Ballard Power Systems

Modeling of IGBTs and Bus Bar Structures for Custom Power Module Development

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Custom Power Modules- Why?

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- Integrated Power Train (including inverter) in the fuel cell car
  - Power modules- size,reliability and cost

Automotive Requirement

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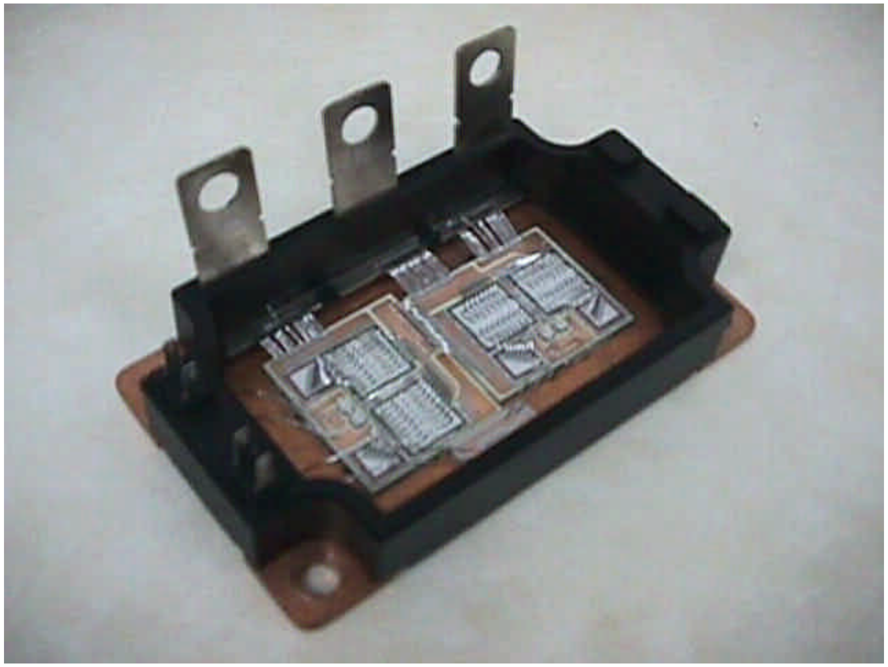
- Partial List of requirements

  - ***Size:*** Inflexible package volume requirements
  - ***Warranty:*** 10 year / 200,000km lifetime
  - **Reliability:** Thermal cycle reliability. Temperature range –40°C to 100°C
  - ***Cost:*** Unreasonably low cost
  - ***Other constraints:*** EMI constraints

Power Semiconductor

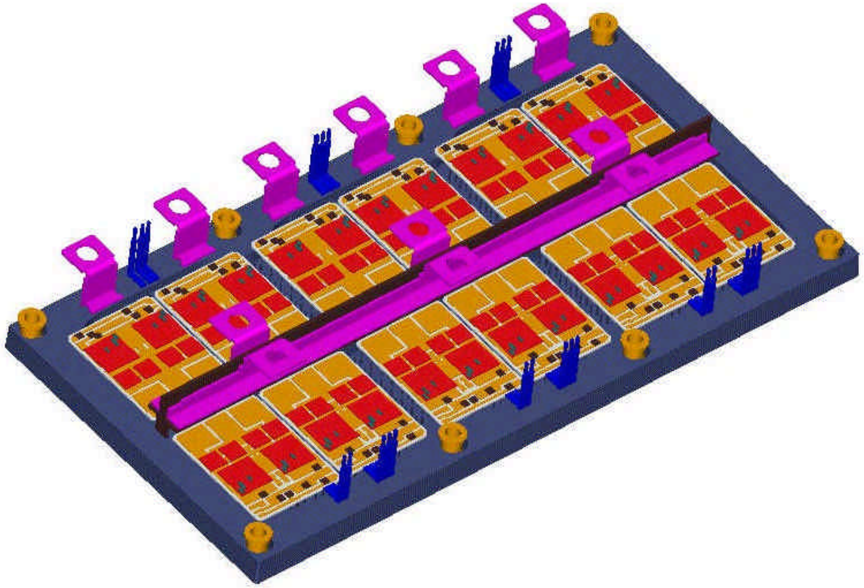
- Operate with as high a bus voltage as may be safely applied
- Conduction and Switching power losses- Heat Dissipation
- Constraint is the temperature of the device
- Temperature inaccessible - current and voltage becomes the constraint
- Rapid turn-on and turn-off operation – extreme di/dt and dv/dt stresses
- Excessive transient voltages – if leakage inductance is not minimized
- Objective: Compute parasitic module inductance to support module design layout decisions

