

Addressing Factory Automation Challenges With Innovations in Power Design



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TI POWER
The TI POWER logo graphic, consisting of four red dots of varying sizes and a red horizontal bar.

The continuing rise in electronic content in factory automation and control systems drives a need for greater power at all levels of the factory, from the edge to the enterprise.

At a glance

This paper examines how the latest innovations in power technologies are helping modernize automated factories and solving challenges in factory applications.

-  **1 Benefits of increasing power density**
There is often little space to add extra power in factory automations but increasing power density can help.
-  **2 Reducing switch losses yields benefits in industrial power supplies**
Optimizing parameters and rising-edge dead time can minimize losses for particular industrial applications.
-  **3 Embracing more passive integration**
Integration of passive components together with the IC in a single package to meet the demand of miniaturization and power density increase.
-  **4 Taming the industrial environment**
Many flexible factory automation work cells are installed in legacy installations that have a noisy electrical environment and increasing DC bus voltage can help.

Power devices used in these applications must provide ever-increasing levels of power in smaller spaces, and they must do so in a harsh industrial environment that has high levels of electromagnetic interference (EMI), voltage surges, and potentially hazardous voltages for both humans and machines.

This white paper reviews power device requirements and discusses some of the ways that innovations in power design are helping modernize the automated factory.

Increasing power density holds the key to success

If you are designing a power solution for factory automation applications, there is often little space available to add extra power, especially at the edge. The best workaround in such a design is to reduce the size of the power supply needed to do the job – that is, to increase the power density.

Power density measures the amount of power that can be processed in a given space, quantifiable as the amount of power processed per unit of volume in units of watts per cubic meter (W/m^3) or watts per cubic inch (W/in^3). These values are based on the power rating of the converter and the “box volume” (length × width × height) of the power solution with all components included.

The primary factors limiting a designer’s ability to improve the power density are converter power losses (including conduction, charge-related, reverse-recovery, and turn on and turn off losses) and the thermal performance of the system. Boosting power density requires innovations such as:

- Reducing switch losses
- Improving package thermal performance
- Adopting innovative topologies and circuits
- Embracing more passive integration

By making improvements in these areas, successive generations of power designs have yielded vast improvements in power density – looking at [Figure 1](#),

from about 10,000 mm³/A in Gen 1 to less than 5 mm³/A in Gen 5.

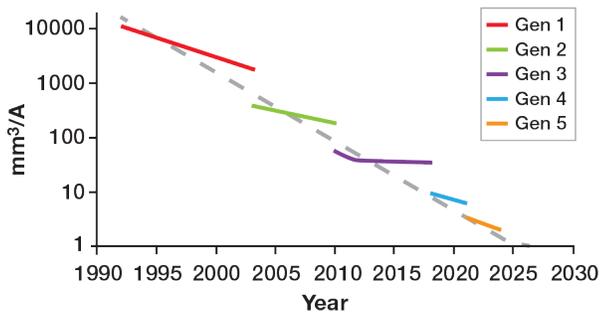


Figure 1. Successive generations of designs yielded vast improvements in power density

Look at each of these techniques and spotlight products that already incorporate these improvements.

Reducing switch losses

Charging and discharging parasitic capacitances (charge-related losses), reverse-recovery losses, and turn on and turn off losses are the main sources of losses in a silicon power metal-oxide semiconductor field-effect transistor (MOSFET). Optimizing such parameters as the charge-related specifications of the MOSFET, parasitic-loop inductances and rising-edge dead time can minimize losses for a particular application.

Designs using silicon MOSFETs can achieve peak efficiencies of over 90%. Power devices based on wide band-gap semiconductors such as silicon carbide (SiC) or gallium nitride (GaN) can boost efficiency further.

Note

For power-switching applications, SiC and GaN offer a unique combination of low output charge and a high slew rate compared with silicon. GaN, in addition, also has zero reverse recovery due to absence of body diode. These wide band-gap devices offer another path to reduce losses.

Designing high-speed power circuits can be challenging as board parasitics between the FET and gate driver can impact performance. It is possible to choose a

product that combines the GaN FET with an integrated silicon gate driver and protection features. The **LMG342x** GaN FET is one example. Designed for high-density industrial AC/DC power supplies, uninterruptible power supplies, industrial robots and industrial motor drives, the LMG342x device includes features such as adjustable gate-drive strength for EMI control, overtemperature, overcurrent protections, and fault indication.

