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The logo consists of a blue stylized "U" with a plus sign inside, followed by a blue stylized "P".

WHITE PAPER

ULTRACAPACITOR SOLUTIONS TO ADDRESS ENERGY STORAGE NEEDS OF VEHICLES

Document Number: 3003457

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MAXWELL TECHNOLOGIES WHITE PAPER:

Distributed Ultracapacitor Modules to Address Power and Redundancy Needs of Vehicles



As the electrification of automobiles continues to accelerate, the need for a safe, reliable, high-power energy storage technology is greater than ever. Maxwell Technologies' line of DuraBlue® and AEC-Q200 qualified ultracapacitors are ideally suited to meet these demands with their wide operating temperature range, industry leading cycling capabilities, long lifetimes, and rapid charge/discharge capabilities.

Ultracapacitors have long been used in Voltage Stabilization Systems (VSS) for Internal Combustion Engine (ICE) Stop-Start applications. By providing additional voltage support during a high-current cranking event, voltage levels are maintained to allow proper operation of accessories without interruption and enable proper operation as battery state-of-health declines. The nearly five million Stop-Start systems in use today include vehicles such as the PSA 308 and other diesel platforms, the Cadillac ATS and CTS vehicles, and Lamborghini's Aventador. Toyota used ultracapacitors in their highly successful LeMans TS040 racing vehicle. With continued pressure on automotive OEMs to reduce CO₂ emissions, the Stop-Start system has become a standard feature, not just an upgrade option.

Major automobile OEMs such as GM, Ford, Stellantis and others have aggressive targets of 40-50% Battery Electric Vehicle (BEV) sales by 2030. To meet these goals there is heavy investment in electric drivetrains as well as redesigns of nearly all electronic systems in the vehicle. Experts expect \$330B to be spent on vehicle electrification over the next five years.

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Examples of applications where Ultracapacitors are being used include:

- Circuits to enable recessed door handles to pop out in case of an accident or loss of power. Having a stored burst of high power available to open the door from a secondary energy source, an ultracapacitor, is not only practical but also a safety feature that can save lives.
- Accessory power applications:
 - Electronic Power Assist Steering (EPAS)
 - Electronic Power Assist Braking (EPAB)
 - Power Liftgate and Plow features
- In autonomous driving vehicles where an emergency backup energy source is required, ultracapacitors can provide the short duration power needed to get the vehicle to the side of the road in the event of a failure of main drivetrain power.
- Body electrical systems including door, seat, window, trunk and other electrically actuated subsystems.
- Customer amenities such as electrically driven air-conditioning, quick heat for seats, steering wheel, and passenger cabin.

Many of the automotive safety critical loads are typically short duration, high power loads. Powertrain functions such as power boosting and energy recuperation as well as body electrical systems are medium term loads. While batteries are ideally suited to deliver energy for long-term events such as cabin air conditioning during the idle-stop mode of a stop-start system, they are not designed to satisfy the most important requirements of short- and medium-term loads: to provide bursts of power in the seconds time frame over many hundreds of thousands of cycles.

Ultracapacitor Technology

Compact in size, Ultracapacitors can deliver much higher peak power compared to batteries and store an incomparably higher amount of energy than conventional capacitors. Ultracapacitors from Maxwell Technologies offered under the trademark DuraBlue® are currently available on the market in larger cylindrical cells with capacitance up to 3000 Farads. These cells incorporate advanced shock and vibration technology, and when combined with Maxwell's patented electrode formulation and manufacturing process, result in a product line specialized for the most demanding requirements of the transportation industry.

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The test standards for Maxwell's DuraBlue® product line are IEC 60068-2-27 for shock and ISO 16750-3, Table 12.

