

Application Guidelines for On-Board Power Converters

Abstract

On-board power converter technology has extensively matured over the last twenty years. Converter power levels have increased dramatically.

High-power converters are physically much smaller than their predecessors, achieving higher energy density levels.

This dramatic shift in performance capability did not materialize without added difficulties to the user. To achieve smaller size, converter manufacturers drifted towards much higher operating frequencies and much more complex circuits. In addition, the higher power levels, by their nature, result in higher orders of magnitude of electrical and magnetic noise; and as such, they require much more attention to detail in order to achieve optimum performance levels.

Our objective in this application note is to address fundamental design requirements for the application of these new high-power, on-board converters. Our intent is to assist the user in order to make the development process simpler, easier, and better understood.

Keywords

On-board converters, power modules, dc-to-dc converters, application guidelines.

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Performance improvements and the need to dramatically reduce the time-to-market of new products. Performance improvements are fueled by the adaptation of distributed architectures [1], high-speed devices that require an order of magnitude better regulation than past converters, and an increasing shift toward noise containment down to the board level. To address shorter time-to-market needs, these converters are available as standard products in a large variety of power and voltage conversion configurations. That is why they are typically called power bricks, which, like Lego*, can be stacked in a variety of configurations to meet the desired need.

Although a large choice of standard input and output voltage selections of converters exist, there is a downside. The manufacturer defines the performance and available feature set of the standard. It is important for the user to understand both the performance advantages and limitations of these standard building blocks. On-board converters are designed for multiple applications. As such, they intend to provide commonly needed functions in the smallest footprint and at the lowest possible cost. Consequently, many necessary but unique functions are not provided on these converters and are left for the user to add as desired. Successful addition of these functions is not trivial. It requires dedicated expertise due to the high-frequency characteristics and behavior of these converters. Our intent in this paper is to highlight the many functions required and to provide to the designer application and implement guidelines.

Introduction

The use of on-board converters has been increasing among developers. The drivers of this trend are

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Functional Blocks

Since most on-board converters contain only the basic regulating elements, additional circuitry must be added by the user to provide the desired performance and protection behavior. These circuits are addressed here as functional blocks such as inrush protection, EMI containment, thermal packaging, and additional output filtering. This paper will concentrate on each of these functions in detail. Strict emphasis will also be placed on layout considerations because of its direct correlation to performance. Our experience suggests that excellent performance is dependent on a good layout, and that it is very difficult to compensate for performance degradation caused by a poor layout. Rework is usually the only way to resolve layout-related problems, so concentration on good design practice will be emphasized throughout.

Application Guidelines

For power levels below 30 W, it is not uncommon for the dc-to-dc converter to be designed using variable frequency techniques to minimize cost. The operational frequency is dependent on the resonant characteristics between the power transformer and a few passive components. As such, the operational frequency could vary by an order of magnitude as input voltage or output loading changes. This performance could be highly undesirable for some electronics where certain keep-out frequencies are desired for optimum circuit performance. EMI characterization may also be troublesome, since variable switching speed causes changes in emissions levels. Unless EMI is contained well below desired levels, such variable performance may mean trouble. The good news is that converters in this power range also emit the least noise, so they are less likely to cause performance problems. Nevertheless, it is important to understand the performance limitations of these converters.

Higher-power converters are typically of the constant frequency type, although this is not true of all vendors. It has been our experience that constant frequency converters are much easier to control from the standpoint of EMI filtering and may be much easier to test for performance during system emissions qualification.

Another very important consideration is the module footprint. Many manufacturers design their modules to fit a standard footprint. Although there is no industry standard for mechanical packaging, the standard is typically set by the industry leader or the vendor who has offered his product on the market first. This standard packaging scheme could be very misleading. Nothing is the same within these packages except the footprint, so be very careful. Modules are not interchangeable.

They most likely are designed using different circuit topologies and could exhibit widely different electrical performance. At the least, EMI performance would be different. If interaction is required among the modules, such as for current share, then they cannot be mixed. Careful analysis is always recommended before entertaining interchangeability of modules from different vendors.

Many applications also require multiple voltages/converters for devices. For these circuits, one must give much attention to potential race conditions resulting from rise time differences among the various output voltage levels. These race conditions may cause integrated circuit (IC) lock up or changes in state, producing an undesired output. Lock up is a condition when the IC simply stops performing. Most integrated circuit manufacturers warn in their device data sheets of such potential lock ups. In such conditions, the best design practice does not rely on verifying typical performance derived during initial testing but instead forces the required behavior. Two methods that work are the remote control of some of the modules so that their turn-on is purposely delayed, or, if possible, the provision of a system reset performed well after the output of the power converters reach their stable voltage levels.

Inrush Protection

Most dc-to-dc converters require a large bulk input capacitor for stable operation. (See Stability Considerations section.) The turn-on current transient posed by this input capacitor could be very large, since the equivalent series resistance of high-performance capacitors is in the milliohm range. Unless some form of inrush limiting is deployed, the system could go into a latched current limit during turn-on, performance degradation may materialize during hot plug-in, or protection fuses could blow. Two types of inrush current protection are usually deployed. A series resistor fed by an extended connector pin has been deployed for controlling inrush in hot pluggable environments. Alternatively, a power relay could be used to short out the inrush resistor. The second method utilizes a thermistor in series with the line. Although these methods are inexpensive, they do have a number of fundamental deficiencies. Connector finger contact sequencing leaves the timing of the inrush dependent on rapidity of circuit-board insertion by the craft person. Some of these circuits provide protection only upon mechanical insertion of the circuit board. Thermistors provide protection only during a cold inrush and consume an appreciable amount of energy, thereby appreciably contributing to the converter's inefficiency.

