

POWER | *designer*

Expert tips, tricks, and techniques for powerful designs

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Feature Article1-7

Secondary-Side Post Regulator2

Synchronous Buck Controllers4

Highly Efficient Intermediate Bus Converter6

Power Design Tools ...8

Analyzing Power Modules

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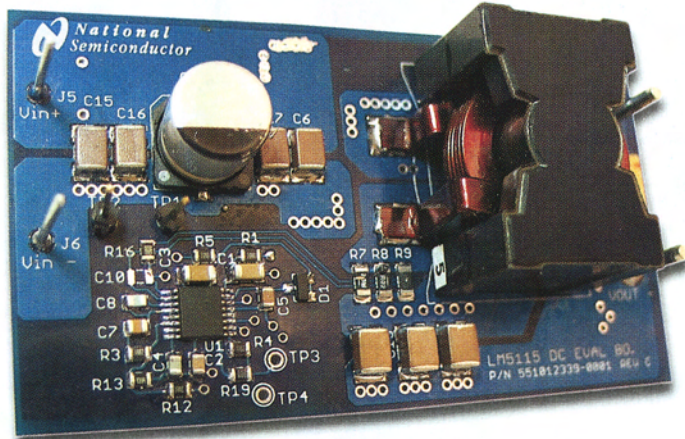


Figure 1. Power Supply

Power-modules are supplies that are mounted directly on the PCB to power ASICs, DSPs, microprocessors, memory, FPGAs, and other digital or analog loads (see Figure 1). These modules are commonly referred to as point of load supplies (POL) or point of use-power supplies (PUPS). Modules are extremely popular in high-performance telecommunication, networking, and data communications systems as they provide a number of benefits to a system. Despite these advantages, several reliability and measurement issues are often overlooked in most on board dc-dc converter designs as well as in power modules. This article will examine and address these issues.

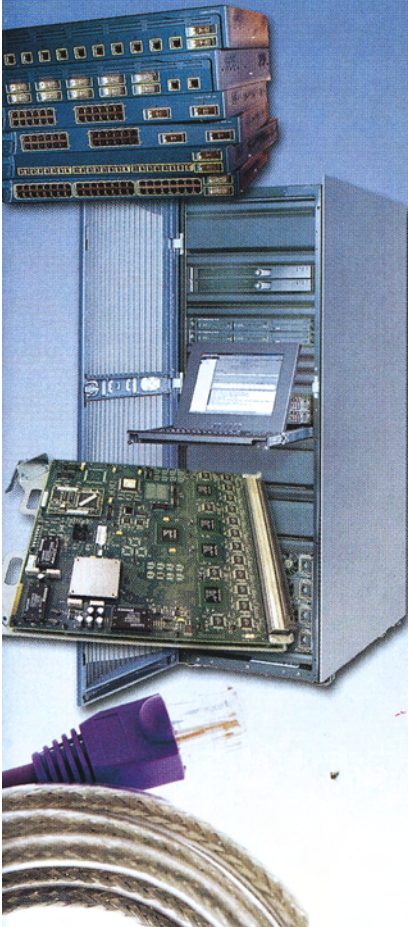
Advantages of Using Power-Supply Modules

A variety of power modules in a combination of input voltages, output power levels, feature sets, topologies etc. are available from several vendors. Relative to down solutions, power modules reduce time-to-market. Other advantages are listed below.

- Every module can be thoroughly tested to ensure high reliability, including burn-in to weed out infant mortality. Conversely, the testing of a down solution is rather difficult as it is integrated with other solutions on the board.
- Multiple vendors can design a module with the same form factor, using one of several existing standards, thus providing the system engineer with alternative sources for his power needs.

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Analyzing Power Modules

- Technical risks are minimized as each module is designed and tested to meet standardized performance requirements.
- The entire motherboard must be replaced if the down solution fails, whereas in the case of a module, the individual module can be replaced, saving cost and time.

Issues Often Overlooked While Designing Power Modules

Despite the advantages of modules highlighted above, a number of issues are often inadequately characterized or measured in module design (as well as in on-board dc-dc converter designs). These issues are:

- Output noise measurement
- Magnetics design
- Shoot-through in synchronous buck converters
- PCB reliability

These issues are examined in this article, with simple techniques for addressing them.

Output Noise Measurement Techniques

All switch mode power supplies generate output noise. As switching frequencies increase, it is becoming more critical to use proper measurement techniques to ensure that measured data are accurate and reliable. Using a Tektronix probe tip (often referred to as a cold-nose probe) for output noise and other critical measurements provides reliable and predictable measurements as shown in *Figure 2*. This measurement technique ensures that the ground loop is minimized.