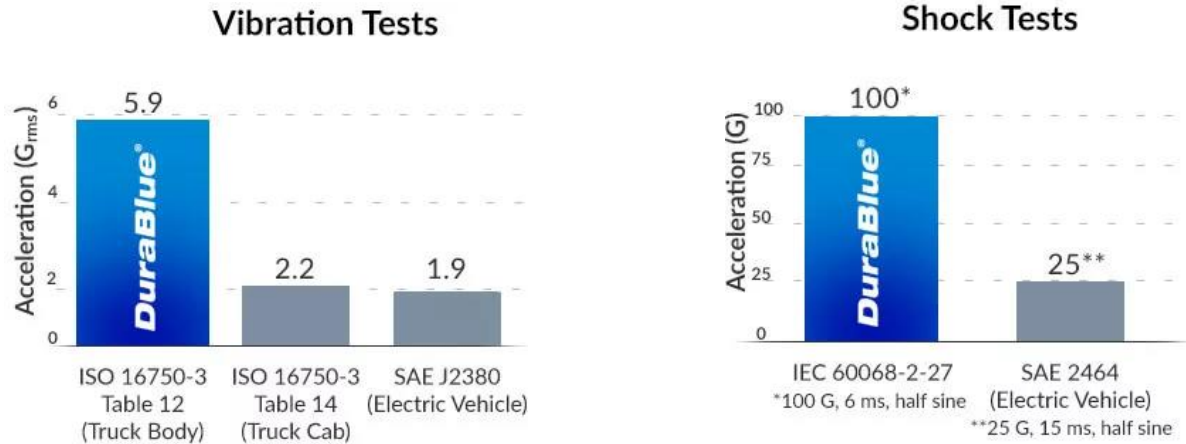


Figure 1: Maxwell DuraBlue® Vibration and Shock comparison to industry standards

The acceleration for IEC 60068-2-27 is 100 G, four times higher than the acceleration of SAE 2464, the test standard for competitor ultracapacitor cells. The RMS acceleration for ISO 16750-3, Table 12 is 5.9 G_{rms}, three times higher than SAE J2380 with an acceleration of 1.9 G_{rms}.

For applications requiring a smaller form factor Maxwell has developed the BCAP325 cell. A high-power cell with ultra-low Equivalent Series Resistance (ESR), it is ideally suited for automotive applications. The cell is AEC-Q200 qualified and provides one of the longest lifetimes available in the industry. Other features include:

- Small 33mm form factor
- 1 million cycle capability
- PCB mountable
- Compliant to UL, RoHS, and REACH standards

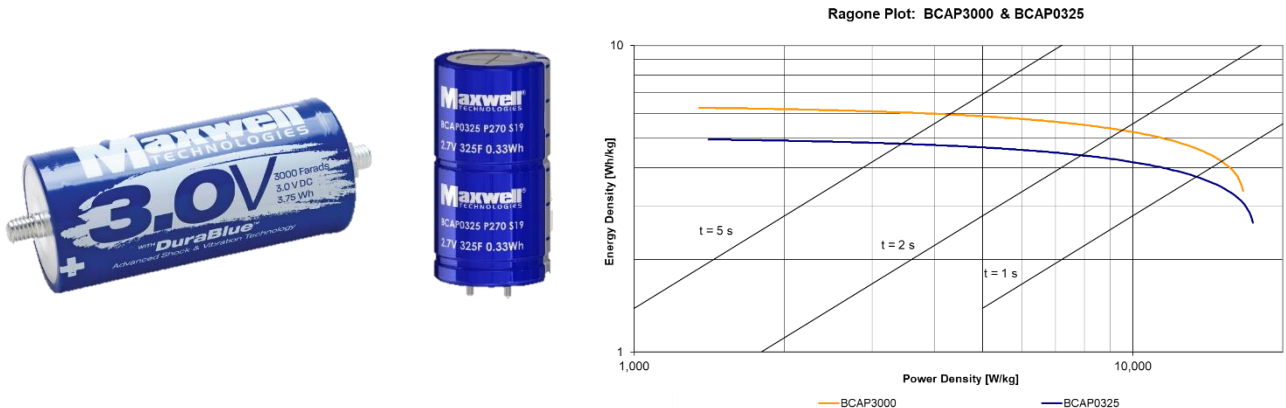


Figure 2: Maxwell BCAP3000 BCAP0325 Cells and Ragone Plot

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Safety-Critical X-by-Wire Applications of Distributed Power Modules

An electrical system architecture with modular and distributed power modules is one method of addressing the need for power and redundancy required by the safety-critical and security systems in automotive applications. Distributed ultracapacitor modules alleviate electrical distribution system voltage sag and transients by supplying peak power locally, while requiring only the average power from the vehicle's primary power system. This essentially decouples the high transient power load from the vehicle's power supply system.

