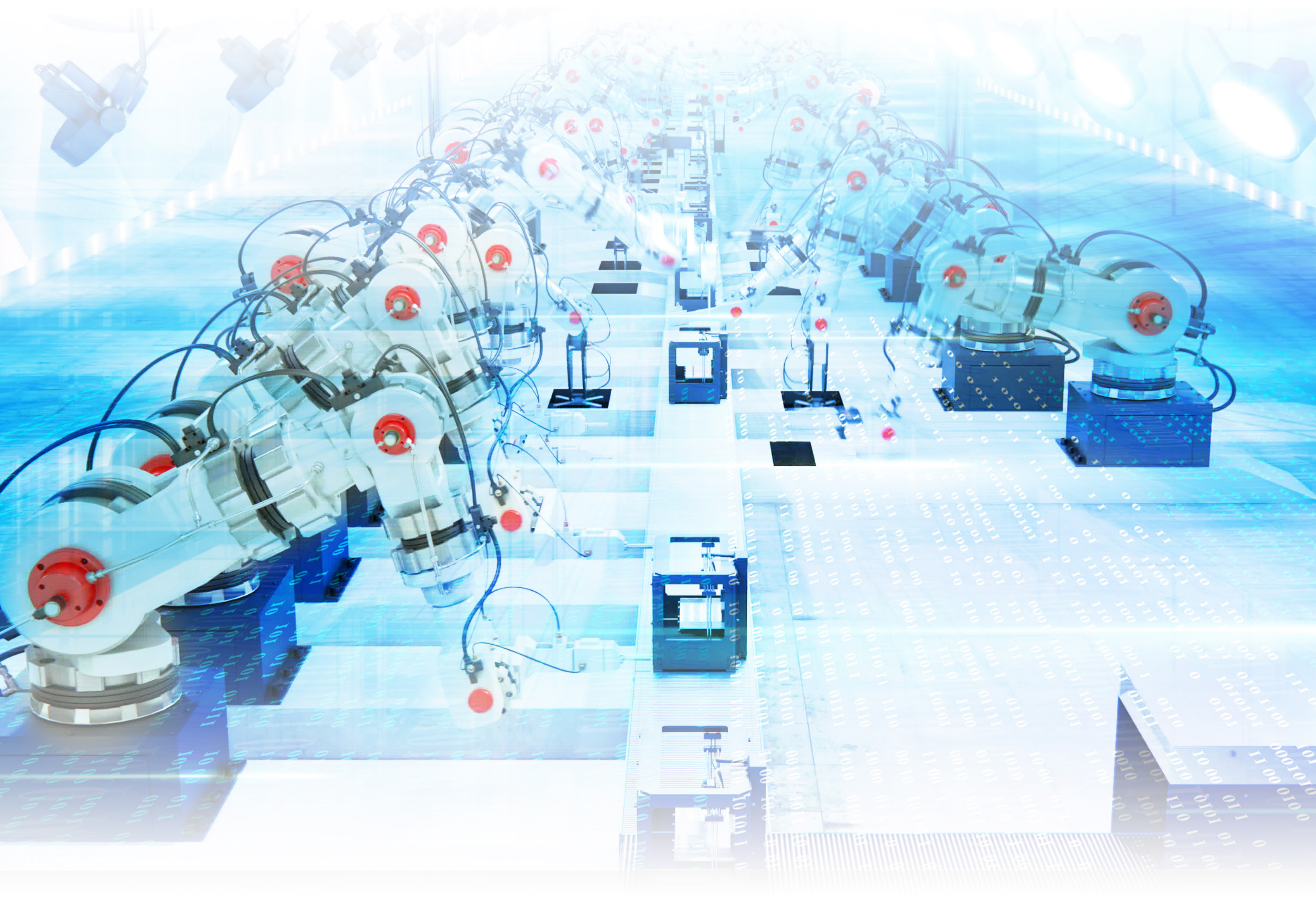
POWER MANAGEMENT FOR THE SMART FACTORY

Design Guide



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Power Management for the Smart Factory

Introduction

Industry 4.0, the current trend of automation and data exchange in manufacturing technologies, continues unabated, fueling the vision of the "smart factory." The smart factory relies on electronic equipment to collect, synthesize, and act upon data. The new technologies and approaches to manufacturing, also dubbed the Industrial Internet of Things (IIoT), have the potential to improve efficiencies and, by extension, profitability. The adoption of IIoT technologies introduces issues in energy efficiency, solution size, system safety, and reliability. This design guide reviews the megatrends underlying the Industry 4.0 revolution and their associated challenges. It then examines new solutions for power management using several case studies.

Figure 1. Industry 4.0 Automation and Data Exchange

Megatrends

An important element of the smart factory is the integration of time-sharing information technology (IT) systems (for data-centric computing) with real-time operational technology (OT) systems that monitor and control events, processes, and devices. This capability is provided by a plethora of sensors deployed across the factory, networked to I/O modules, actuators, controllers, and ultimately to the enterprise cloud ***(Figure 2).*** The networking of manufacturing equipment and sensors enables real-time manufacturing line reconfiguration, increased quality control, advanced sustainable and green practices, supply chain traceability, and overall efficiency.

Figure 2. Industrial Internet: Networking of Equipment and Sensors

The payoff for factory operators is increased utilization and throughput, reduced downtime, predictive maintenance of impending equipment faults, higher standardization, flexible and adaptive manufacturing, and integrated security. Examples of this include GE's Predix™ industrial platform and Siemens' Mindsphere™ operating system. Operators benefit by linking demand to production, optimizing stock management, maintenance, and higher visibility.

