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Integrated High Voltage IC

Power Player - page 10

MOSFETs

Power over Ethernet

Energy Measurement ICs

MEMS

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The Evolution of Power Distribution Architectures Continues

Factorized power architecture reorganizes conversion functions

Factorized Power Architecture (FPA) reorganizes the basic power conversion functions _ voltage transformation, isolation, and regulation _ and implements them in IC-style packages. A buck/boost Pre-Regulator Module (PRM) provides a stable voltage from an unregulated DC bus, and a Voltage Transformation Module (VTM) steps the voltage up or down and provides isolation at the point of load.

By Andrew Hilbert, Vicor

With each generation of processor, memory chip, digital signal processor (DSP), and application-specific integrated circuit (ASIC), the trend to lower voltages at higher currents continues to challenge the infrastructure needed to support these contemporary loads. This trend has exposed, in turn, the limitations of known distribution architectures, including Centralized Power Architecture (CPA), Distributed Power Architecture (DPA), and Intermediate Bus Architecture (IBA). The newest of the power architectures _ Factorized Power Architecture _ promises to provide the performance needed to meet these challenges today.

Centralized Power Architecture. The classic CPA, which is simple and cost effective, continues to be applied wherever appropriate. Starting with communications systems applications, however, Centralized Power ran into a brick wall because of its inability to effectively deliver lower voltages at higher currents.

A centralized power supply contains the entire power supply in one housing æ from the front end through the DC-DC conversion stages (Figure 1). It converts the line voltage to the number of DC voltages needed in the system and buses each voltage to the appropriate load. It's cost effective and doesn't consume valuable board real estate at the point of load with the power conversion function. It is fairly efficient because it avoids serial power transformations, and it concentrates the thermal and EMI issues into one box. In the past, the centralized system, usually a custom design, was often chosen because it was the least expensive approach. These systems, in general, work well when the power requirements, once defined, are not likely to change and space is not an issue.

In order to minimize I2R distribution losses, the central supply should be located near the load. For safety and EMI reasons, it should be located as close as possible to the AC entry point. This is often a difficult trade-off.

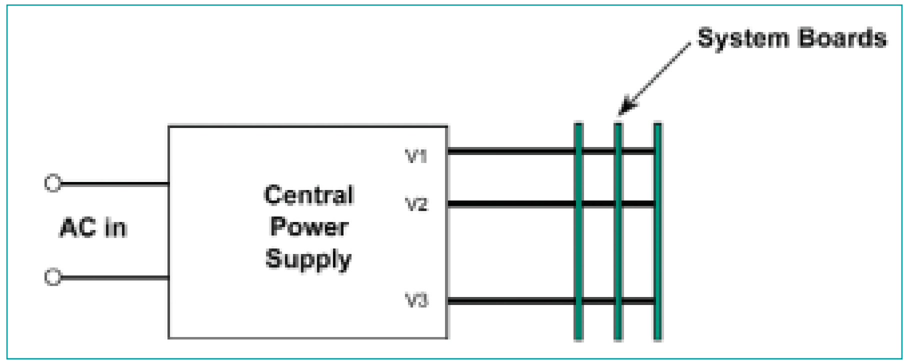

Figure1. A centralized power supply contains the entire power supply in one housing and buses each voltage to the appropriate load.

Although centralized power works well for many applications, it becomes most unsuitable when it is necessary to distribute the hundreds of amps common with low voltage loads today. Centralized power is also not scalable. Many systems can be configured with varying numbers of function cards representing widely varying loads (e.g., line cards in a PBX). With centralized power, the power supply must be sized to handle the maximum configured system, which could put the small configurations at a cost disadvantage.

What's more, the remoteness of the supply from the load negatively impacts its transient response – the ability of the supply to react to rapidly changing loads. Also, thermal management can be a special challenge in a centralized architecture, where excess heat could amount to hundreds of watts all in one concentrated area. Large heat sinks and fans are often needed to keep the power supply from becoming overheated. System hotspots are a source of reduced reliability.

Distributed Power Architecture. As low voltage loads proliferated, bricks and distributed power came of age. Distributed power put DC-DC converter "bricks" on system boards near the loads they were powering. Since the 1980's, the bricks of DPA have delivered the classic functions of the DC-DC converter (isolation, voltage transformation and regulation) to the point of load. But as the number of voltages required at the board level continued to increase, DPA began to take up too much valuable real estate and the cost of duplicating the full converter functionality many times over became too much.

Distributed power is a decentralized power architecture characterized by bussing a "raw" DC voltage, usually 48 or 300 Vdc depending on the power source, which is then converted by on-board DC-DC converters located near the loads they serve. On-board isolated DC-to-DC converters are matched to the load requirement. This helps with dynamic response and eliminates the problems associated with distributing low voltages around the system.