A further requirement of safety-critical applications is the necessity of redundant power supply in the event of loss of the main electrical distribution system branch circuit for x- by-wire functions. Distributed power modules located at critical loads such as the electric power assist steering system offers the vehicle designer additional redundancy for such safety critical applications.

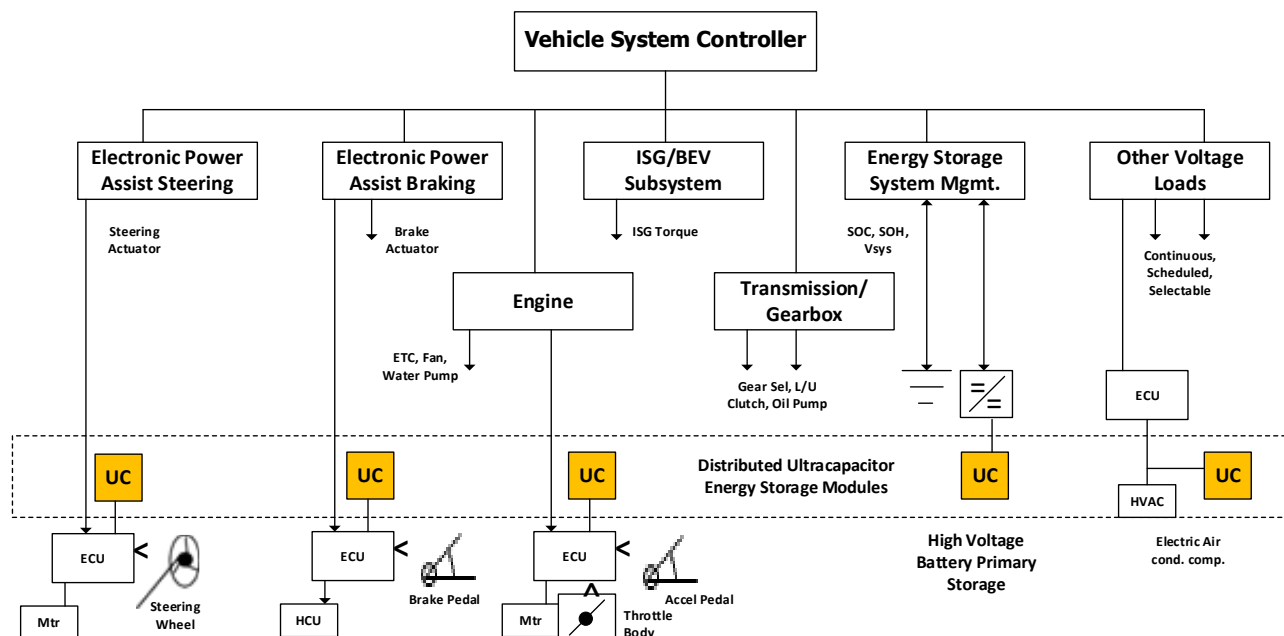


Figure 3: Distributed module architecture for vehicle safety-critical and hybrid functionality

As outlined above and prevalent in the market today, ultracapacitors are an excellent tool for vehicle engineers to use in support of high-power, short-duration loads. With their extremely fast charge and discharge capabilities, unmatched cycling durability, wide operating temperature range, long lifetimes, and environmentally friendly design, ultracapacitors offer many benefits in a small, lightweight package. Visit www.maxwell.com for more information and to view the full portfolio of industry leading ultracapacitor products.

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