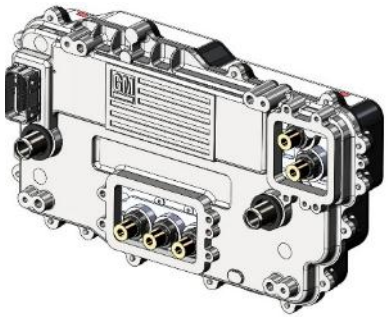
	SPIM1	SPIM2	NGI Lo/Hi	TPIM1	TPIM2	TPIM3
# of 3ph bridges	1	1	1	2	2	2
kVA/L	14.6	21.8	31.4 / 38.7	34.6	23.7	26.8
kVA/kg	14.6	22.7	24.4 / 30.0	25.5	26.7	23.9

Note
- DOE's 2020 targets for a 55 kW single inverter are 13.4kW/L and 14.1kW/kg.
- Dual inverters have higher power density due to sharing of components between the two 3-phase bridges.

- Manufacturability vs. Volume tradeoff: High power density could lead to high cost
- Next Gen Inverter pushes for even higher volumetric power density
  - Smaller: Easier to package in vehicle
  - Smaller: Less materials and less expensive
  - Inverter level optimization: all components must be optimized for the chosen inverter architecture
  - Manufacturability must be improved simultaneously

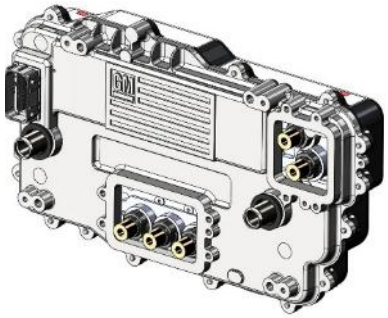
Integrated Power Stage

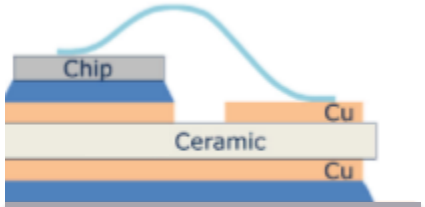
KEY ACCOMPLISHMENT: INTEGRATED POWER STAGE



- Integrated power stage: Eliminate boundaries and empty spaces; new partitioning of functionality
- Vertically integrated process: Power stage manufacturing integrated into inverter assembly
- Manufacturability: Unidirectional (bottom to top) assembly process; reduced assembly steps

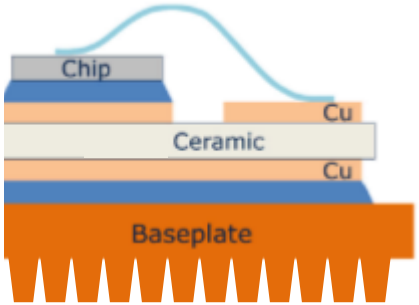
KEY ACCOMPLISHMENT: DBC DIRECTLY ATTACHED TO CLOSED COOLING MANIFOLD





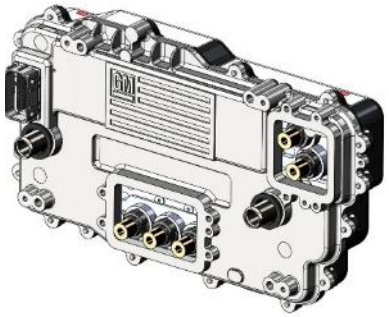
Aluminum – closed cooling manifold

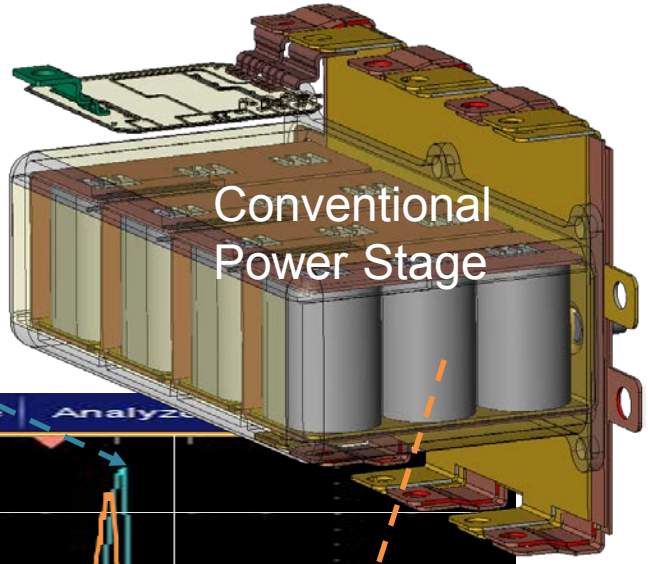
NGI	Current Gen
Die	Die
Solder	Solder
Copper	Copper
Ceramic	Ceramic
Copper	Copper
Solder	Solder
Aluminum	Copper
0.304 k*cm^2/W @ 4 LPM	0.288 k*cm^2/W @ 10 LPM