Integrated Busbar



one half bridge with standard DC terminals:

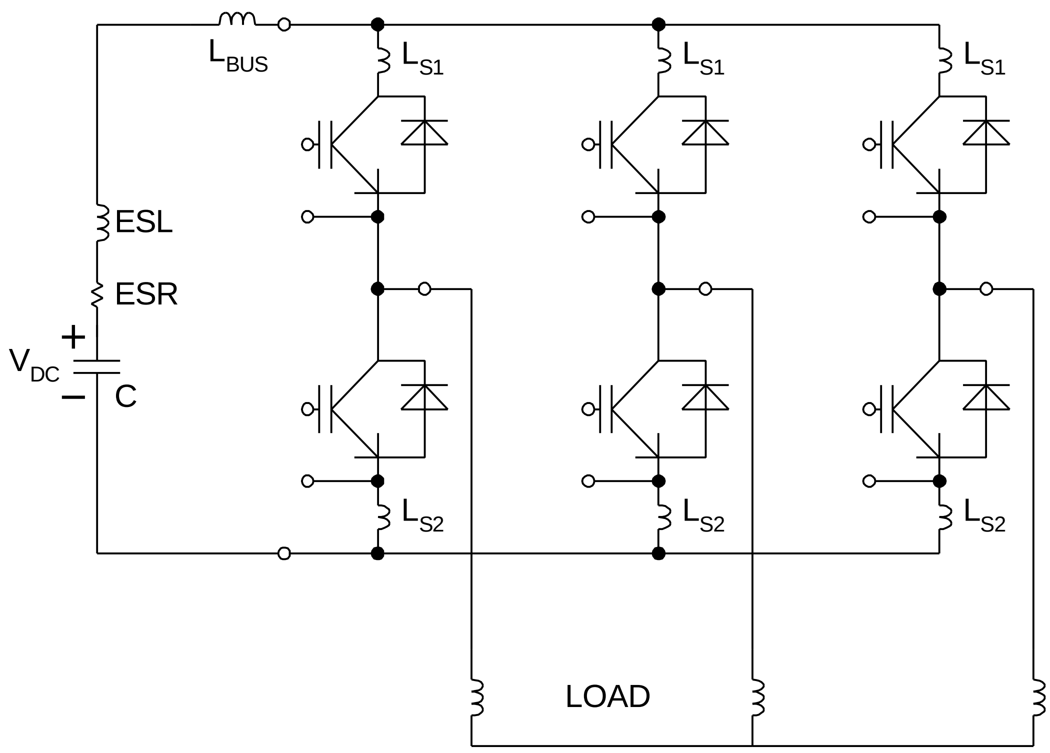
they are far apart; not optimized for inductance.



