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FEATURE POWER ARTICLE

Second Generation DC-DC Converter Modules Improve Power Density, Reliability, and Cost per Watt

Steve Montminy, Vicor, Andover, Massachusetts

Second generation dc-dc converters combine fundamental architectural improvements, functional enhancements, and high levels of silicon integration to achieve increased power density, lower noise, higher efficiency, improved reliability, and lower cost per watt.

Great strides in performance and cost have been made in moving from first to second generation dc-dc converter modules. Both first and second generation modules use zero current switching (ZCS), quasi-resonant, single-ended forward converter topology. In a single-ended forward converter, the energy is transferred from the source to the load during the "on" time of a single solid-state switch, a MOSFET Integrated Power Device (IPD). A quasi-resonant converter, unlike a resonant converter, has a unidirectional flow of energy from the source to the load, which optimizes the efficiency and power density of the conversion process. Both genera-

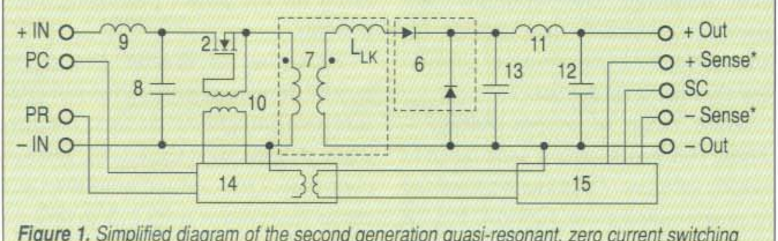

Figure 1. Simplified diagram of the second generation quasi-resonant, zero current switching converter.

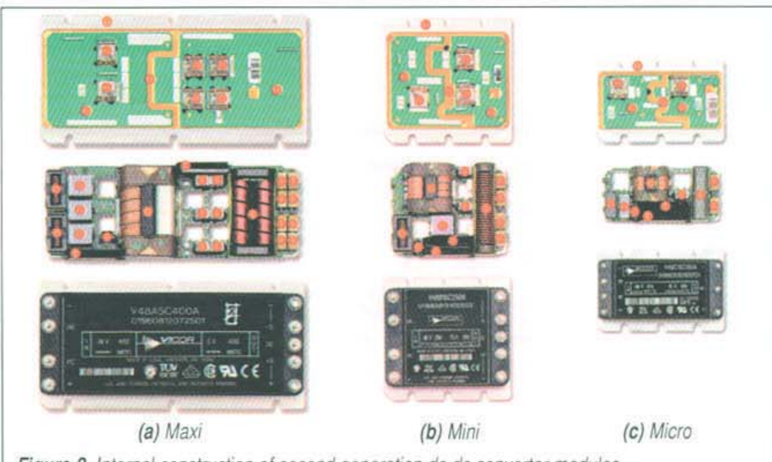
(a) Maxi (b) Mini (c) Micro

Figure 2. Internal construction of second generation dc-dc converter modules.

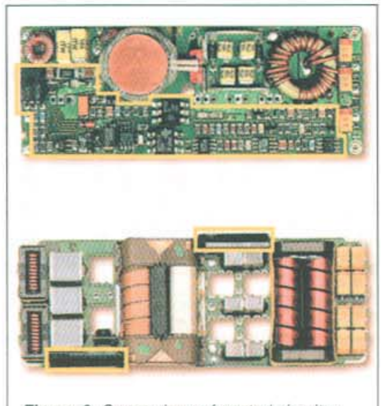
Figure 3. Comparison of control circuitry footprint (outlined in yellow) of a full-size "brick" in first generation (top) and second generation converters (bottom).

tions also incorporate a patented transformer active reset circuit that facilitates zero voltage switching (ZVS) of the MOSFET IPD. ZCS combined with ZVS virtually eliminates all switching losses in the MOSFET IPD. A simplified diagram of the second generation topology is shown in *Figure 1*, and details of the high-density modular components are in *Figure 2*.

Attributes of the converter – efficiency, power density, noise, cost – are largely determined by the power train topology (e.g., the ZCS, quasi-resonant conversion scheme). Second generation dc-dc converters, benefiting by an extreme reduction in the space required by control circuitry, provide the desired attributes. *Table 1* lists the features of the second generation.

Higher temperature rating: Baseplate operating temperatures of 100°C, with low internal temperature rise, are possible with these converters due to advances in thermal design, new materials development, and assembly processes that include in-line testing and inspection to confirm low thermal impedances.

Wide range of output voltage – These converters offer a wide range of output voltages. They can be adjusted or programmed from 10% to 110% of the nominal output voltage using fixed resistors, potentiometers, or voltage DACs. A 12V output, for example, can be trimmed over the range of 1.2V to 13.2V.