Inrush Protection (continued)

An improved method of current surge protection is the active inrush circuit shown in Figure 1. This circuit relies on the slow turn-on control of a semiconductor for limitation of the transient, and it is highly effective for any power interruption.

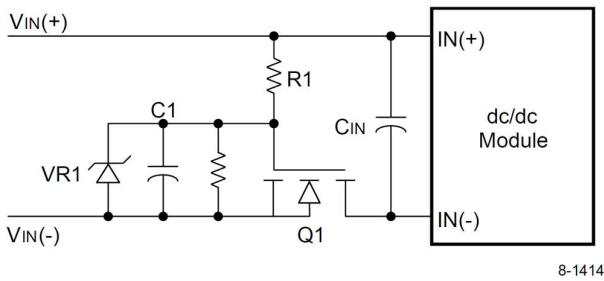


Figure 1. Active Inrush Circuit

However, the rate of saturation of the device does have to be carefully designed into the application. One would perceive that the slower the turn-on, the better the performance. This is not so. Board-mounted power modules typically have a voltage sensor circuit on their inputs that turn off the module if the input voltage falls below a set threshold. If the inrush circuit has a slow time constant, as the input capacitor charges, the voltage across the capacitor gets to a level where the module turns on. As the module turns on, it draws a much higher input current than the capacitor and thus creates a voltage divider between itself and the active inrush. This voltage divider could cause the voltage across the input of the module to fall below the low voltage set point of the module, thus turning it off.

The consequence is the so-called "motor-boating" phenomena, where the module goes through a number of on/ off cycles. What is even more disturbing is the fact that every successive turn on causes a higher inrush surge from the input mains since the active inrush is slowly being driven into saturation. There are two solutions to this problem. First, ensure that the turn-on timing is fast enough to limit the voltage divider action by ensuring that the module turns on far above the point at which the module would turn itself off. Second, control the turn-on of the module via remote on/off.

Current Share

The current share feature may either be included within the module or it may be added externally. If this is an available feature, then typically a single electrical connection ties modules together. For modules without the current share feature, control can be accomplished by regulating the module via the output voltage adjustment pin. Implementation of current share is deployed either for redundancy, reliability, or improved thermal performance. If redundancy is desired, then careful attention must be placed on the design technique of the vendor to determine whether a democratic selection or master/slave technique is employed. In master/slave, one of the modules is the designated master and all others respond to the direction of the master. The major problem with technique is that if the master fails, the entire system goes down. Thus, true redundancy is not achieved. A second type of current share works under the principle of the democratic designation. This method assigns the module with the highest set point as the master, thus controlling the current share bus. Masters can be redesignated as the highest voltage set point changes. True redundancy is achieved because failure of the master causes a reassignment of a new master without service interruption.

Current share accuracy is also a function of layout. Careful attention must be placed on the routing and placement of the module sense points for precision regulation. Sense points should not be connected to the power leads at any other point but the point of regulation. Figure 2 demonstrates the recommended inter-connection technique. Power leads are shown by solid lines and sense leads by dotted lines. Note that the regulation points are at some distance from the modules. Each rectangle represents a resistance drop of the power leads. The sense leads of each module separately connect to the desired regulation point. The current share lead connects the two modules. This is a highly sensitive point that should be routed away from any noise producing sources.

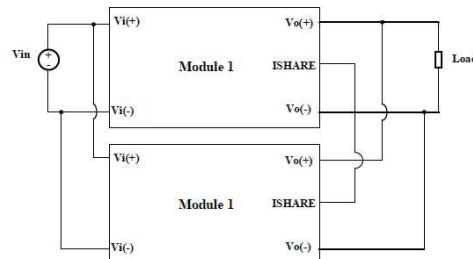
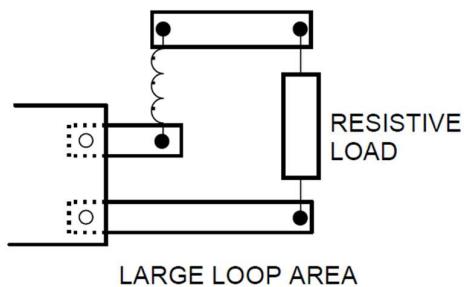


Figure 2. Interconnectivity of Two Paralleled High-Power Modules

Recipe for a good layout

Always remember that the dc-to-dc converter is the high-frequency noise source. As such, noise containment near the converter is crucial. Most modules have five-sided shielding that contains radiated emissions away from adjacent components on the circuit board. The sixth side, pointing into the board, is typically not shielded. It is good practice to provide a ground plane directly below the module, tied to the case of the module, to achieve a six-sided shield. As will be observed in the following EMI section, this method will also provide the best noise containment for EMI.