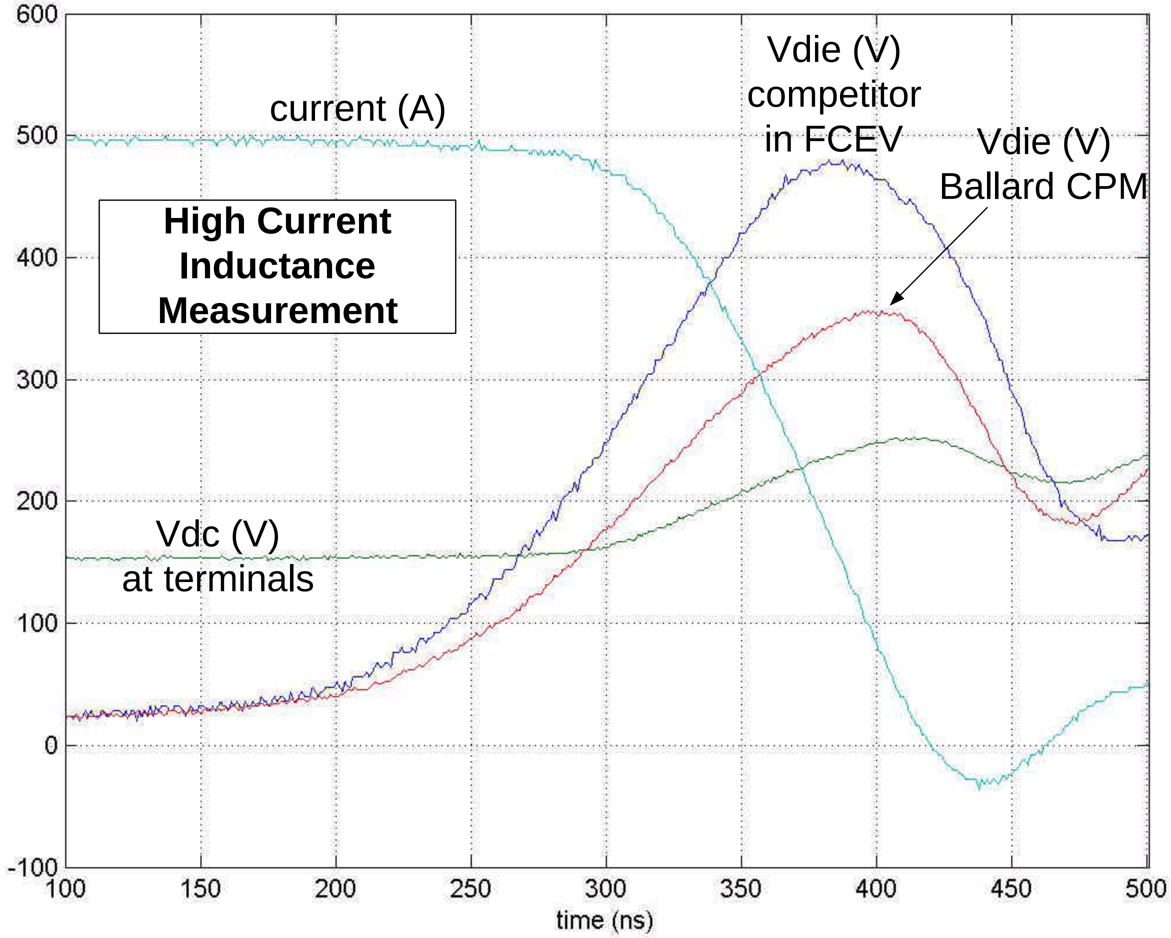
- Three half bridges
- Eliminate the need for external high inductance interconnects.
- The DC terminals on the Ballard module - optimized for lowest stray inductance.

Busbar Inductance

- busbar inductance contributes to device voltage overshoot



Busbar Inductance



Ballard's CPM
has half the parasitic inductance of the competitor's module.

This results in less wasted energy storage.

Direct benefits are:
- ✓ lower voltage overshoot => better bus utilization
- ✓ 5% decrease in total inverter loss
- ✓ lower EMI