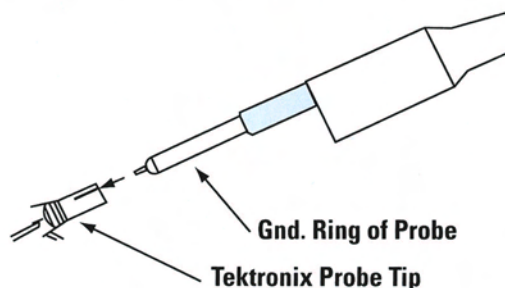


Figure 2. Output Noise Measurement

Another factor to consider when making measurements is that test instruments have propagation delays. Most current probes have greater propagation delays than voltage probes. Consequently measurements that require both voltage and current waveforms simultaneously cannot be done accurately unless the unequal delays are manually equalized.

Current probes also introduce inductance into the circuit. A typical current probe will introduce 600 nH of inductance. Thus in high-frequency designs where the desired circuit inductances can be 1 μ H or lower, the probe inductance will introduce a significant error in the current di/dt measurements. Therefore, a more accurate way to measure the current at which an inductor saturates is to measure the voltage across a small shunt resistor in series with the inductor.

Magnetics Design

Another often overlooked issue is that of the reliability of the magnetic cores. Powdered iron is used as the core material in most output inductors because it is the lowest cost material available. Powdered iron cores are made from approximately 95% pure iron particles that are bound together with organic binders. The binders also insulate the iron particles from each other and provide a distributed air gap in the cores.

The powdered iron raw material used to form the cores contains small traces of impurities such as manganese (Mn) and chromium (Cr). The degree to which these impurities are controlled affects the reliability of the core. Examining the cross-section of the core using Spectral Electron Microscope (SEM) one can examine the relative distribution of impurities. Predictability of material and its supply chain are critical factors for core reliability.

Powdered iron cores are susceptible to a permanent increase in core loss when they are exposed to elevated temperatures for prolonged periods of time. This is due to the organic binders breaking down and resulting in an increase in the eddy current losses. This condition is referred to as thermal aging and can eventually result in thermal runaway of the core.

Analyzing Power Modules

Factors that affect the core losses are the AC flux density, the operating frequency, the volume of the core, and the material type. At high frequencies, eddy current losses are the dominant loss mechanism, whereas at low frequency hysteresis losses dominate.

Eddy current losses, which result in heating of the core and reduced efficiency, are due to the existence of circulating currents within the body of a ferromagnetic material under conditions of time varying magnetic flux. Eddy current losses can be reduced by constructing the magnetic core with thin laminates of ferromagnetic materials rather than a solid piece. An example of such a core is Metglas, which are tape wound cores. Other magnetic vendors such as Magnetics Inc also produce tape wound cores.

To help magnetics designers core vendors like Micrometals (www.micrometals.com) provide the latest thermal aging information and calculations for their cores. Powdered iron cores that use inorganic binders that do not exhibit thermal aging are now available (such as 200C series cores from Micrometal)

Shoot-Through in Synchronous Buck Converters

Synchronous buck converters (*Figure 3*) are widely used in POL and PUPs supplies. A synchronous buck converter consists of a high side and a low-side MOSFET, which is placed in place of the conventional buck converter catch diode to provide a lower loss path for the load current.

One issue that is often overlooked in buck converter design is “shoot-through.” Shoot-through is a condition in which both high-side and low-side MOSFETs are simultaneously fully or partially turned on, providing a current path from the input voltage to ground.

Shoot-through leads to current spikes at the switching instants and manifests itself as a decrease in the efficiency of the converter. A current probe cannot be used to measure it because the inductance of the probe significantly affects the circuit operation. An alternative way to detect shoot through is by looking for spikes on the gate source voltages of the two FETs. (The gate-source voltage of the top MOSFET can be monitored differentially).

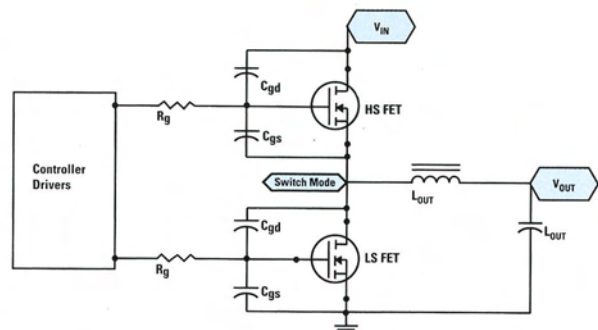


Figure 3. Synchronous Buck Converter

A number of techniques are used to minimize shoot-through.

One approach is to employ a controller IC with a “fixed dead-time,” which ensures that there is a delay after the top MOSFET is turned-off before the lower MOSFET is turned on. This approach is simple, but has to be implemented carefully. If the dead time is too short, shoot-through may not be averted. If it is too long, the conduction losses increase because during the dead time the body diode of the bottom FET is on. Because of the conduction of this body diode during the dead-time, the efficiency of the system when using this technique depends somewhat on the bottom MOSFET’s body diode characteristics.