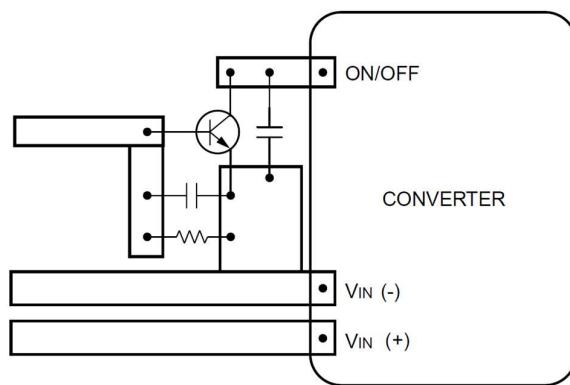
Voltage paths to and from the module should either run adjacent to each other with a ground plane below, or even better, the paths should be stacked on top of each other. This method is equivalent to providing a twisted-pair conductor, which is ideal for canceling common-mode noise. Close proximity of the power conductors minimizes loop area, which reduces radiated emissions. Figure 3 demonstrates this recommendation.



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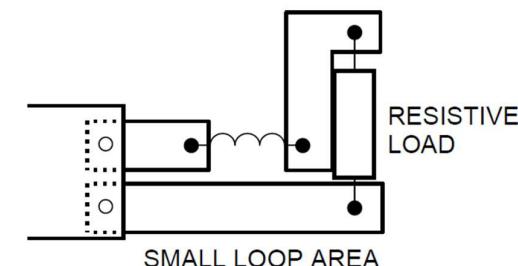
Figure 3. Loop Area Containment

Control signals can be very troublesome because of noise pick-up. Control components should be in close proximity to each other with snubbing capacitors included to further reduce the chance of signal bounce. Grounding should be tightly coupled to the reference point so that voltage offset is not generated. The example of Figure 4 demonstrates the close coupling recommended for the remote ON/OFF circuit for Tyco's modules.



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Figure 4. Positioning of Remote On/Off Control Near the Module



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EMI and EMC Containment

Containing electromagnetic interference (EMI) is often a key concern for the system designer. By their very nature, on-board switching converters have fast voltage and current changes that generate conducted noise on the input. Fast switching logic loads also produce conducted noise that reflects back onto the input of the on-board converter. This conducted noise, in turn, generates electric and magnetic fields that radiate noise into other circuitry. The system designer must be aware of the noise emanating from the on-board converter and be able to control this noise so it does not interfere with other system circuitry, cause an excess of noise to radiate from the system, or propagate into the ac mains.

Modules are typically designed for low cost and small size, and as such, modules are intended to pass both the CISPR and FCC radiated emissions Class A requirements for commercial, industrial, or business environments. Meeting this performance parameter is normally sufficient for ensuring that near field electric and magnetic waves do not affect the performance of other nearby circuits. To meet the more stringent environment of the Class B radiated interference requirements for use in residential and general public use, the systems developer has to provide containment external to the module. The recommendations of this section should assist greatly in meeting the intent of these more stringent requirements.

Conducted emissions containment is seldom provided within the latest high-power modules, and therefore it must be designed by the user. There are a number of good reasons for this technical direction. First, it makes the module truly applicable to a variety of applications with varying emissions needs. Second, the flexibility exists for the user to provide a single-filter module when a number of modules are used on the same circuit pack. Thus, significant cost and real-estate savings are realized for the user in this type of application. Most manufacturers are fully aware of the external filtering needs for their module products and are therefore willing to assist the user with noise containment recommendations. Recently, many manufacturers also started to offer packaged filter modules to be placed in front of the dc-to-dc converters. Although some of these modules may be somewhat more expensive than individually purchased components, they do offer a comprehensive turn-key solution that makes the development substantially easier.

Below are some layout and filtering guidelines that will aid in reducing both the conducted and radiated EMI noise produced by or passed through the on-board converter.

The importance of a good board layout is often over-looked, but layout can dramatically affect the amount of noise that the on-board converter conducts back to the input or radiates to surrounding circuitry. A good board layout has wide power paths routed closely together in parallel. Any loop of copper on the board can act as an antennae picking up radiated noise and converting it into conducted, or converting conducted noise into radiated. To reduce this effect, all loop areas must be kept to a minimum. For example, remote-sense leads are connected from the converter output to a local regulation point some distance from the converter. The output leads also take parallel paths from the converter to the same remote point. The actual distance between these two parallel paths creates a loop. This loop is minimized when the remote-sense leads are routed in very close proximity to the power paths.

To help shield other circuitry from noise radiating from the fast-switching power train, a ground plane should be placed under the converter whenever possible. It is also wise to separate all signal paths from power paths to reduce susceptibility of the signal paths.

Our experience suggests that for optimum design the circuitry should follow the electrical connectivity path in a straight line. The inrush circuit should first be placed in between the board connector and the rest of the circuitry. This circuit should be followed by direct connections to the input filter. The output of the filter should be tied in a straight line to the input capacitor. The capacitor should be in close proximity to the input of the dc-to-dc converter module. Output filtering should follow similar direct line noise containment with the filters located as close as possible to the output of the module in order to minimize any noise radiated by the output power leads.

There are two types of conducted noise: common-mode noise is coupled between frame ground and both input conductors, and differential mode noise that is across the input conductors as shown in Figure 5.

Common-mode noise exhibiting high-frequency content can be steered back to the on-board converter by ceramic capacitors (typically 0.01 mF to 0.1 mF) between input and output conductors and case ground. Lower-frequency differential mode noise can be addressed by ceramic capacitors (typically 0.1 mF to 1.0 mF) placed close to the converter between the input leads [2]. A similar capacitor should be placed between the output leads

EMI and EMC Containment (continued)

These components should be placed in very close proximity to the on-board converter in order to minimize the areas of the loops. Figure 6 provides a visual representation of the interconnection scheme described.

