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Modular Converters Speed Power Designs

Though Easy To Use, Modular DC-DC Converters Must Still Be Chosen Carefully To Get A Jump On Noise, Heat, And Safety Issues.

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Modular dc-dc converters, in numerous standard designs, provide reliable, field-proven, power solutions. While users can easily specify inputs, outputs, and power levels, the main advantage of these devices is that a user need not be an expert in power conversion to design them into a pc-board application. Their successful use, however, does require the designer to carefully consider noise, heat, and safety issues. In addition, the design choices made by dc-dc converter manufacturers can have a profound impact on the modules' design-in process. This makes it imperative that the designer select carefully among these relatively standard products.

These issues have always been at the forefront of power-system design. However, user demands for higher power densities, higher efficiencies, and smaller packages continue to raise the ante.

The main and most obvious reason behind opting for a modular solution is design simplicity. A complete power system using modular components can be implemented with an ac-dc front end, dc-dc converters for each of the outputs needed, and a few discrete components. More output voltages can be obtained with additional dc-dc converters and filters. A simplified set of inputs and outputs is all a designer needs to consider.

With thousands of dc-dc converters and multiple manufacturers to choose from, the process of selecting the right module can be a major challenge. What's more, each supplier is, of course, seeking a competitive edge. As a result, one supplier provides the highest efficiency, another the smallest footprint, and yet another a new high for power density, and so on. Unfortunately, each achievement likely comes with trade-offs elsewhere in the specification.

Noise And Topology

Noise can vary widely among converters from supplier to supplier and model to model. The reasons range from the fundamental technology employed, to simple differences in design choices, to variations in intended applications.

Many converter topologies are used to produce the output voltage, power, and regulation needed by electronic equipment. These topologies reduce to essentially two classes—pulse-width modulation (PWM) and quasi-resonant designs, such as zero-current-switching (ZCS).

In switch-mode converters, common-mode conducted noise is a function of the dv/dt across the main switch in the converter, and the effective input-to-output capacitance of the converter. It's not always easy to identify the specific noise generator, so here are some typical sources, derived from real-life modules:

Topology: Noise is highly dependent on the topology. A PWM topology, for example, often produces noise at high frequencies (above 5 MHz). The most likely source of that noise is construction-method parasitics generated by the high dv/dt and di/dt associated with this topology. Components such as diodes and MOSFETs generate heat, so they are mounted on an insulating ceramic substrate, which is mounted to the aluminum baseplate of the module. Because ceramic is a dielectric, there is capacitance from the diode and the FET to the baseplate. So, while this construction facilitates heat removal, it also produces parasitic capacitance, which generates noise.

Switching harmonics: Multiples of the 300-kHz switching frequency up to 9 MHz—or 30 times the switching frequency—have been found in some modules. Such converters, used with a typical EMI filter, have been known to fail VDE0871 B requirements for conducted noise.

Packaging and circuit-design: High capacitive coupling, common in metal pc boards and planar-transformer designs, can produce noise as much as 25 times higher than a typical module. Although isolation is normally thought of as a safety issue, the high capacitive coupling associated with nonisolated converters, or those with low isolation voltage, also contributes to higher system noise.