Ballard Custom Power Module

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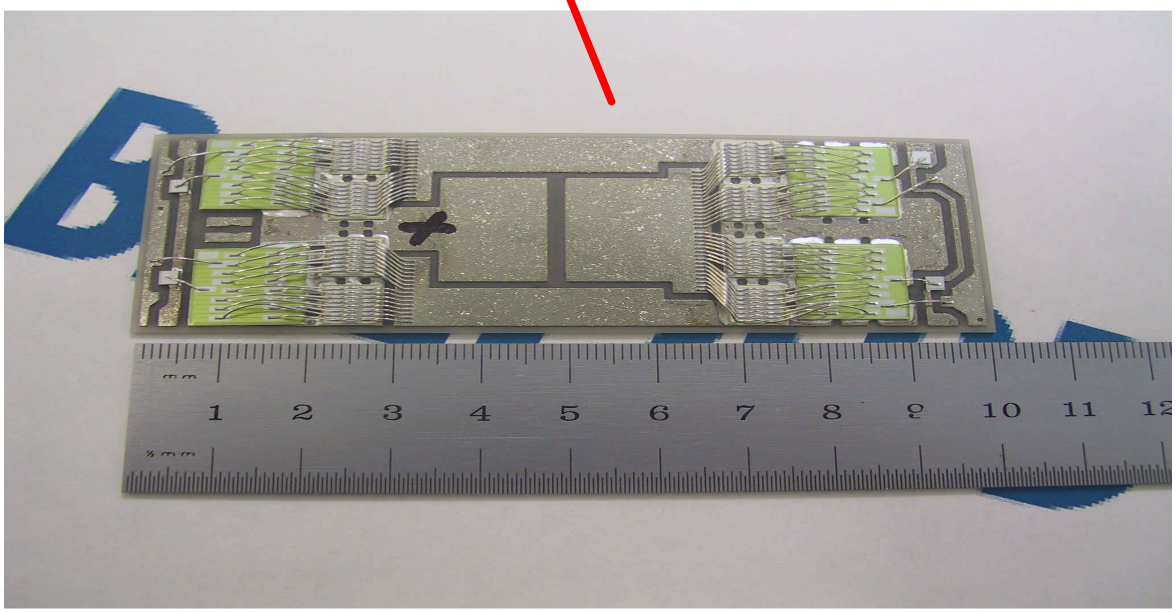
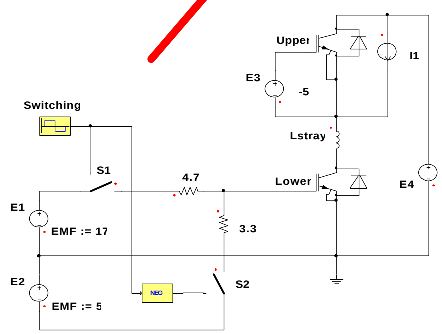
- Custom Power module

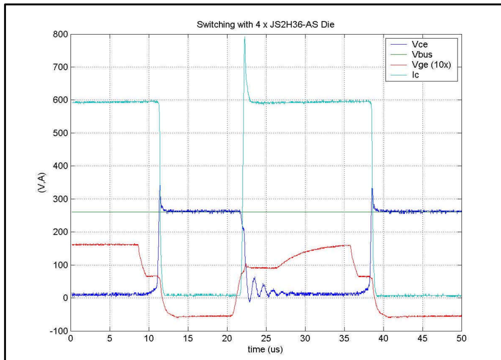


Maxwell 3D – Simplorer Interactions

- Use Maxwell 3D to provide inductances for Simplorer inverter model
  - Maxwell 3D used to compute stray inductances
  - Simplorer detailed IGBT model used for inverter circuit simulation