Note the connection to the case of the converter and the copper trace below the module providing the sixth sided shielding affect.

If these noise reduction strategies are insufficient to meet the conducted noise requirements of the particular application, then it may be necessary to add an input EMI filter. When designing an EMI filter for an on-board converter, the best place to start is with the converter vendor. Many vendors sell filters that are already optimized for their products. If this is the case, depending on your design resources and schedule, it may be prudent to buy such a filter off the shelf. If an off-the-shelf filter is not available, ask the vendor for a few guidelines in designing your own filter. At your request, the vendor may be able to provide data on the converter's EMI performance with and without external filtering.

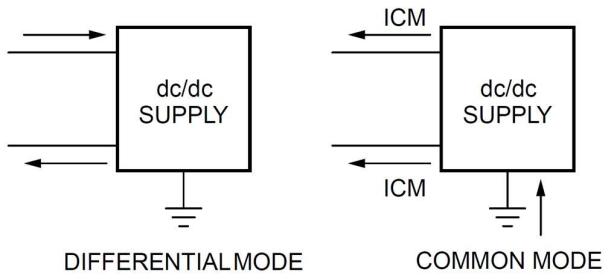


Figure 5. The Two Types of Conducted Noise Sources

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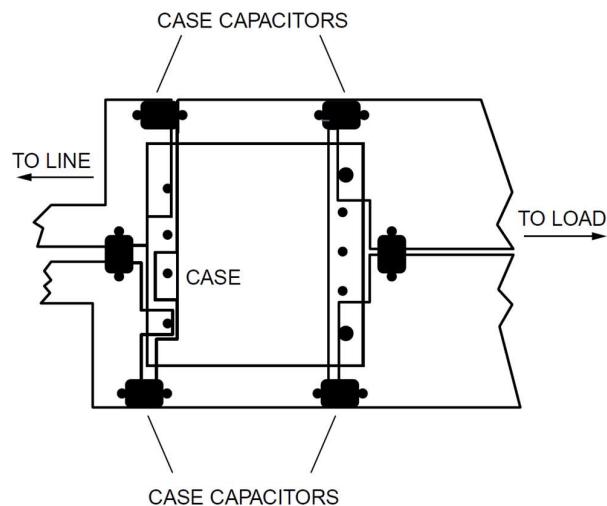
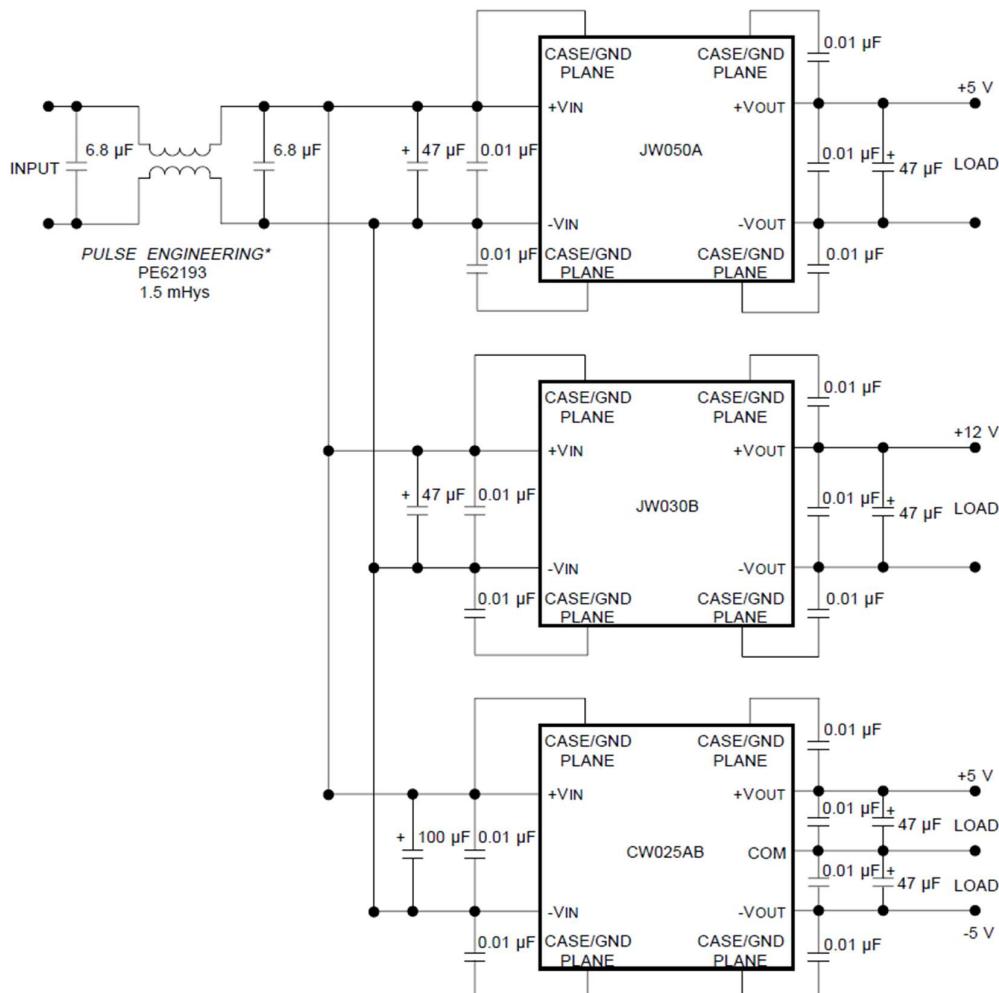


Figure 6. Typical Layout Recommendation of Bypass Capacitors

If data is not available, a good guideline is to assume 24 dB of filtering will be needed at the converter's switching frequency and a minimum damping factor of 0.707 [3]. Typically, a common-mode inductor of less than 1 mH will be sufficient to meet class B limits. A bulk capacitor may also be necessary at the input to maintain converter stability (see Stability Considerations section).