A distributed approach spreads the heat throughout the system, greatly reducing or eliminating the need for heat sinks or high velocity airflow. With temperatures more evenly maintained throughout the system, reliability specifications are easier to meet. Also, since the power is located on the board, configuring system variations and options is much more cost effective than in a centralized architecture, which requires the power supply to be sized for worst-case

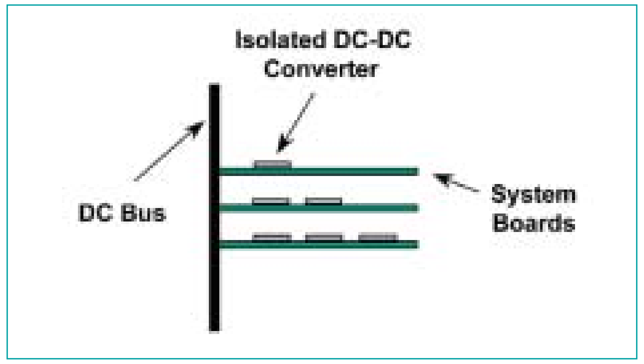

Figure 2. Distributed power is a decentralized power architecture consisting of DC-DC converters located near the load they serve.

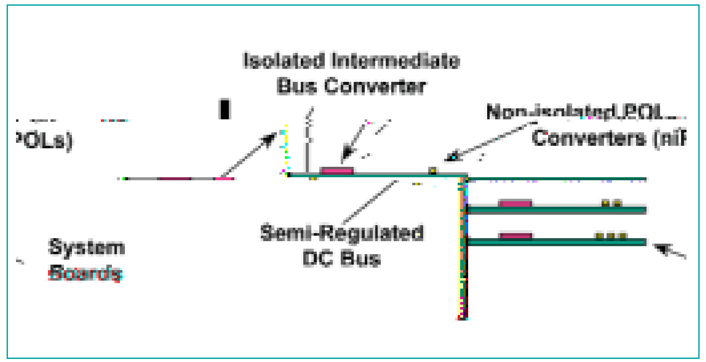

Figure 3.The intermediate bus architecture uses an isolated intermediate bus converter to provide an unregulated voltage to power non-isolated and relatively inexpensive POL converters.

loading. Redundancy is easy to implement for any critical load by simply paralleling additional DC-DC converters where required.

DPA, however, can also be more costly. Since isolation, regulation, transformation, EMI filtering, and input protection are repeated at every load, as the loads proliferate, both the costs and board area for power conversion increase.

Intermediate Bus Architecture. To deal with the multiplicity of low voltages more cost effectively, IBA relies on non-isolated point of load regulators (niPOLs), reducing the POL function to regulation and transformation. The niPOLs operate from an intermediate bus voltage provided by upstream isolated converters. IBA can be a more cost-effective solution because niPOLs, being non-isolated, are less expensive than complete DC-DC converters. But typical niPOL buck converters are in constant conflict between efficient power distribution and efficient power conversion duty cycle.

The intermediate bus architecture differs from the distributed power architecture in that it converts the raw DC voltage (e.g. 48 or 300 Vdc) to an intermediate voltage, typically 9.6 or 12 Vdc, to feed non-isolated and relatively inexpensive POL converters (Figure 3). The niPOLs are also likely to be smaller and lighter than DC-DC converters, providing the benefits of a small footprint and consuming correspondingly less board real estate. Non-isolated POL converters within the Intermediate Bus Architecture forego isolation and high voltage transformation ratios to improve cost-effectiveness.

The niPOLs of IBA depend upon a bus converter to provide isolation and voltage step-down from the raw DC bus. This is accomplished by the intermediate bus converter, which is usually either a complete DC-DC converter operating from a wide range DC source, or an unregulated IBC operating from a narrow range input. The conversion to the intermediate bus voltage intrinsically reduces efficiency of the system. Also, the intermediate bus converter really does need to be located close to the load, because, even with a 12 Volt intermediate bus, four times the current needs to be moved around the board as compared to a 48V distributed power system, so larger traces or shorter runs are needed.

The 12-Volt intermediate bus is also too high for efficient conversion to low voltage outputs (<2 Vdc) as the transformation ratio becomes too high, and the switch duty cycle becomes too low. Lowering the bus voltage to overcome this limitation simply increases the problems associated with the previous issue.

Since the niPOL includes regulation, it needs an inductor in series with its output. These same low voltage loads generally need fast transient response, but now inertia has been imposed right where agility is most needed. These are the fundamental limitations of IBA when it comes to powering today's sophisticated low-voltage, high-speed loads.

Another disadvantage with niPOLs is their lack of isolation: loads are vulnerable to deadly faults and the entire system is susceptible to ground-loop and noise coupling problems.