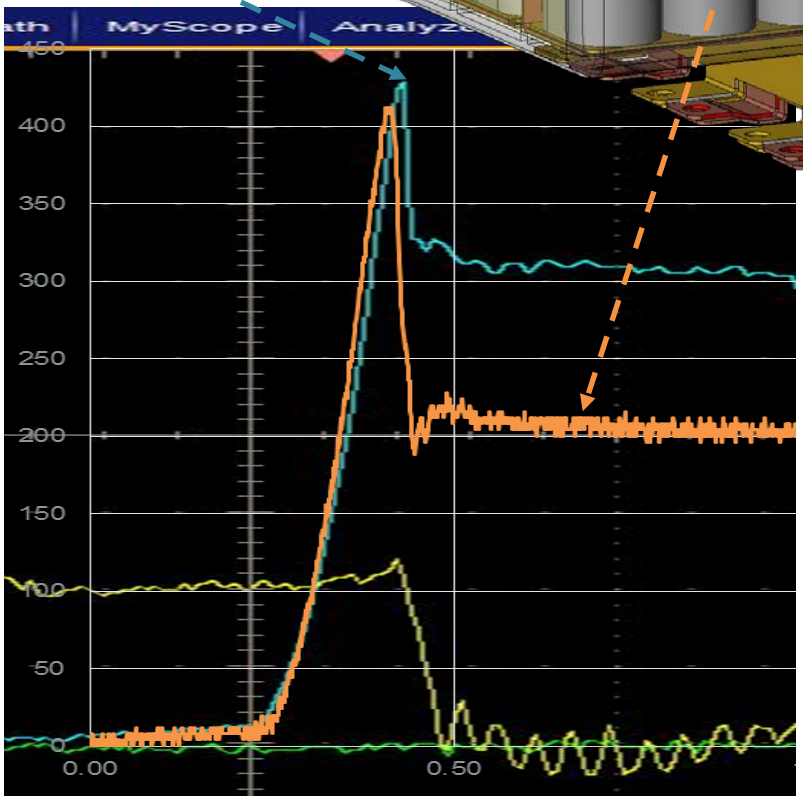


- Switching circuitry built directly on closed cooling manifold
- Thermal performance on par with Cu pin-fin base-plate
- Manufacturability
  - DBC to Al attach is a challenge
  - Vertically integrated process

KEY ACCOMPLISHMENT: LOW INDUCTANCE DC LOOP (INVERTER LEVEL)



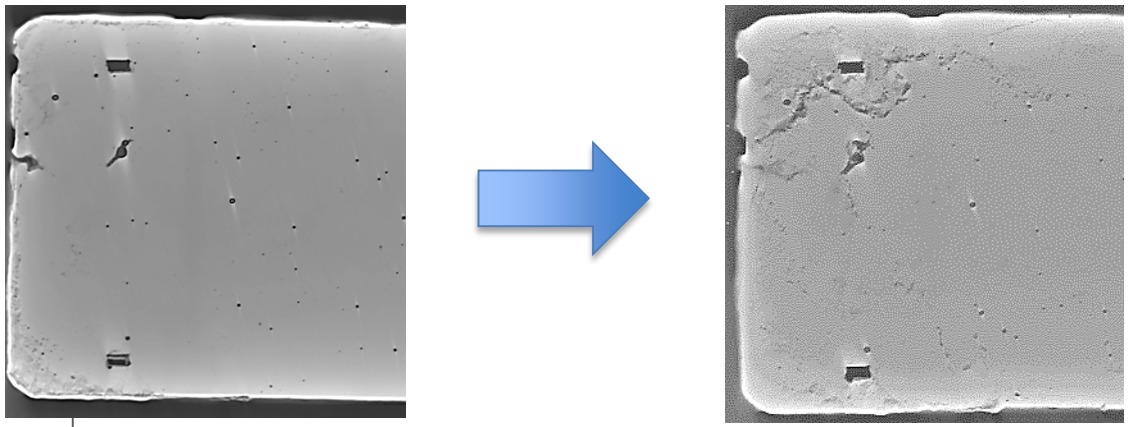




- Low stray inductance in the complete DC loop
- Manufacturability
  - Vertically integrated process
  - Press-fit pins