Figures 7 and 8 demonstrate the product of good layout practices and the use of a single discrete filter circuit for a three-module board. This circuit layout met with margin the requirements of the stringent CISPR Class B conducted and radiated emissions standards. The three modules of the circuit are a 50 W single-output 5 V module, a 30 W single-output 12 V module, and a dual-output 25 W \pm 15 V module. Traces of different layers are annotated by a difference in shading. Rectangular components indicate ceramic capacitors. Circular components represent low ESR electrolytic capacitors. On the input of the modules, these capacitors are used for improved stability. The input EMI inductor is a common-mode inductor. Component values for this circuit may be obtained from the authors

EMI and EMC Containment (continued)



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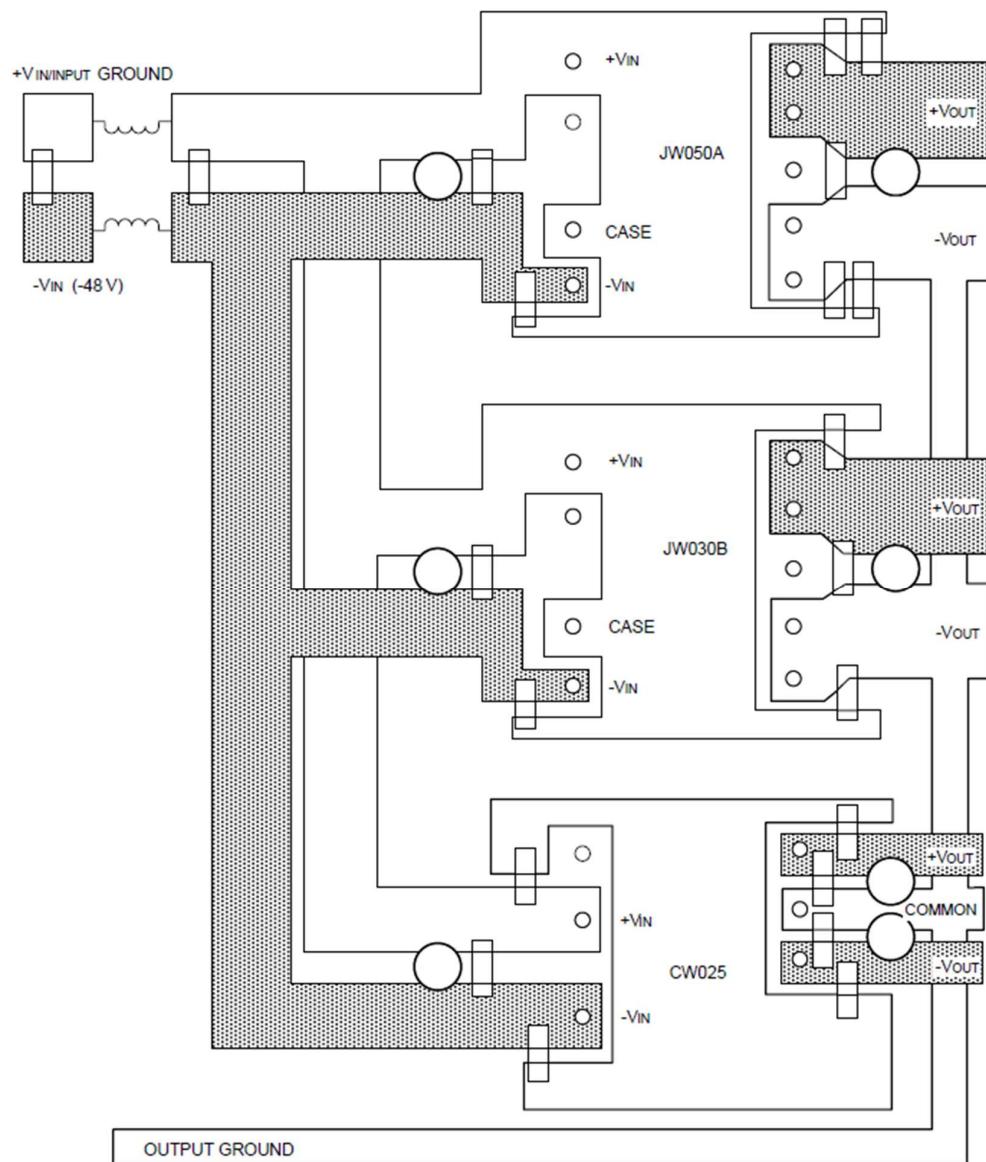
Figure 7. Schematic of a Three-Module CISPR Class B EMI Solution

Typically, radiated noise will be contained to acceptable levels if the layout guidelines are followed and the conducted noise is filtered to an acceptable level. However, in some cases, further filtering may be necessary in order to bring radiated emission to acceptable levels. The key procedure to follow is to first bring the conducted emissions down to acceptable levels and then proceed with verifying radiated emissions.