Factorized Power Architecture. FPA reorganizes the basic power conversion functions _ voltage transformation, isolation, and regulation _ and implements them in IC-style packages. A buck/boost Pre-Regulator Module (PRM) provides a stable voltage from an unregulated DC bus, and a Voltage Transformation Module (VTM) steps the voltage up or down and provides isolation at the point of load. High-frequency FPA V x I Chips using zero-current/zero-voltage soft switching topologies, offer designers a number of advantages such as small size, high efficiency, low noise and fast transient response combined with extremely high power density (>1,000 W/in3 at the point of load).

Figure 4 shows the FPA modules in a basic arrangement, but the PRM and VTM can be operated alone, together, open loop, local loop, adaptive loop, remote loop, co-located, separated, paralleled, or combined with conventional power conversion devices (e.g., DC-DC converters, point-of-load converters, charge pumps) to achieve the desired power solution.

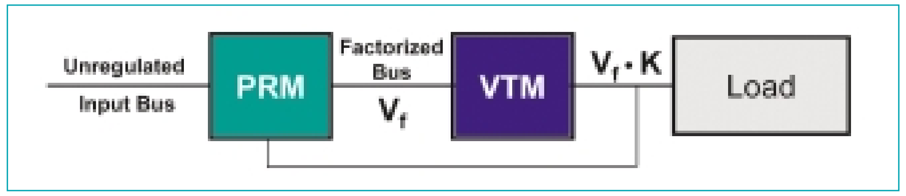

Figure 4. Basic FPA block diagram.

The VTM is enabled by a new class of power conversion topologies called Sine Amplitude Converter (SAC), which offers designers a number of benefits that include, for example, high power density, high efficiency, fast transient response, and low noise.

Characteristics of the SAC that contribute to these benefits and that overcome the limitations of IBA include:

- 3.5 MHz fixed switching frequency. The high switching frequency significantly reduces the size of all reactive components, is very easy to filter, and decreases the response time.
- Zero-voltage and zero-current soft switching. Lossless switching increases efficiency, reducing power losses and heat dissipation. It also reduces _ by as much as an order of magnitude _ dV/dt and dI/dt, resulting in low noise.
- Minimal serial energy storage (no output inductor). There is no power loss associated with an output inductor, a loss element in a typical converter. There is no current inertia to overcome, contributing to very fast dynamic response.
- 100% switch duty cycle at any transformation ratio. The high duty cycle results in efficient power train utilization.
- Bi-directional power processing. Load dump energy is recycled to the input, improving transient response.
- Capacitance reflection and multiplication. This SAC characteristic results in high effective point-of-load capacitance without the physical presence of bulk capacitance.
- Power train symmetry. Symmetry produces cancellation of common mode noise.

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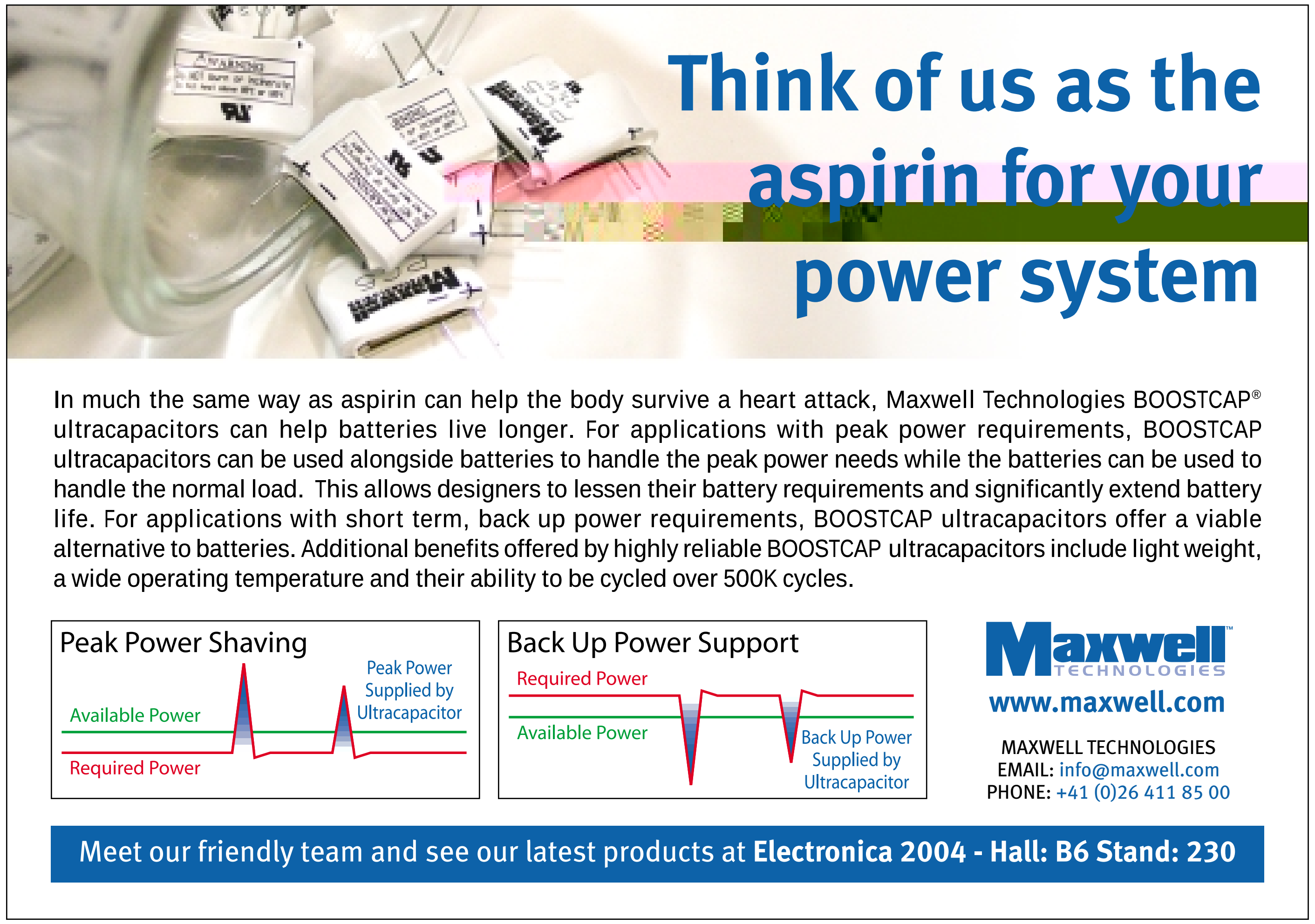