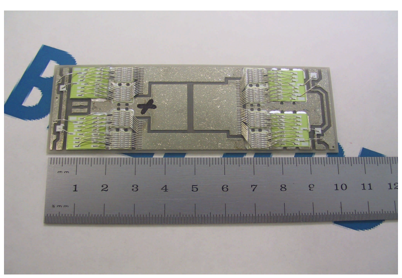


Laboratory Test Circuit



Experimental Turn On/Turn Off Waveforms

Simplorer Experiment Tool

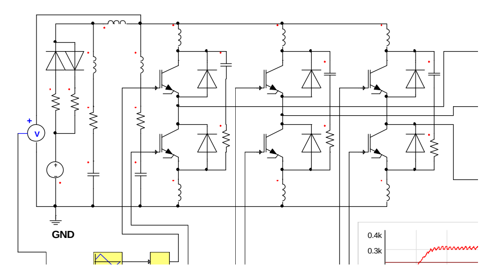


Custom Power Module

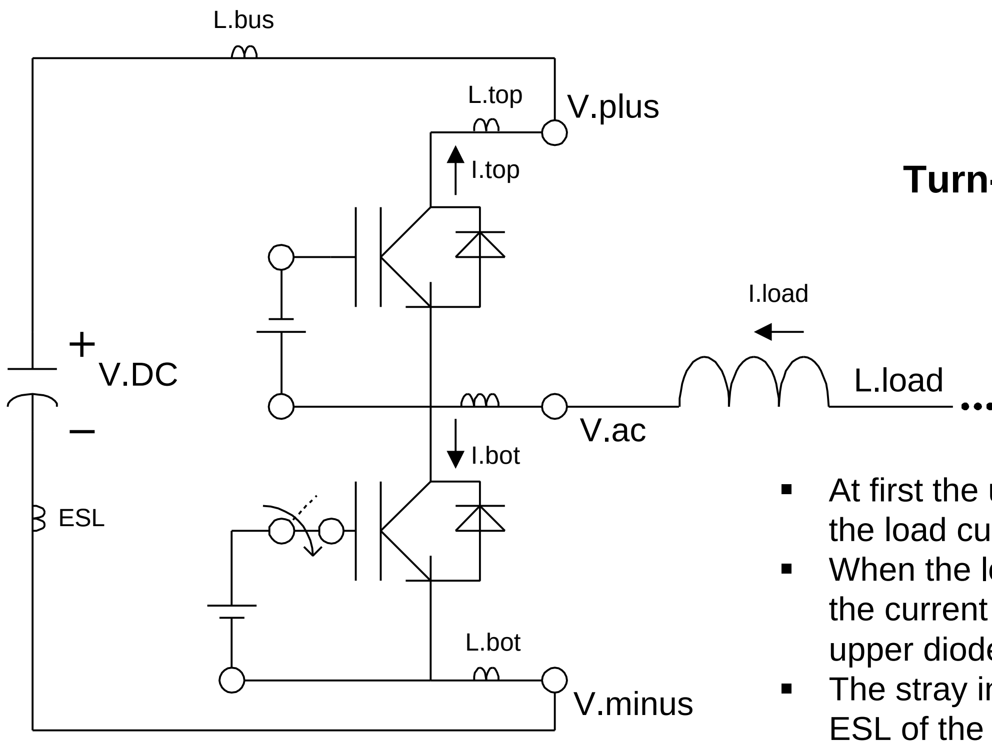
Maxwell 3D

Simplorer IGBT DeviceModel

In Inverter Circuit Model



Modeling of Ballard Custom Power module



Turn-on of bottom IGBT

- At first the upper diode is conducting the load current.
- When the lower device is turned on, the current commutates between the upper diode and the lower device.
- The stray inductance of the bus and ESL of the capacitor are in series with this "high frequency" current.

The peak voltage on the device is:

V.peak = V.DC + (L.top + L.bot + L.bus + ESL) * di/dt

Therefore, minimizing all stray inductances, including the module's stray inductance, allows optimal utilization of the semiconductor's voltage blocking capability.