Improving package thermal performance

An industrial input/output (I/O) module must be able to drive multiple high-power loads, such as solenoids, from a pluggable module in a space-constrained rack. In such cases, a state-of-the-art power package reduces the junction-to-ambient thermal resistance ($R_{\theta JA}$) of the power regulator device, allowing it to dissipate more power without exceeding its operating temperature. TI's HotRod™ package, for example, replaces typical bond-wire type, quad flat no-lead packages (QFNs) with a flip-chip style package. Here, a HotRod QFN can eliminate the bond wires while keeping a QFN-like footprint, resulting in a significant reduction in parasitic inductance while also keeping some of the thermal performance benefits of the QFN package.

Taking a closer look, the Enhanced HotRod QFN package combines the bare flip-chip integrated circuit (IC), the power inductor, bypass capacitors, and feature-programming resistors into a three-dimensional stack. **Figure 2** shows the inductor is mounted above the IC and other passive components.

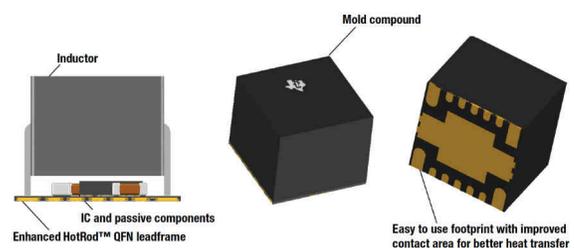


Figure 2. The enhanced HotRod™ package combines superior thermal performance with an increased level of integration

The placement of a high-frequency bypass capacitor together with the direct copper connection to the die

results in greatly improved switch-node ringing and lower switching losses.

The **TPSM53604** power module is a highly integrated 4-A power solution that combines a 36-V input, step down DC/DC converter with power MOSFETs, a shielded inductor and passives in a 5-mm-by-5.5-mm-by-4-mm 15-pin Enhanced HotRod QFN package. This power module can provide up to 20 W of output power without requiring airflow at temperatures up to 85°C because of its low 19.5°C/W $R_{\theta JA}$.

The total solution requires as few as four external components and eliminates the loop compensation and magnetics part selection from the design process. The full feature set includes power good, programmable undervoltage lockup, pre-bias startup, and overcurrent and overtemperature protections. Pin-compatible 2-A and 3-A versions make the TPSM53604 easily scalable for powering a wide range of factory automation applications.

Another product family in the 5-mm-by-5.5-mm-by-4-mm Enhanced HotRod QFN package is the **TPSM5601R5H**. The TPSM5601R5H is a 4.2-V to 60-V input step-down power module with output current capability up to 1.5 A and supports wide output voltage range from 1 V to 16 V.

The inductor can also be placed side-by-side the IC and other passive components to reduce the height of the package.

The **TLVM13630** power module is a highly integrated 3-A power solution that combines a 36-V input step-down DC/DC converter, a shielded chip inductor, and passives in a 6mm-by-4-mm-by-1.8-mm, 30-pin package. The package footprint has all signal and power pins accessible from the perimeter and four larger thermal pads beneath the device for simple layout and easy handling in manufacturing. The module is designed to help engineers quickly and easily implement a power design in a small PCB footprint.

Adopting innovative topologies and circuits

Programmable logic controllers (PLCs), which include a flexible number of analog input/output modules (shown in **Figure 3**) with isolated power and signal paths, are widely used in factory automation and industrial/collaborative robotic applications. But increased channel counts and smaller packages require improvements to existing isolated switching topologies.