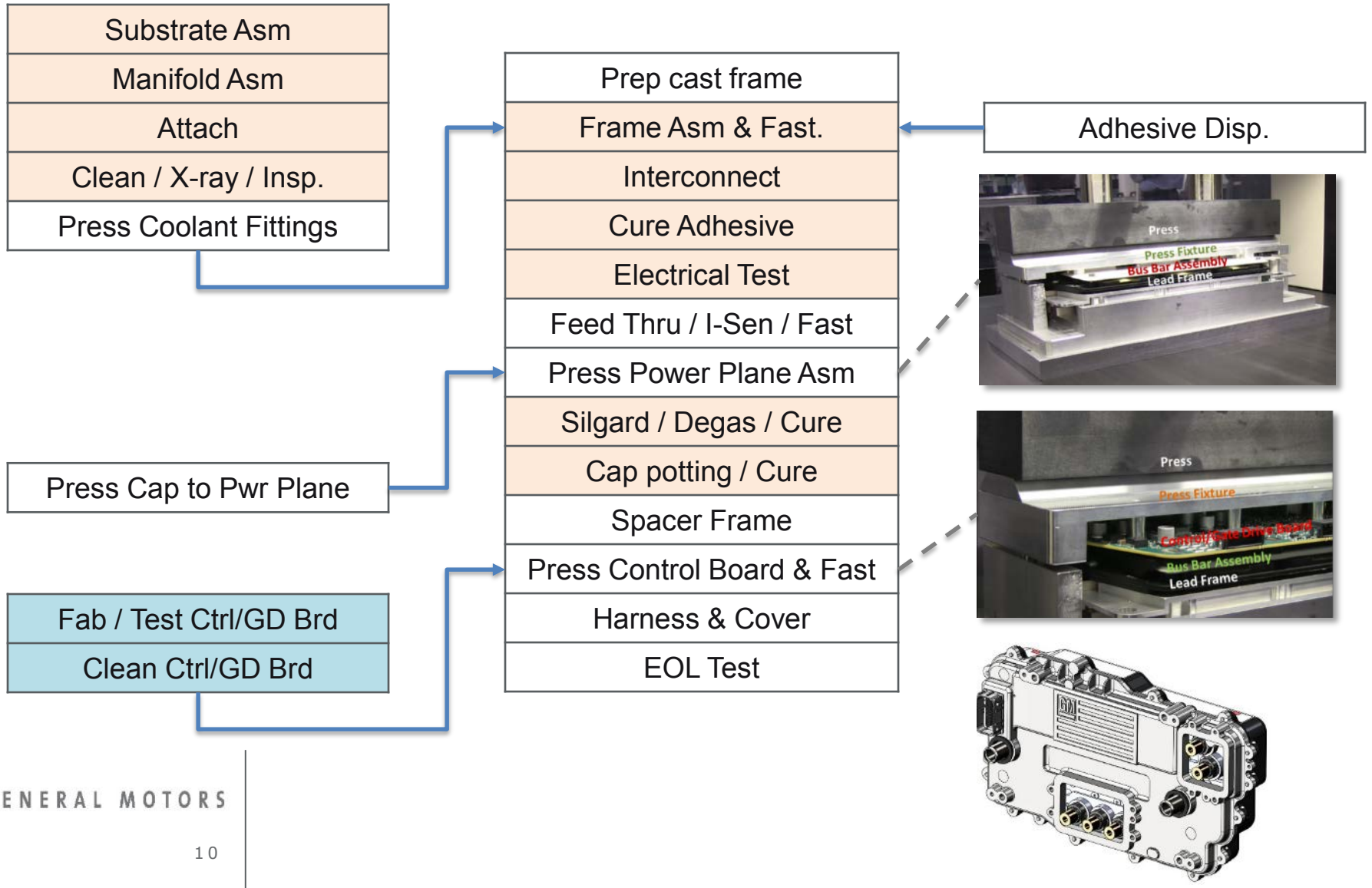
KEY ACCOMPLISHMENT: PROCESS DEVELOPMENT

- Key Processes: die attach, DBC attach, wire bonding, encapsulation of dies and cap bobbins, press-fit pin, final assembly
- Die/DBC attach
  - 20+ configurations evaluated – oven type, solder type, processing parameters
  - Evaluation: Yield, thermal shock (-55^{o}C to 150^{o}C), 3D Xray, Cross-Sectioning
- Encapsulation
  - 5 Configurations evaluated – chemistry, process parameters
  - Evaluation: High temp / high humidity



3D X-Ray: DBC attach before and after thermal shock

ACCOMPLISHMENT: PROCESS FLOW



NEXT STEPS AND FUTURE WORK

- Finish asset builds
- Complete tests per plan and reliability analysis
- Performance demonstration
- Final cost assessment