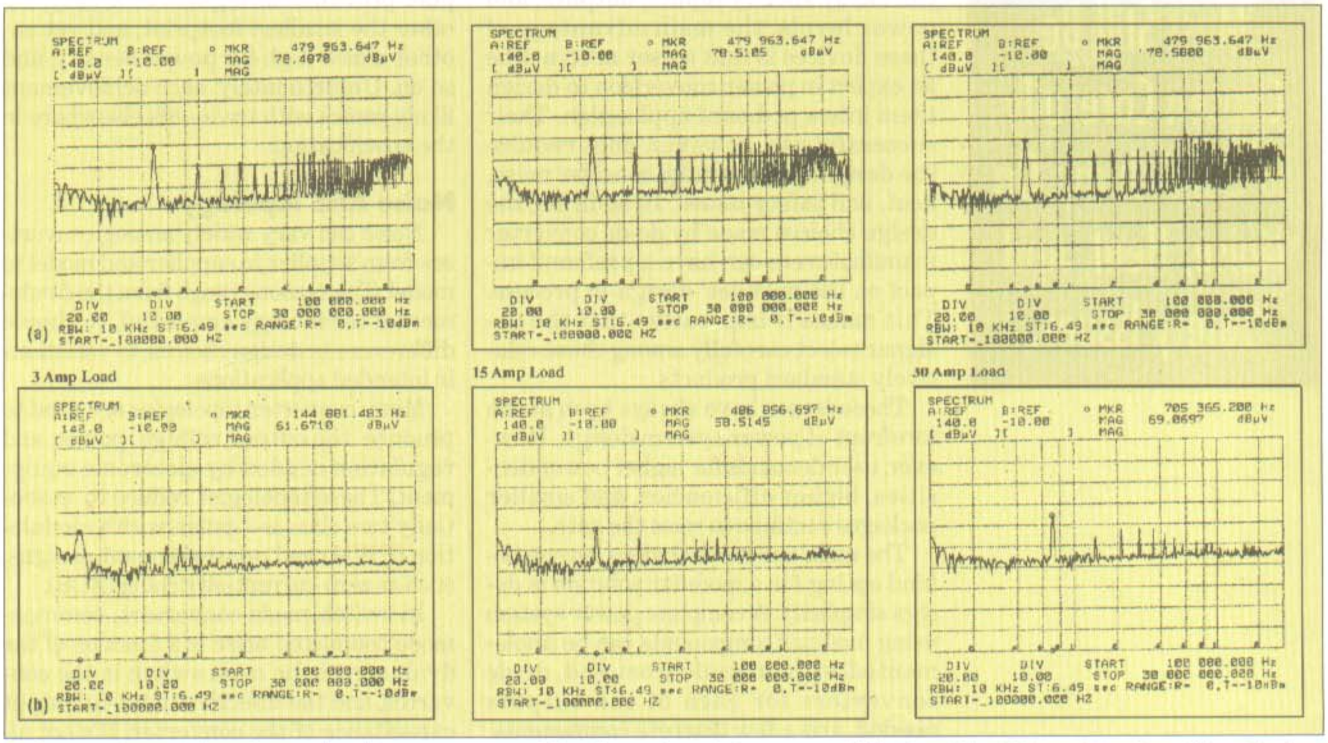
A comparison of the noise produced by converter modules of different design is shown *(Fig. 1a and 1b)*. The fundamental comparison in this case is technological: one module employs pulse-width modulation (where the frequency is fixed and the duty cycle is variable) *(1a)*, while the other uses a quasi-resonant topology (where the pulse-repetition rate is variable) *(1b)*.

A partial explanation for the difference in noise is the relative ease or difficulty with which each topology filters harmonics of its pulse-repetition rate or operating frequency. In PWM converters, most of the energy is found at the fixed frequency or at an odd harmonic of it. A 100-kHz PWM converter will have most of its conducted noise at 100 kHz, and some at 300 and 500 kHz. They also have significant harmonics at or above 1 to 2 MHz due to non-zero-current-switching (high di/dt). The input conducted filter has to be sized to handle maximum power at 100 kHz.

Quasi-resonant converters simplify the design of the conducted line filter because the energy that needs to be filtered is spread between 1/T2 (where T2 is the pulse repetition rate) and approximately 2 MHz. For example, if the converter is operating at its maximum frequency of 1 MHz, all of the energy is contained in a narrow band. This band is easily filtered due to its high frequency. If the converter is operating at a relatively low 100 kHz, the energy is spread between 100 kHz and 2 MHz. In the case of energy spread, for example, by a factor of 10, the peak amplitudes of the harmonics are reduced by a factor of 10.

Thermal Management

Thermal management can be a challenge in any system, but manufacturers of modular dc-dc converters can employ a range of strategies to cope



1. A comparison of the noise produced by converter modules shows the relative ease or difficulty with which each topology filters the harmonics of its pulse repetition rate or operating frequency. In PWM converters (a), most of the energy can be found at the fixed frequency or an odd harmonic of it. These converters also have significant harmonics at or above 1 to 2 MHz, due to non-zero current switching (high di/dt). The quieter, quasi-resonant converters (b) simplify the design of the conducted line filter because the energy that needs to be filtered is spread between 1/T2 (where T2 is the pulse repetition rate), and is approximately 2 MHz.

with the unavoidable generation of heat. All, of course, strive to make their modules as efficient as possible, and design their packaging to manage the generated heat. High operating efficiency minimizes heat loss, while the use of electrically isolated, low-thermal-resistance interfaces facilitates the removal of heat.