Assumptions

- Copper Busbar
- Aluminum bondwires
- Input Current (Fig. 1)
- DBC: copper

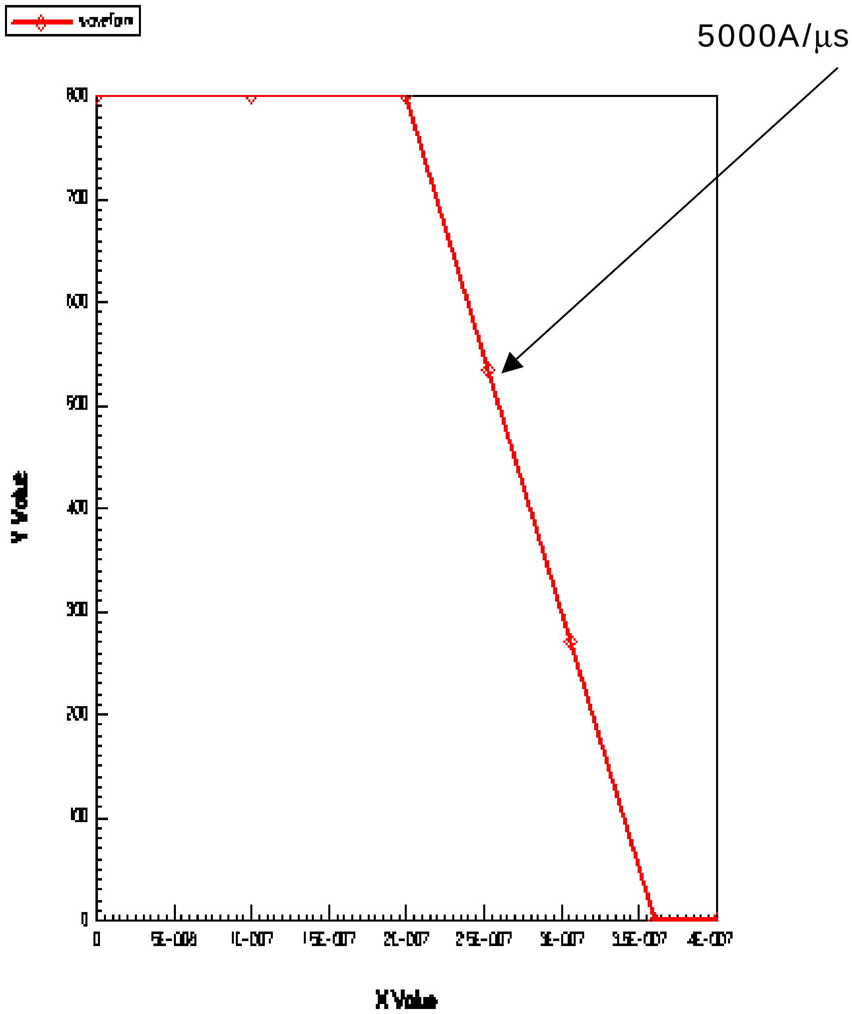


Figure 1: Input Current Profile

Power Module Modeling Case Studies

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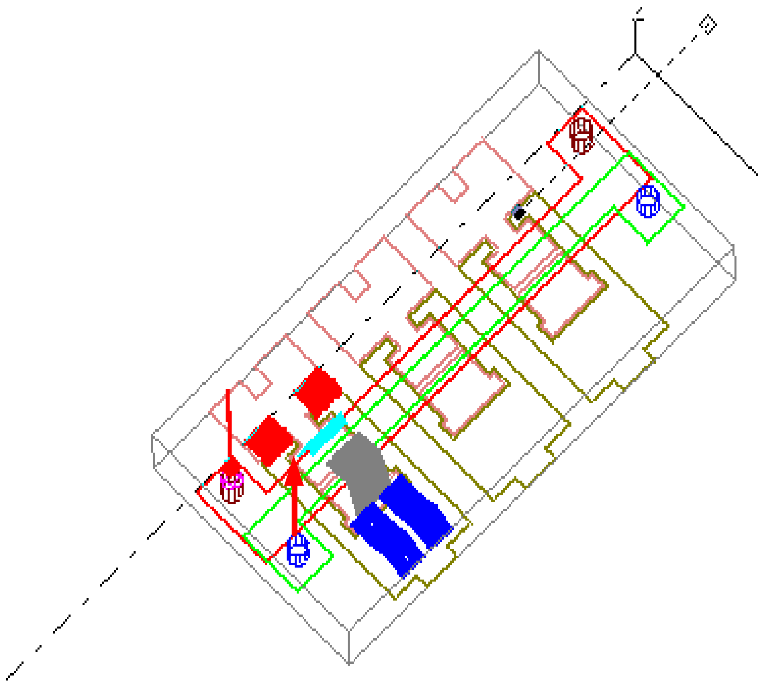