- Scalability and further process improvement for WBG devices

SUMMARY

- Inverter level optimization is necessary to achieve high power density with reasonable manufacturability.
- Integrated power stage design and vertically integrated process can lead to desired targets.
- DOE’s funding helps GM design and build prototypes to show/achieve the potential of inverter level optimization.

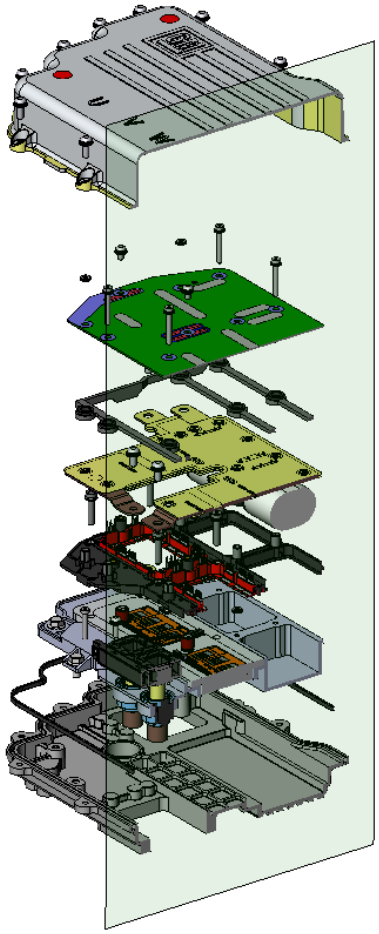
THANK YOU FOR YOUR ATTENTION!

GENERAL MOTORS

TECHNICAL BACKUP SLIDES

GENERAL MOTORS

KEY ACCOMPLISHMENT: INTEGRATED POWER STAGE



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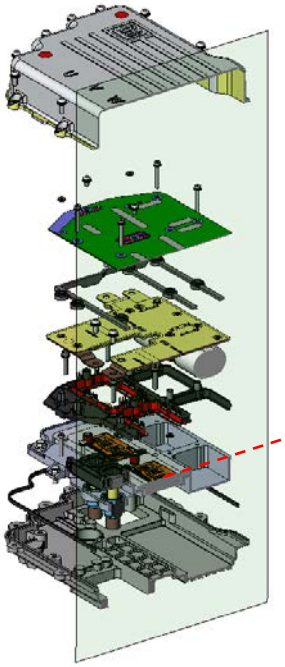

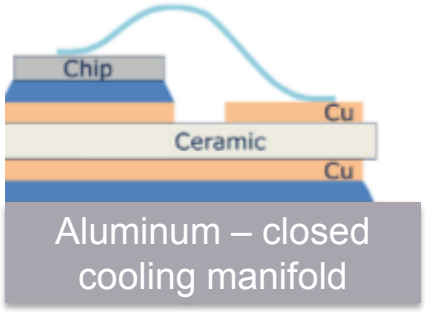

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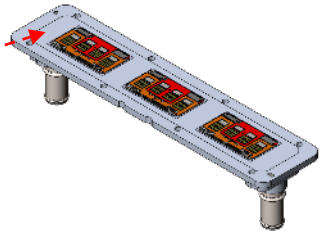