Parallelable: Second generation converters are parallelable and feature a patented N+M fault tolerant architecture. One module in a parallel array will automatically assume control at start-up, and the other modules will synchronize to it. Modules communicate with high-speed pulses over a primary-side bus. In the unlikely event that the controlling module fails, another module will automatically be elected master and the system will continue operating without interruption.

Control Elements

Among the design objectives for the second generation were higher power density, improved heat and noise management, higher reliability, and enhanced manufacturability. One of the keys to achieving these objectives was integration of the control circuitry in silicon and use of the space saved for the power processing components.

Packaging of second generation control functions and active circuitry into two integrated circuits, occupying a volume of only $1/10\text{in.}^3$, which contributes to a reduction of the total component count from 113 to only 35 (*Figure 3*).

The entire control function for second generation converters is contained within two "integrated control devices" (ICDs) or "brains," one on the primary side and one on the secondary. The resultant reduction of the total parts contributes to a reduction in cost per watt up to 50%.

The primary and secondary brains are molded in epoxy and include a copper plate that is soldered directly to the baseplate. This provides a very low thermal impedance path to the baseplate for improved cooling. In addition, because the brains are molded in an epoxy as a separate component, they can undergo environmental screening and electrical conditioning well beyond conditions likely to be met in an actual application. After extensive tests are performed on a mixed signal tester, every brain is burned in and temperature cycled from -65 to +125°C, while being continuously tested over worst-case electrical conditions.

Besides the dramatic savings in space resulting from integration, the brains provide an order of magnitude greater functionality than that of first generation control circuits. In the secondary control IC, for example, patented adaptive loop compensation provides consistent crossover frequency and stability margins over the entire operating line and load ranges. In first generation modules, seven components were used to compensate

the feedback control loop; in second generation converters, there are only two.

An integrated multiplexed MOSFET driver is another example of improved functionality. The driver is located directly on the MOSFET IPD and provides an efficient and effective means of charging and discharging the gate of the MOSFET. Logic in the driver interprets incoming pulses of varying widths to determine the desired MOSFET on-time. The driver looks like a low impedance in the forward direction, enabling the gate to be charged non-dissipatively, and looks like a very high impedance in the reverse direction, until directed to discharge the gate. The short turn-on pulse reduces the required size of the pulse-coupling transformer by a factor of five.

Optical couplers, used in first generation converters to convey information across the isolation boundary from secondary to primary, exhibit variations in gain with time and tem-

ITEM	FUNCTION	MAXI V48A5C400A	MINI V48B15C250A	MICRO 48C12C150A
1. Baseplate	Provides mounting, mechanical rigidity, and heat spreading.	Aluminum 6063T-5	Aluminum 6063T-5	Aluminum 6063T-5
2. MOSFET IPD(s)	The main switch with common drain for low conducted and radiated noise.	Quantity-2 111°C(175°C) $\theta_{j\text{-}bp}$ = 2.1°C/W 81V (100V)	Quantity-1 112°C(175°C) $\theta_{j\text{-}bp}$ = 2.1°C/W 79V (100V)	Quantity-1 106°C(175°C) $\theta_{j\text{-}bp}$ = 2.1°C/W 77V (100V)
3. Primary shield	Heat-spreader that lowers thermal impedance from MOSFET to baseplate. Also, EMI shield to reduce conducted and radiated noise.	Clad Aluminum	Clad Aluminum	Clad Aluminum
4. Insulator	Provides electrical insulation between primary and secondary circuits and baseplate.	Polyimide	Polyimide	Polyimide
5. Secondary shield	Heat-spreader that lowers thermal impedance from rectifier to baseplate. Also, EMI shield to reduce conducted and radiated noise.	Clad Aluminum	Clad Aluminum	Clad Aluminum
6. Rectifier IPD(s)	Dual diode output rectifier.	Quantity-4 123°C(150°C) $\theta_{j\text{-}bp}$ = 2.22°C/W 21V (35V)	Quantity-2 115°C(150°C) $\theta_{j\text{-}bp}$ = 2.55°C/W 52V (100V)	Quantity-1 123°C(150°C) $\theta_{j\text{-}bp}$ = 2.55°C/W 52V (100V)
7. Main transformer	Provides primary to secondary isolation.	111°C(240°C)-core 121°C(180°C)-windings	135°C(240°C)-core 132°C(180°C)-windings	129°C(240°C)-core 133°C(180°C)-windings
8. Input capacitor(s)	The "C" part of the input "LC". filter	Quantity-3 Film 48V (100V)	Quantity-1 Film 48V (100V)	Quantity-1 Film 48V (100V)
9. Input inductor	The "L" part of the input "LC" filter.	Quantity-2 105°C (125°C)-core 110°C(180°C)-windings	Quantity-1 105°C (125°C)-core 110°C(180°C)-windings	Quantity-1 105°C (125°C)-core 110°C(180°C)-windings
10. Pulse transformer	Drives the common drain MOSFET	110°C (170°C)	110°C (170°C)	110°C (170°C)
11. Output inductor	The "L" part of the output "LC" filter.	109°C (125°C)-core 112°C(180°C)-windings	108°C (125°C)-core 113°C(180°C)-windings	118°C (125°C)-core 121°C(180°C)-windings
12. Output capacitor(s)	The "C" part of the output "LC" filter.	Quantity-8 Tantalum 5V (10V)	Quantity-4 Tantalum 15V (25V)	Quantity-2 Tantalum 12V (20V)
13. Resonant capacitor(s)	The "C" part of the quasi-resonant tank for this zero-current-switching converter.	Quantity-6 Film 21V (35V)	Quantity-2 Film 52V (100V)	Quantity-1 Film 52V (100V)
14.Brain (primary)	Contains primary ICDs (integrated control devices).	111°C (135°)	109°C (135°)	108°C (135°)
15. Brain (secondary)	Contains secondary ICDs (integrated control devices).	109°C (135°C)	109°C (135°C)	108°C (135°C)