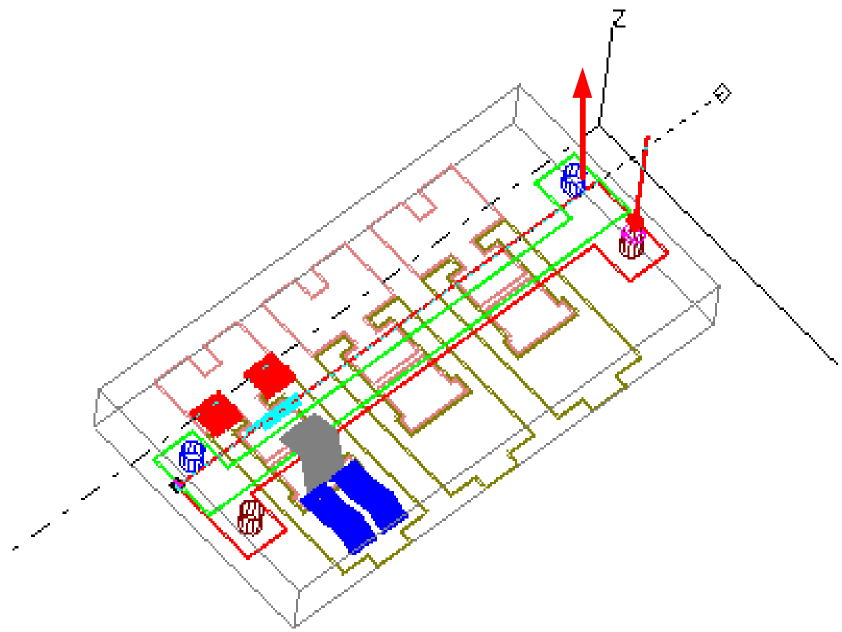

- **Case 1: Bottom IGBT Switching; Current source closest to bondwires**
- **Case 2: Bottom IGBT Switching; Current sources furthest from bondwires**