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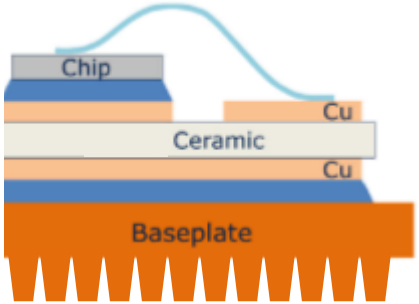

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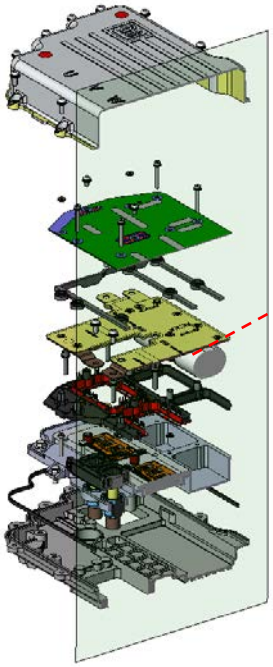

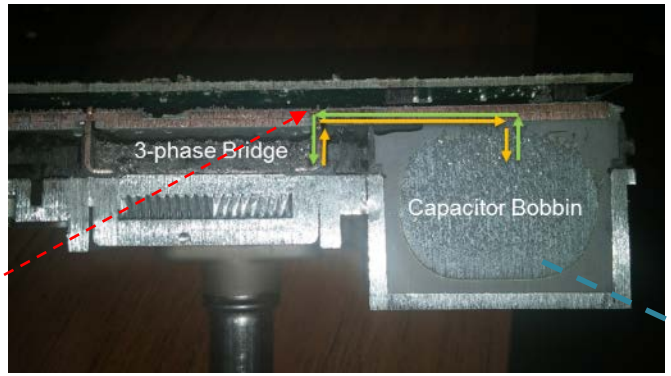

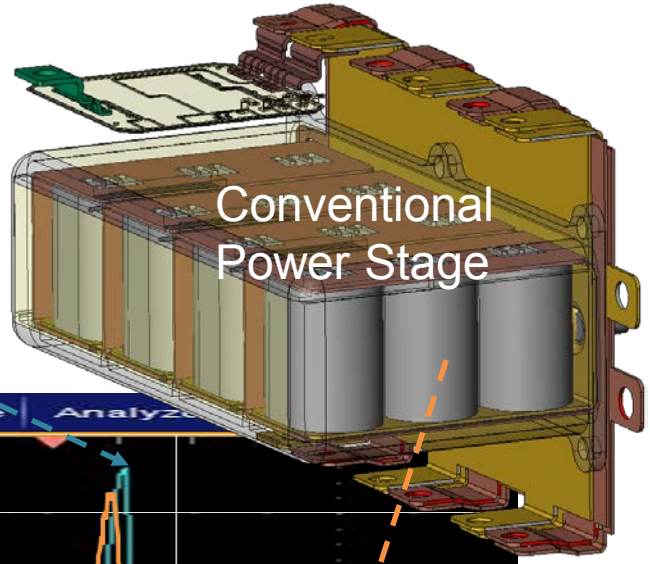

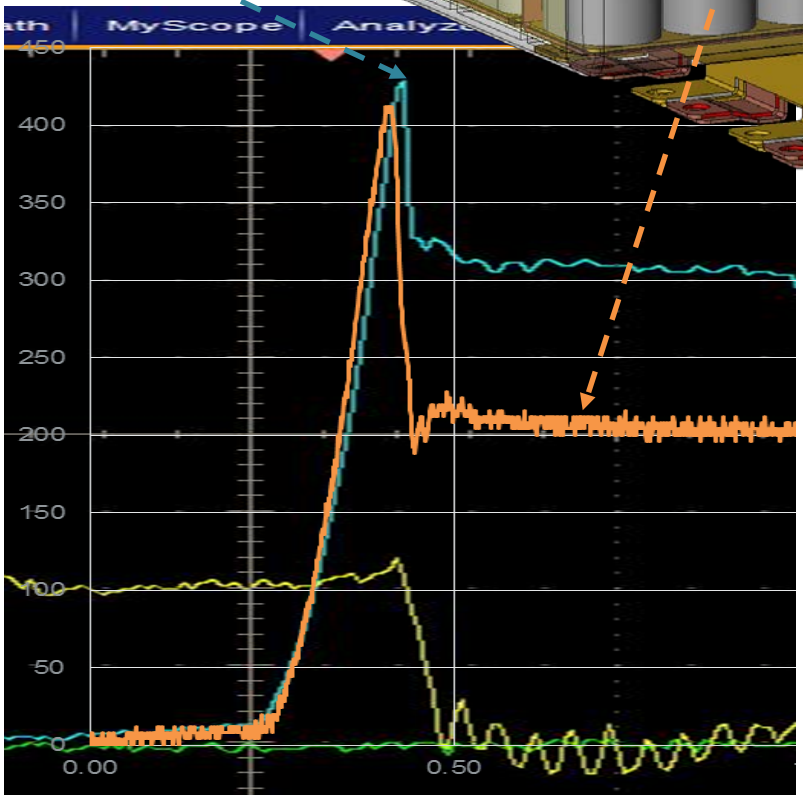

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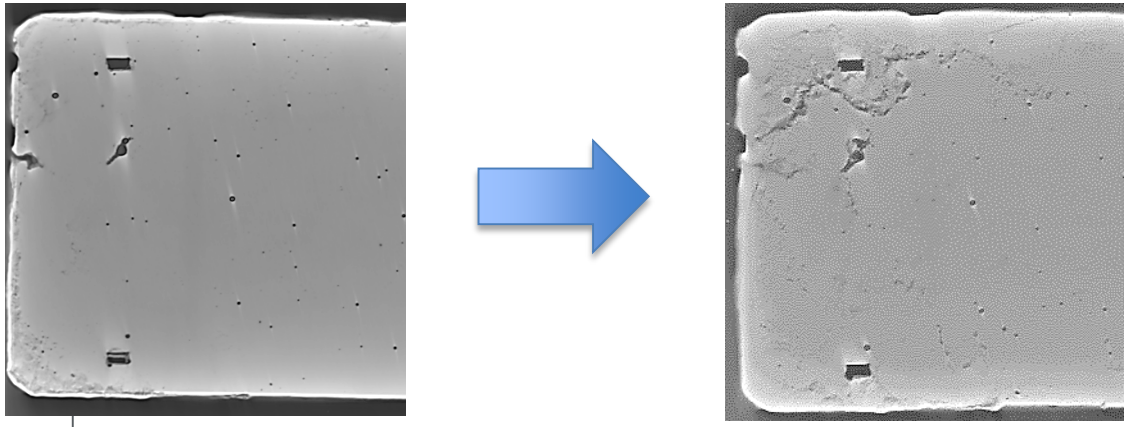
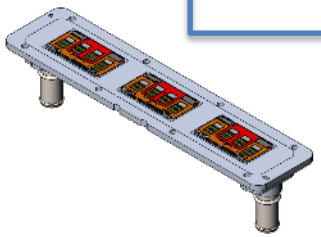


3D X-Ray: DBC attach before and after thermal shock