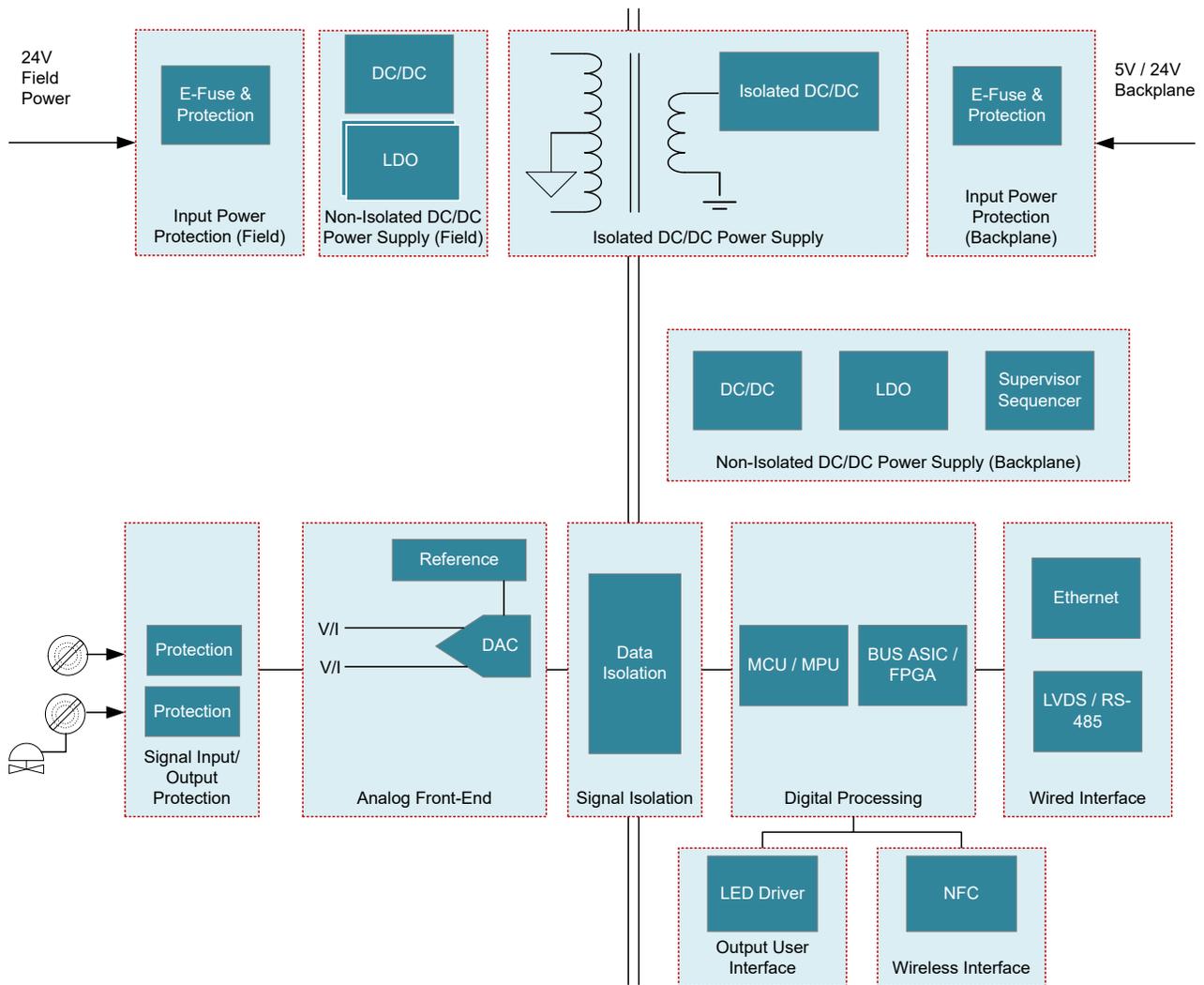


Figure 3. A typical industrial automation analog input module

Adding synchronous rectification can extract greater efficiency even from time-honored designs such as the flyback regulator. Efficiencies well in excess of 90% are possible, but synchronous rectification adds complexity and cost to the classic flyback design, as it typically requires a synchronous rectifier controller on the secondary side of the transformer and optocoupler feedback to the primary-side flyback controller.

In such cases, a flyback converter such as the **LM25184** may provide the answer: The **LM25184** uses primary-side regulation and does not require an optocoupler

or auxiliary transformer winding to provide feedback. The LM25184 can achieve 90% efficiency over a wide load range and is available in a 4-mm-by-4-mm thermally-enhanced very thin small outline no-lead (WSON) package. The maximum input voltage of 42 V provides ample headroom to accommodate transients on a standard 24-V industrial bus.

Embracing more passive integration

Factory automation equipment is increasingly relying upon machine vision for numerous operations such as

quality inspection and defect analysis; mobile industrial robots also use machine-vision systems for real-time control. Many machine-vision cameras and industrial sensors are extremely small, which constrains the size of any printed-circuit board (PCB). For instance, an ultrasonic sensor with an M12 housing needs a PCB width less than 9 mm. Incorporating power-supply components on a small PCB in a subsystem becomes very challenging for hardware designers.

As a result, the demand for miniature, feature-rich power ICs to power these devices is also growing. Bundling the required passive components of a converter design together with the IC in a single package provides another way to increase power density.

The **TPSM265R1** is a good option for such space-constrained, lower-power factory automation applications. The **TPSM265R1** is a 3-V to 65-V input 100-mA step-down power module that integrates a controller, MOSFETs, and an output inductor in a 2.8-mm-by-3.7-mm-by-1.9-mm package. There are two fixed output voltage options, 3.3 V and 5 V, and an adjustable output voltage option from 1.223 V to 15 V. Two external capacitors complete the design.

The pulse-frequency modulation mode of the TPSM265R1 provides optimal efficiency at light loads and does not require loop compensation, providing excellent line and load transient performance. Applications for the TPSM265R1 include ultra-small Internet-of-Things transmitters and sensors, as well as a range of factory automation modules, including PLCs and distributed control systems.