Always keep in mind the objective to be realized, containing the noise generated by the power module. The three basic rules are:

1. Return the noise currents to the source in as short a route as possible.
2. Identify alternate routes and suppress these routes by adding impedance.
3. Reduce inductance and increase capacitance of the loop to reduce impedance.

EMI and EMC Containment (continued)



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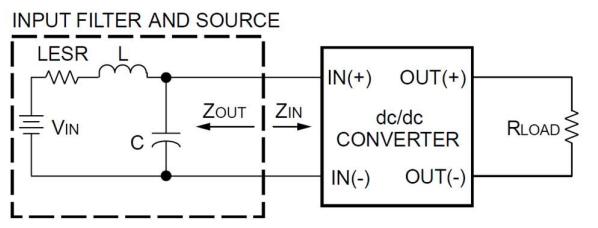
Figure 8. Layout of Same Three-Module CISPR Class B EMI Solution

Stability Considerations

Input Circuits

Although on-board converters are generally simple to use, there are a number of design considerations to be aware of when adding additional input and output filtering. Even when the input filter added is no more than the inductance of the interconnect wires, or the output filter is only a capacitor, the system designer must still evaluate carefully the reaction of the circuit in order to avoid any undesirable effects in the completed on-board powering system.

Additional input filtering may be required to prevent high-frequency ac voltage on the power bus from passing through the on-board converter to the output. It may also be necessary, as mentioned above under EMI containment, to reduce the conducted electromagnetic noise produced in the on-board converter and the load from traveling back to the dc bus. When designing an input filter, one must keep in mind impedance mismatches that can occur between the input filter and the on-board converter. (See Figure 9.)



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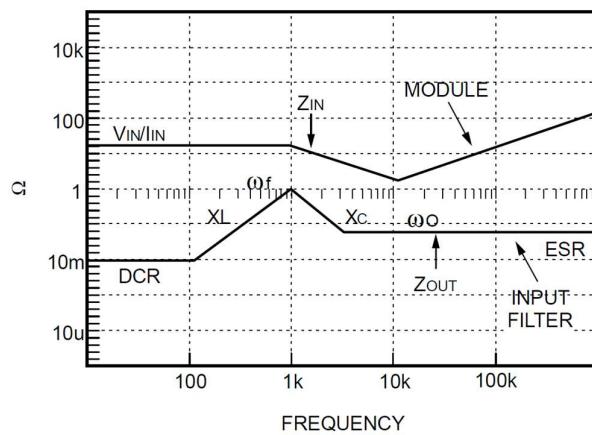
Figure 9. Impedance Matching

At low frequencies, the input of a dc-to-dc converter is a constant power input. As the voltage increases, the current decreases. This presents a negative impedance to the input source. An impedance mismatch occurs when the combination of the input filter impedance and the on-board converter impedance become negative, causing the converter to oscillate. To avoid this condition, care must be taken to ensure the input filter output impedance remains much smaller than the input impedance of the on-board converter for all frequencies. Figure 10 shows a plot of impedance vs. frequency of the output of the input filter and the module input.

The lower graph shows the plot of the output impedance of the input filter. At each slope change we highlighted the component that contributed to

the change in the curve. The resonant frequency of the filter is annotated by ω_f . Its peak is proportional to the filters damping ratio.

As can be seen, an underdamped filter could easily cause oscillations if its maximum impedance gets near the impedance of the module.



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Figure 10. Stability Plot of the Input Filter and Converter Module

The upper curve is the plot of the input impedance of the converter. The resonant frequency of the converter's output filter is represented by ω_o . Note that any external output filtering shifts this point.

A good guideline is to design the filter such that the peak of the filter output impedance (the resonant frequency of the filter) is 1 decade or more below the dip in the power module input impedance (the resonant frequency of the on-board converter's output filter in combination with external filtering applied). Additionally, it is equally important to design the filter with a minimum damping factor of 0.707 [4].

Even if an input filter is not intended to be used, the system designer may need to place a $33 \mu F$ or greater capacitor near the input leads of the module to reduce the impedance seen by the converter due to the inductance of the interconnects. This is required because without the input filter, the impedance of the input circuit will be determined by the inductance of the input wires and the input capacitance of the converter. Since the inductance is a variable parameter, it is much safer to simply add a large input capacitor so that the input impedance is lowered to a level where the contributions of the wiring inductance is negligible. In fact, many designers elect to leave the input capacitor in place even with the addition of the EMI filter because of its contribution to minimizing the differential conducted emissions of the module.

Output Circuits

Additional output filtering may be required by the system designer for a number of reasons. First, there may be a need to further reduce the output ripple and noise of the converter. Second, the transient response characteristics may need to be customized to a particular load step change. Thirdly, there may be a desire to localize hold-up of the load. As with the input filter, the addition of an output filter may interfere with the module stability.

At its resonant frequency, a filter not only passes the noise it is intending to filter, it may, depending on the damping, amplify it significantly. When designing any output filter, care must be taken to ensure that the resonant frequency of the filter be different than the switching frequency of the converter. A single stage differential mode filter also creates a double pole that may interfere with the control loop. This is also true when a capacitor alone is used on the output. In this situation, the double pole is created by the combination of the capacitor and the inductance of the interconnects and parasitic impedances in the layout. Another important consideration is the reactive impedance of the filter components. For example, Figure 11 demonstrates that increasing the output capacitance from 400 μ F to 10,000 μ F, or an order of magnitude of 25 times the original value, resulted in lowering of the transient response ratio by less than 3 to 1.