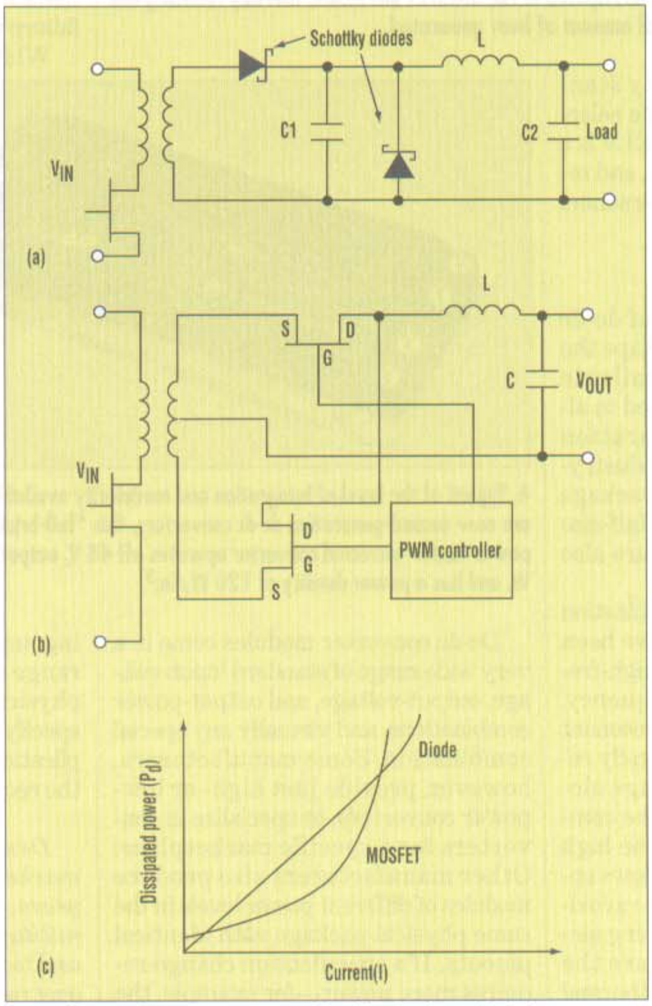
A distributed approach (rather than a centralized architecture) spreads the heat throughout the system, minimizing the need for heatsinks or high-velocity airflow. With the temperature more evenly maintained throughout the system, reliability specifications are easier to meet. Most modular dc-dc converters are well suited for use in distributed power systems.

As you might expect, the heat problems faced by designers using modular components also depend on the many design decisions made by suppliers. These decisions can include design approach (PWM versus quasi-resonant), packaging (potted versus removable plastic cover), component selection (Schottky diode versus MOSFET), material (ceramic versus insulated metal substrate), and many more.

By way of illustration, one such choice is whether to use diode rectification or synchronous rectification. Diode rectification uses a Schottky diode, which has a small resistance and an essentially constant voltage drop *(Fig. 2a)*. Consequently, the dissipated power is roughly proportional to the current through the diode.

Synchronous rectification, on the other hand, operates a little differently, with additional cost and complexity. It employs a MOSFET switch, or switches, to accomplish rectification *(Fig. 2b)*. The MOSFET has a small internal resistance called $R_{DS(ON)}$, which is the resistance from the drain to the source when the MOSFET is on. The power dissipated in this case is roughly proportional to the square of the current *(Fig. 2c)*. At lower currents, the MOSFET will generate less heat than the diode until the output current is reduced to a point where the switching or ac losses in the FET again exceed the essentially dc losses in the rectifier. After a crossover point, perhaps about 20 A, diode rectification will generate less heat loss than the MOSFET, and at no load or light loads, ac losses result in lower efficiencies.

Unlike diodes, where the forward voltage drops as junction temperature increases, when the temperature rises in a MOSFET, $R_{DS(ON)}$ increases for the same amount of current. As a result, the power dissipated in the MOSFET increases, thereby lowering efficiency, which increases the heat generated *(Fig. 3)*.



2. Diode rectification (a) uses Schottky diodes, which have a small resistance and an essentially constant voltage drop. Consequently, the dissipated power is roughly proportional to the current through the diode. Synchronous rectification, on the other hand, uses a MOSFET switch, or switches, for rectification (b). Due to the MOSFET's internal resistance, RDS(ON), the power dissipated is roughly proportional to the square of the current (c).