Taming the industrial environment

In addition to maximizing power density, power designs for industrial use must also handle an environment that is hostile to semiconductor products. Many flexible factory automation work cells are installed in legacy installations that have a noisy electrical environment. Causes include inadequate grounding systems and high-power equipment such as electric ovens and arc

welders. Varying power demands lead to problems such as surges, safety issues, and widely varying DC bus voltages.

One solution: increasing the standard DC bus voltage to reduce current. DC bus voltages in industrial applications include 12 V_{DC}, 24 V_{DC}, and 48 V_{DC}. Options include isolated converters and devices with wide-range inputs, including those mentioned in this white paper.

Increased electronic content in factories also increases the potential for disruptions caused by EMI, especially because the drive toward greater power density depends heavily on switching power topologies that operate at higher frequencies. Switching power supplies are certainly highly efficient, but they are also prolific generators of noise and must meet applicable industrial standards for electromagnetic emissions and immunity.

European Standard (EN) 55011 and Comité International Spécial des Perturbations Radioélectriques (CISPR) 11 describe emission requirements for industrial, scientific, and medical equipment. EMI susceptibility – covering fast transients, repetitive surges and discharges – is also of primary importance and is described in International Electrotechnical Commission (IEC) 61000 standards. For example, IEC 61000-4-5 governs surge immunity, including classification levels and test procedures, while IEC-61010-1 covers safety requirements for electrical equipment.

Power designs for industrial use include features to minimize EMI, including new packages, galvanic isolation, and features such as spread-spectrum operation. TI has designed several products for low EMI. The TPSM265R1 and TPSM53604 power modules are both compliant with the EN 55011 (CISPR 11) radiated emissions standard, and the LM25184 primary-side flyback converter exceeds the CISPR 25 Class 5 conducted EMI standard. **Figure 4** shows the CISPR 11 plot for the TPSM53604.

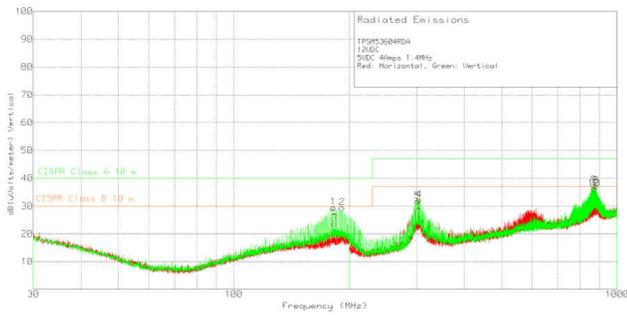


Figure 4. The TPSM53604 EMI performance exceeds the CISPR 11 radiated emissions standard

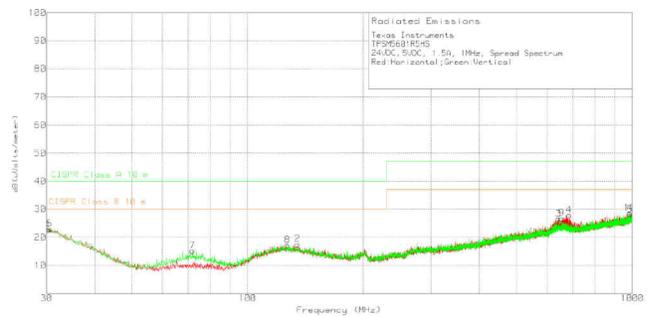
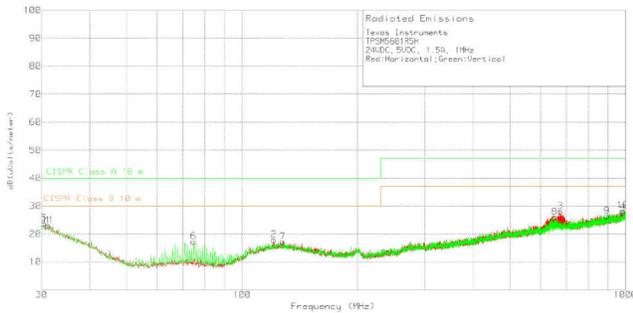


Figure 5. The TPSM5601R5H radiated emissions performance without spread spectrum (left) and with spread spectrum (right)

Figure 5 illustrates how the **TPSM5601R5H** exceeds the CISPR11 radiated emissions standard and is also available with spread-spectrum enabled for further EMI reduction. The TPSM5601R5HS device with triangular spread spectrum uses a $\pm 4\%$ spreading rate (typical) with the modulation rate set at 16 kHz (typical).

Conclusion

Designing a power supply for a factory automation application is a complex task. Depending on the application, the solution must survive a busy factory environment, fit into the available space, comply with EMI requirements, deal with varying bus voltages, and provide protection for humans and machines alike.

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