Power Module Modeling Case Studies

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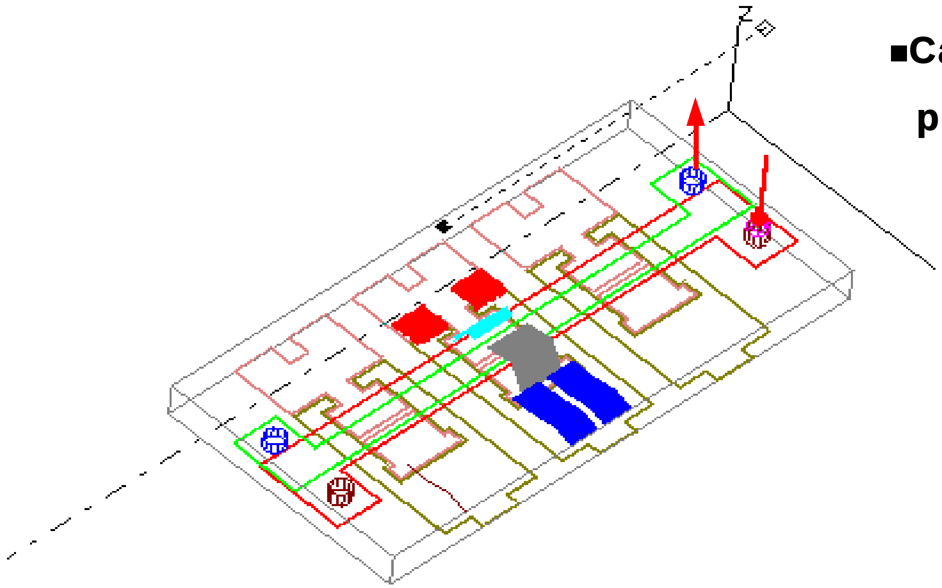
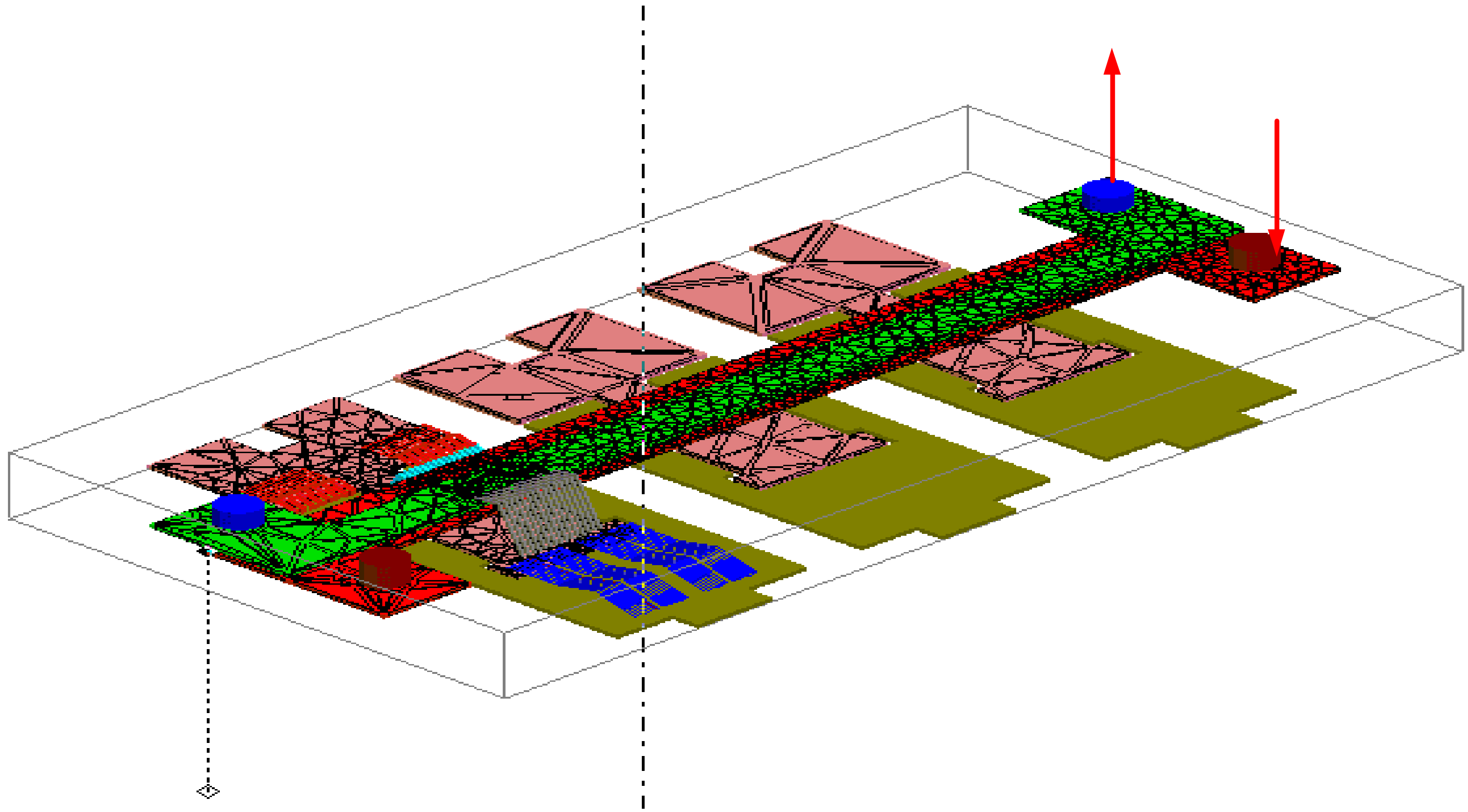


■Case 3: Current flow through 2nd power modules

- Bottom IGBT Switching, Current flows along the copper busbar, down the bondwires (opposite to the connector) to copper plate, through the diode, through the bondwires to the other copper plate, through the IGBT switch and up the bondwires back to the copper busbar.
- Devices and diodes are not modeled; replaced by wires
- Transient solver
- Inductance = flux linkage / current
- Alternatively, Inductance = Energy*2 / (I^2)

High Mesh Density

- Mesh created using the eddy current solver
- Frequency of 2 MHz
- 130K tetrahedra elements (case 2)



Measured versus FE Simulation

	Measured	FE	FE(high Mesh Density)
■ Case 1	21 nH	31.5nH	27.4nH
■ Case 2	26 nH	46.4nH	48.6nH
■ Case 3	23.5nH	38.5nH	37.7nH

Power Module Modeling: Conclusion

- Increased mesh density helps to improve inductance determination but not all the time
- FE calculated inductance 50-80% higher than measured values
- Any suggestions to obtain more accurate inductance values?