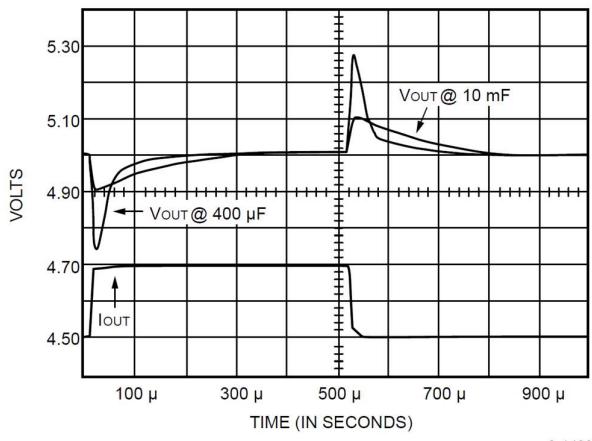


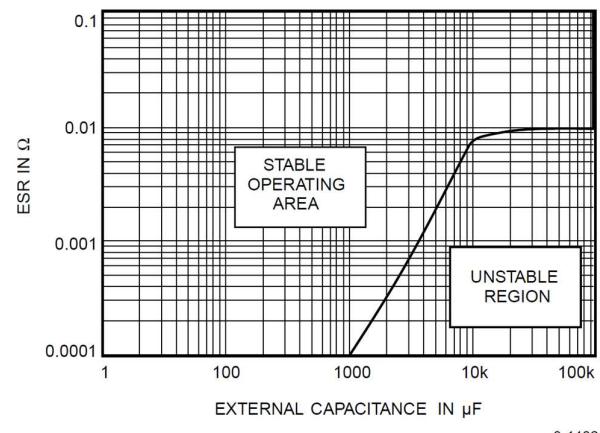
Figure 11. Transient Response Performance vs. Output Capacitance

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This response clearly demonstrates that very little pay-back is achieved by simply increasing the output capacitance of the module. The cause of the problem is related to the compensation of the feedback loop that is designed for optimum performance over a wide range of loading configurations. Major performance improvements can be made if the loading configurations of the

specific application are clearly defined and some of the constraints are removed from the circuit. Make sure to work in concurrence with the vendor on specific solutions to dynamic response problems.

Besides transient response, the main reason for adding output capacitance is to lower the output ripple and noise content. It is prudent to verify that the desired output capacitance meets the stability performance criteria of the module. Observe whether the module data sheet recommends specific capacitors or a range of values with recommended component characteristics. If the desired value is not in the data sheet, obtain a recommendation from the vendor that clearly shows the stable region of operation for various output capacitors. Figure 12 shows a characterized plot of external output capacitance versus capacitor ESR



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Figure 12. Graph of Stability Characterization

Using this plot, the designer can choose a capacitor type and determine whether that component will affect circuit performance. For further information on circuit techniques for maintaining tight transient regulation, please refer to reference [5].

Protection Circuits

Attention to low cost and small size does have some drawbacks. For example, the current-limit circuits of many modules operate typically at between 150% and 200% overload. This may be unacceptable in high-power, redundantly configured circuits. The user could be required to add much tighter overcurrent-limit circuits. Note that in most circuits, the overcurrent shut-down accuracy of the module is sufficient. High-power modules also provide thermal shutdown as an additional level of protection so that if the dissipated energy level within the module increases to a level which could be destructive, the module shuts down.

Many modules do not employ overvoltage shutdown but instead use an overvoltage clamp. Arguably, such clamps do have some advantages such as providing an output voltage even when the main control circuit malfunctioned. The user is given the choice of either continuing to operate until the module is eventually replaced, or immediately provide an external shut-down. The intent is to maintain service until repair personnel are dispatched to the site.

Redundant configurations provide additional fault detection challenges. In such critical circuits, an output isolation diode is employed in series with the module to ensure that any shorting or shutdown does not influence the critical bus. In these cases, it is not sufficient to monitor the bus voltage for overvoltage. Instead, the monitoring must be accomplished prior to the isolation diode, and in some cases, even the output diode is monitored to ensure that it is not shorted, as shown in Figure 13.

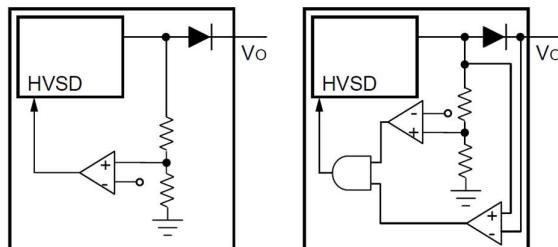
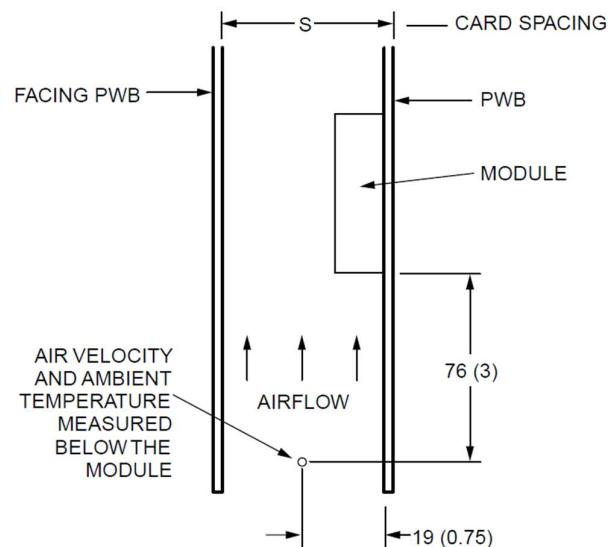