POWER Micro-Electro-Mechanical Systems (MEMS)

Innovative design for ambient vibration scavengers

Key elements of the future intelligent environment are wireless autonomous sensors, embedded in numerous objects and constituting an entire network. Both low-power electronics and energy-scavenging devices are necessary to realize this vision of autonomous sensor nodes.

By Els Parton, Tom Sterken and Paolo Fiorini, IMEC Leuven

Vibration energy can be harvested from the ambient using MEMS technology. These MEMS vibration scavengers are expected to generate power density levels in the range of 100 µW/cm_ to 1 mW/cm_. Recently, prototypes were developed based on an innovative design using electret layers. This concept ensures high-voltage operation and eliminates the need of any voltage source in the scavenger.

Small, smart, autonomous

The ever continuing scaling of transistor dimensions has led consumer electronics into a world of portable devices. Whereas these devices rely on batteries, this will not be an option for the next generation of applications: small wireless computing and communication devices embedded in our surroundings and even in our body. It is not feasible to replace depleted batteries in medical implants, embedded sensors (for example in buildings) or elaborate networks of miniaturized sensor nodes.

The solution lies in energy scavenging from the ambient. The evolution towards low-power electronics compensates for the small power density of this type of energy source. The best-known and most mature energy scavenging devices are solar cells, transforming light energy into electrical energy. On a sunny day this system can realize a power density of 15,000 µW/cm_. However, less than 10 µW/cm_ is available when used indoors. Another option is the use of thermal energy. Experiments showed that thermo-electrical power generators are able to output 15 µW/cm_ from a 10°C temperature difference. Again, this type of energy source is not available for many applications envisaged. Mechanical energy on the other hand is amply available in the environment, be it as strain or vibrations. Vibration-rich environments include spaces with industrial equipment, small household appliances, heating and cooling ducts in buildings, automobiles and aircrafts. Researchers expect power densities in the order of 100 µW/cm_ from this type of ambient energy source.

Scavenging vibration energy

Most vibration-scavenging devices are based on Newton's law of inertia and use the relative movement of a mass, suspended by a spring, as compared to the frame to which the spring is attached. There are different methods to convert this relative movement into useable electrical energy, illustrated in electromagnetic, piezoelectric and electrostatic vibration scavengers. Electromagnetic vibration-to-electricity converters connect the mass with a magnetic material and combine this with an inductive coil. Movement of the mass is translated to a flux change in the coil. A second option is the use of piezo-electric vibration converters based on a beam of piezo-electric material to connect the mass with the reference. Movement of the mass results in beam stretching, creating a dielectric displacement across the beam. Finally, electrostatic vibration scavengers make use of variable capacitors between the mass and the reference mass. When the mass moves, the overlapping area between the parallel plates of the capacitor changes and thus the capacitance changes, a factor capable of generating an electrical current in an external circuit.

Choosing between these three conversion mechanisms is easily done