Another approach is to use a controller IC with an “adaptive dead-time.” In this approach, the gate-source voltage of the top MOSFET is monitored in order to determine when to turn-on the bottom MOSFET.

When the high-side MOSFET turns on, this induces dv/dt spikes on the gate of the low side MOSFET causing its gate voltage to rise (*Figure 4*). If the gate-source voltage becomes high enough to turn it on, this will result in a shoot-through spike.

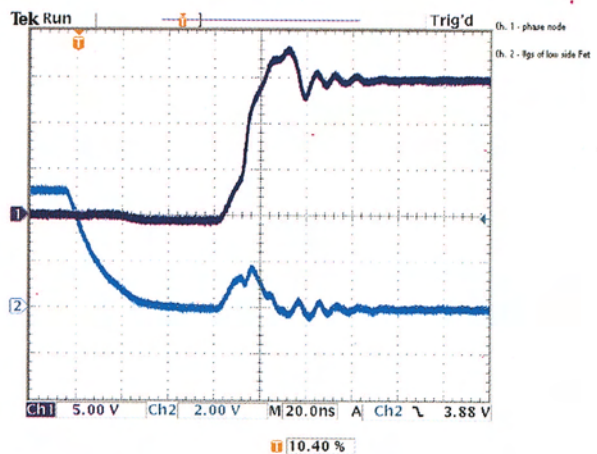


Figure 4. dv/dt induced step on the low-side MOSFET
Ch 1 Switch node
Ch 2 Vgs_low-side MOSFET

Analyzing Power Modules

Adaptive dead time controllers monitor the MOSFET gate voltage externally. Thus, any added external gate resistors form a voltage divider with the internal pull down resistor of the controller. The gate voltage will actually be higher than the voltage monitored by the controller.

Predictive gate drive is an alternate approach where digital feedback is used to detect body diode conduction and to adjust the dead time delay to minimize the body diode's conduction, thus maximizing the efficiency of the system. This technique needs additional pins on the controller IC, increasing cost of the IC and the power module.

Note that predictive gate drive does not ensure protection against dv/dt induced turn-on of the FETs.

One way to minimize shoot-through is to slow down the turn-on of high-side MOSFET. This will reduce or eliminate the shoot-through, but at the expense of higher switching losses and lower efficiency. Proper selection of MOSFETs can also help to reduce the dv/dt induced voltage step on the gate of the lower MOSFET. A higher ratio of C_{gs} to C_{gd} will result in a lower voltage being induced on the gate of this MOSFET.

Test conditions for shoot-through are often overlooked during load transients especially when the load is released, or reduced suddenly, which results in the controller producing narrow pulses. Most of today's high-current applications utilize multiphase designs using driver ICs to drive the MOSFETs. Driver ICs add another dimension to the shoot-through issue, especially during transient conditions. The presence of narrow drive pulses, in conjunction with propagation delays in the driver, can result in shoot-through.

Most driver IC manufacturers are adding minimum pulse-width requirements, i.e. if the pulse from the controller is below a minimum pulse width, no pulse is applied to the gate of the MOSFETs.

Another feature that is designed in by IC manufacturers is programmable dead time (T_{RT}). This is enhancement to adaptive transition timing. A resistor from the RT pin (deadtime programmable pin) to ground programs dead time between high and low side transitions. This, in conjunction with

propagation delay (t_p), disables the complementary MOSFET during transitions, and prevents shoot-through in synchronous buck converters.

Reliability

Thorough testing of a module at an early stage is critical to ensure a reliable design and obviate last-minute surprises. Testing the module in the customer's system is critical to ensure that all possible factors that can cause failure such as fan failure, partial blockage of fans etc, have been considered. Distributed architectures demand that the system be in service for many years with little or no downtime. Since the calculated MTBFs of power modules are in the several million hour range, this goal is not hard to achieve.

However, one thing that is often overlooked is the reliability of the PCB. With the trend in present designs of processing ever higher currents on ever smaller PCBs, the increased current density can cause buried and other vias to malfunction.

It is critical that buried vias on the PCB that have to carry significant current have adequate copper surrounding them to provide the design robustness. This also minimizes z-axis thermal expansion, which can result in open vias when the PCB is subjected to temperature variations during manufacturing as well as during its product application. PCB design must be reviewed thoroughly with feedback from PCB manufacturers. Thus PCB manufacturers can provide feedback with regards to robustness of PCB design based on their manufacturing capabilities.

Summary

To implement a reliable power supply system using modules, a number of issues relating to design robustness must be addressed. Issues highlighted in this article include: reliability of powdered iron magnetic cores, magnetics, shoot-through in synchronous buck converters, and reliability of the PCB in high-current applications. ■

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