Table 1. *shows details of numbered features. *Senses closed internally on MicroMod.*

(2) MOSFET IPD
(6) Rectifier IPD
(7) Main transformer
(8) Input capacitor
(9) Input inductor
(10) Pulse transformer
(11) Output inductor
(12) Output capacitor
(13) Resonant capacitor
(14) Brain (primary)
(15) Brain (secondary

perature. Second generation converters use an integrated, small magnetic air core "pulser" – a pulse transformer – providing higher isolation, better temperature stability, and wider bandwidth.

Also, a patented "lossless" current limiting technique is integrated in silicon and uses only two small external components to set the current limit value. This is in contrast to first generation products that use a conventional resistance shunt to sense current and a comparator reference amplifier to implement the current limiting function.

Plated-Cavity Transformer

The patented second generation transformer consists of proprietary plated-cavity cores that couple widely separated primary and secondary windings. Wide separation of the windings reduces parasitic capacitance and produces lower noise, and the plated armor confines the magnetic flux.

The plated-cavity design helps conduct heat away from the transformer, increasing the power train's power handling capability. Open construction of the transformer also provides a better thermal path to the baseplate. These advancements not only produce better thermal and noise performance, but higher reliability and lower cost as well.

In the "full-brick" version of the module, the power transformer has the same 0.5 cm^2 cross-sectional area as the comparable first generation module, but it has a substantially longer magnetic path length that results in a larger winding area. Resistances are lower, so winding power losses are lower.

Separation of the windings maintains low interwinding capacitance, but, in the absence of the core plating, it would lead to high leakage inductance. The copper armor plating is formed in a particular pattern to confine the leakage flux and produce a very low leakage inductance. Then, the required leakage inductance is "built-up" by inserting a "leakage lug" of appropriate permeability into the transformer.

Plating also facilitates heat sinking the core. Copper "core coolers" – heat sinks – are attached onto the ends of the cores and attached to the baseplate to remove heat. The significantly improved thermal performance provided by the core coolers is one of the enabling technologies for increased power density. The transformer can process over 600W, resulting in a transformer power density greater than 1000 W/in.^{3}, with only a 30°C to 40°C rise in temperature, depending on the module design.

Switching Elements

Power semiconductors are mounted to a low thermal resistance ceramic package. The MOSFET IPD includes the main switch and its driver in a common drain configuration for low conducted and radiated noise. The MOSFET and rectifier IPDs are soldered to 20 mil thick, thermally conductive primary and secondary shields, inset within a grounded aluminum base. Both baseplate shields function as heat spreaders to lower the thermal impedance from the MOSFET (primary) and the rectifier (secondary) to the baseplate. The shields also help reduce conducted and radiated noise.

The thermal path from the MOSFET was reduced by eliminating a number of interface layers. The shorter path helped reduce the thermal impedance from junction to baseplate by 50% when compared with first generation units.

Module Packaging

Each package size – Maxi, Mini, and Micro – has four baseplate options, two pin sizes, and a wide range of mounting options. The power train p. c. board assembly is mounted between the baseplate and a "terminal block assembly" comprising the outer package and the pins. Input and output pins are recessed to provide volumetric efficiency and mounting flexibility. The pins can be either wave soldered or plugged into new very low resistance "Surfmate" sockets. For on-board mounting, very low resistance socket headers are also available.

Modules feature a stepped profile that allows them to be recessed into a board cutout for an above-board height of only 0.43-in. In-board mounting also offers the advantages of exposing the underside of the module to air flow for more effective heat removal.

References

1. U.S. Patents 4,415,959; Re036098; 5,546,065; 5,659,460; 5,555,165; 5,490,057 and other U.S. and foreign patents and patent applications, assigned to VLT Corporation.

Component Solutions For Your Power System

25 Frontage Road
Andover, MA 01810
Tel: 978 470 2900
Fax: 978 475 6715
www.vicr.com

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