Figure 13. External Output Protection Circuits

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Thermal Performance Considerations

Modules below 30 W are designed to perform without the need for heat sinking. However, strict application guidelines are normally provided by the manufacturer listing the constraining parameters under which the module must be operated. These parameters include at least minimum airflow and maximum operational ambient around the module. Note that the manufacturers count on cooling provided by the five-sided case. Obstructions by other large components or brackets around the module could dramatically alter the anticipated performance. It is important to understand how the vendor determined the appropriateness of the performance criteria. Obtain the test measurement technique and verify that the application is in fact within the anticipated guidelines. Figure 14 shows a typical measurement technique used in performance verification of all Tyco Electronics modules.

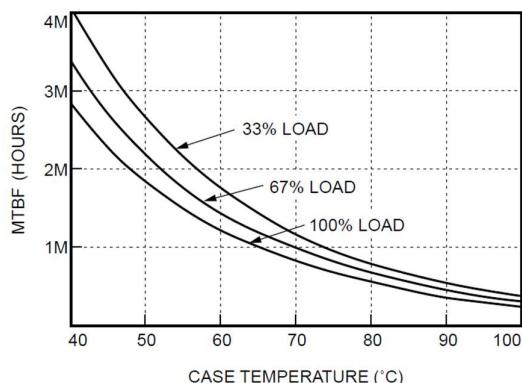


Note: Dimensions are in millimeters and (inches).

Figure 14. Module Thermal Performance Measurement

Manufacturers should also provide measurement hotspot points of their particular modules. It is prudent practice to verify the anticipated performance and measure the worst-case temperature rise in the highest design ambient and with all obstructions in place. Only when such performance is well within the manufacturer's maximum guidelines should designers approve the product. This has always been a difficult problem. Designers are purposely pushing the modules to their thermal performance extremes in order to provide the lowest cost option. They seldom consider the drastic impact of such high temperatures. The rule of thumb is that for every 10 °C temperature rise the reliability of the module is reduced by one half as can be seen from Figure 15.

Thermal Performance Considerations (continued)



Note: CW030A, A1 MTBF vs. Case Temperature at 1/3, 2/3, and Full Output Power (AT&T Reliability Information Notebook, Issue 6).

Figure 15. Reliability Prediction vs. Module Case Temperature

Modules above 30 W can seldom perform at their power without the addition of sizable heat sinks, even if a hurricane blows around the module. This is caused by the miniaturization of the electrical circuits. There is simply not enough surface area to dissipate the internal losses. Consult the manufacturer's recommendations and find out if they have evaluated and can provide standard heat sinks for these high-power modules. Figure 16 shows a typical performance curve that plots available air velocity versus permissible case temperature rise when different heat sinks are deployed

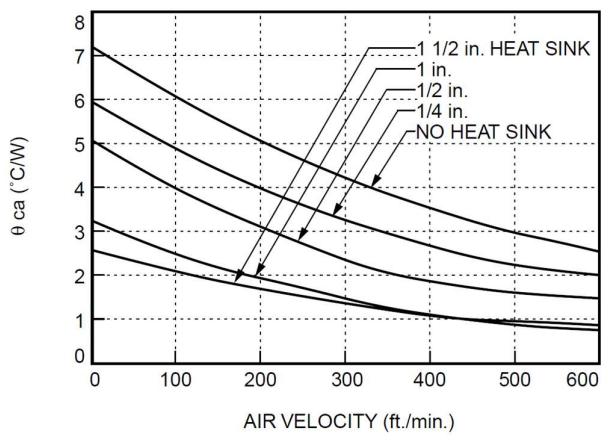


Figure 16. Thermal Performance Curve with Various Heat Sinks

In order to guarantee low thermal resistance between the module and the heat sink, a thermal conductor must be placed between the two surfaces. Determine if the manufacturer is able to either provide a complete thermal kit or recommend an available source for an approved thermal assembly. Another consideration is component or lead stress during assembly. Mounting to heat sinks after the solder process could cause bond stress of the circuit pack as the module is physically stressed against the mounting body. Review of the assembly practice with the manufacturer is always a good practice. You may be surprised to learn how much the manufacturer may know of appropriate assembly techniques and what one must watch out for.

Summary

On-board converters require careful attention to detail in order to implement an efficient, high-performance, trouble-free powering system. The discussions, guidelines, and recommendations within this application note attempt to highlight to the user the major design techniques that would ensure a successful, rapid development. Only those features that tend to be troublesome are covered in detail.

The payback of on-board power conversion is that once the circuit-board layout of the complete power circuit with all its additional features is developed, it is fully portable from design to design. Our past experience indicates that board-to-board is excellent.

References

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Change History (excludes grammar and clarifications)

Revision	Date	Description of the change
1.0	1997	Initial Release
2.0	02/13/2026	Updated as per OmniOn Power Template. Updated abstract.

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