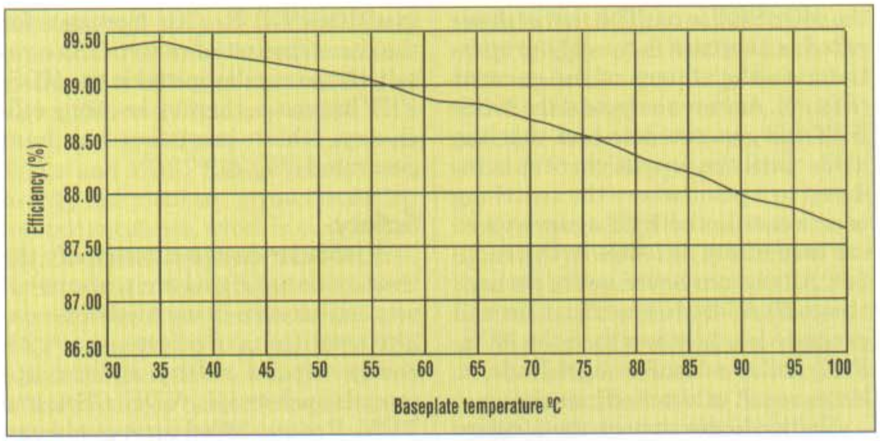
Safety

A modular design can simplify the time-consuming agency approval process because many modules—unlike traditional designs—have already earned safety-agency approvals such as UL, VDE, CSA, and TÜV. Prequalified approvals can shave significant development time and cost from a project.

Isolation, the electrical separation between the input and output of a power supply, is a basic safety issue in the selection process. For ac-input or high-voltage, dc-input systems, isolation is a must to protect the end user from dangerous voltages and currents. Isolated dc-dc converters simplify a design by using internal transformers to supply the needed isolation. Nonisolated converters need an external transformer to reduce the input voltage to a safe level, and provide protection from the ac-line voltage.

A look at data sheets from a number of converter suppliers will reveal that some units have no isolation, some have isolation up to 3000 or 4000 V, and many fall in between. A design, for example, with 500 V of I/O isolation, can have Safety Extra-Low Voltage (SELV) outputs only when the inputs are SELV. An application using such a module would have to obtain its "safety" isolation from some other source, because the module does not provide it. This can add cost, increase space requirements, and reduce the mean-time between failures (MTBF).

Bus voltage is also an important factor. The higher the voltage, the lower the power loss and the smaller the con-



3. Unlike diodes, where the forward voltage drops as junction temperature increases, when the temperature rises in a MOSFET, the device's RDS(ON) increases for the same amount of current flow. As a result, the power dissipated in the MOSFET increases, thereby reducing the efficiency, and increasing the overall amount of heat generated.

ductor size. However, safety standards typically conflict with the selection of a higher bus voltage. SELV is a requirement of most countries, and restricts the voltage to which personnel may be exposed.

Packaging Issues

The modular form factor of dc-dc converters helps a designer shape the power supply to fit the available space. A supply can be designed to almost any physical configuration rather than just a box. The "industry-standard," full-size module package measures 2.4 by 4.6 by 0.5 in. Half-size and one-third-size packages are also available *(Fig. 4)*.

These small modules, in combination with high power densities, have been achieved as a direct result of high-frequency operation. High-frequency, zero-current-switching, quasi-resonant converters do, in fact, dramatically reduce the size of energy-storage elements and, thus, the size of the complete module. What's more, the high efficiency of such converters allows operation in excess of 1 MHz while avoiding energy losses in the switching element. These energy losses are the leading cause of electrical and thermal stresses that undermine reliability.

4. Typical of the level of integration and modularity available in what are now second-generation dc-dc converters, this "full-brick"-sized, power-factor-corrected converter operates off 48 V, outputs up to 600 W, and has a power density of 120 W/in.^{3}

Dc-dc converter modules come in a very wide range of standard input-voltage, output-voltage, and output-power combinations, and virtually any special combination. Some manufacturers, however, provide just high- or low-power converters, or specialize in converters for a specific marketplace. Other manufacturers also produce modules of different power levels in the same physical package with identical pinouts. If a specification change requires more power—for example, the 12-V output now requires 150 W instead of 100 W—a higher-power module can easily be used with a minimum of design changes.

Both potted and unpotted modules are available. Potting, in general, gives more uniform thermal distribution, while also providing improved shock and vibration resistance. All contribute to a more reliable module. Some packaging designs, however, lead to lower-quality, less-reliable modules. The use of trimpots and bonding materials with very different coefficients of thermal expansion, are good examples of undesirable design. Another involves the bonding of large ceramic capacitors directly to the aluminum baseplate. This is a significant failure mechanism.

While the more common, hard design issues revolve around noise, heat, safety, and packaging, less tangible factors, such as technical support, agency approvals, price, and delivery, can often be the key differentiators among manufacturers or suppliers. With time-to-market and cost issues breathing down the necks of most designers, these latter issues cannot be ignored. Leading suppliers are likely to have the range of products and technical and physical resources to help engineers specify the right products for their application, and enjoy timely deliveries of the required volumes.

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