ACCOMPLISHMENT: PROCESS FLOW

Substrate Asm
Manifold Asm
Attach
Clean / X-ray / Insp.
Press Coolant Fittings

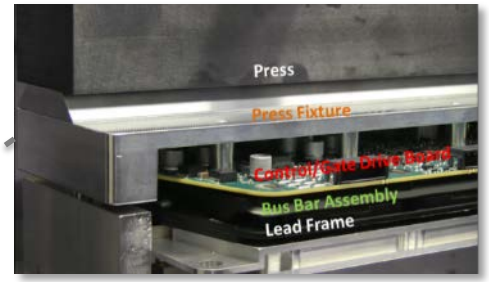


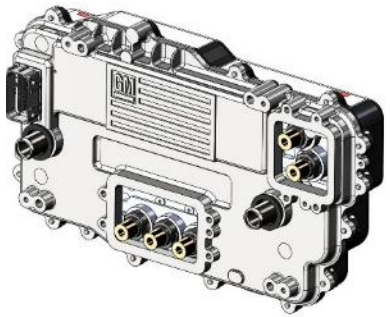
Press Cap to Pwr Plane

Fab / Test Ctrl/GD Brd
Clean Ctrl/GD Brd

Prep cast frame
Frame Asm & Fast.
Interconnect
Cure Adhesive
Electrical Test
Feed Thru / I-Sen / Fast
Press Power Plane Asm
Silgard / Degas / Cure
Cap potting / Cure
Spacer Frame
Press Control Board & Fast
Harness & Cover
EOL Test

Adhesive Disp.





Next Steps