System size reduction has allowed the evolution of highly modular manufacturing lines. Consider multiple networked robots performing tasks in an assembly line ***(Figure 3)***. By having similar robots performing functions in sequence, a failing robot's tasks can easily be taken over by the adjacent robot. Likewise, adding intelligence can help optimize the tasks performed by each robot and improves throughput.

Artificial intelligence, or AI, is the ability of computers to perform complex tasks that normally require human intelligence. In conjunction with factory automation equipment, it is another important element of the smart factory. Through robotic process automation of software and machine learning (e.g., IBM's Node-RED, Preferred Networks, Siemens' Mindsphere, and GE's Brilliant Manufacturing Suite), bottlenecks are identified and corrected in real-time.

Figure 3. Robotic Assembly Line

Another significant element of the smart factory is the use of augmented reality (AR) or computer-generated images of a user's view of the real world ***(Figure 4)***. AR provides a composite view that helps improve safety, assembly, and maintenance. Examples include ESI IC.IDO, Oculus Rift™, HTC Vive™, DAQRI Smart Helmet™, Microsoft Hololens™, and Google Glass™.

Figure 4. Service Maintenance Aided by a Handheld Tablet Equipped with AR

The Technology Enablers

All this additional intelligence, networking, and control are enabled by phenomenal advances in sensing, connectivity, processing, and cloud computing. On the factory floor, it is manifested through controllers, sensors, I/Os, and actuators. A controller can be a programmable logic controller (PLC), motor/motion controller, or a distributed control system (DCS) using advanced processors and microcontrollers. Sensors can be either digital or analog and used for proximity, vision, weight, or temperature. Actuators can be robots, valves, motors, computerized numerical control (CNC), contactors, and other moving mechanisms. Inputs and outputs (I/Os) can be digital or analog or even universal I/Os that connect sensors and actuators to controllers.

Figure 5 shows a PLC or an industrial computer that monitors and controls a single manufacturing process. It includes a processor, I/O modules, memory/programming, and a power supply. PLCs and other control systems are orchestrated by software packages like SCADA (supervisory control and data acquisition), that monitor and control multiple interfaces and peripherals.

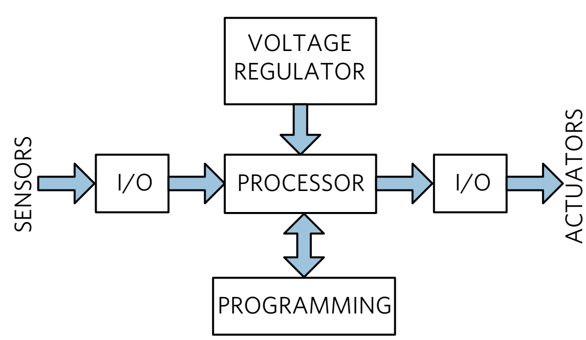

Figure 5. The PLC System

The PLC receives inputs from sensors on the factory floor, processes them locally and drives the proper actuators. Today's sensors, I/Os, and actuators are equipped with internal processors that make simple decisions locally without the need to escalate to the controller, thereby improving throughput. Unless multiple devices need to be considered, the PLC is not even involved. By networking the data generated by all the equipment to the cloud, analytics can be run in real-time using advances in AI to determine the action to be taken.

The Challenges

The proliferation of intelligent, internet-connected equipment in the smart factory requires a proliferation of processors and connectivity interfaces into every controller, sensor, I/O, and actuator on the factory floor. This, in turn, places new requirements on system hardware including: reduced component size to fit additional electronics in the same chassis, improved energy efficiency to perform within the same or lower thermal budget and increased electrical/ mechanical safety and reliability to reduce downtime. In summary, the challenges for the electronic components are:

1. Higher Energy Efficiency
2. Reduced Solution Size
3. Increased Safety and Reliability

In the following sections, we will present a few examples of how power management electronics can come to the rescue in each case.

Challenge 1
Higher Energy Efficiency

Case Study: Design 20W to 30W power supplies with over 90% efficiency for +24V industrial automation systems.

The smaller PCB size that results from miniaturization presents a challenge for thermal dissipation. Thermal management options, such as heatsinks, are ruled out since board space is at a premium. Fans for forced airflow cannot be used due to sealed enclosures that prevent ingress of dust and pollutants. Therefore, it is crucial that the power-supply solution is extremely efficient, while delivering higher power and occupying a smaller area than ever before.

Solving the Power Dissipation Problem

Industrial applications are characterized by a 24V nominal DC voltage bus that has its history in old analog relays and remains the de-facto industry standard. However, the maximum operating voltage for industrial applications is expected to be 36V to 40V for non-critical equipment, while critical equipment, such as controllers, actuators, and safety modules, must support 60V (IEC 61131-2, 60664-1, and 61508 SIL standards). Popular output voltages are 3.3V and 5V with currents varying from 10mA in small sensors to tens of amps in motion control, CNC, and PLC applications. Thus, the obvious choice for industrial control applications is a step-down (buck) voltage regulator.

The most common step-down architecture available is the nonsynchronous buck converter because it is easy for semiconductor manufacturers to design nonsynchronous buck regulators for high voltages. In this architecture, the low-side rectifier diode is external to the IC.

For a 24V input and 5V output, the buck converter works with a duty cycle of about 20%. This means that the internal high-side transistor ***(T in Figure 6)*** conducts only 20% of the time. The external rectifier diode (D) conducts the remaining 80% of the time, which accounts for most of the power dissipation.

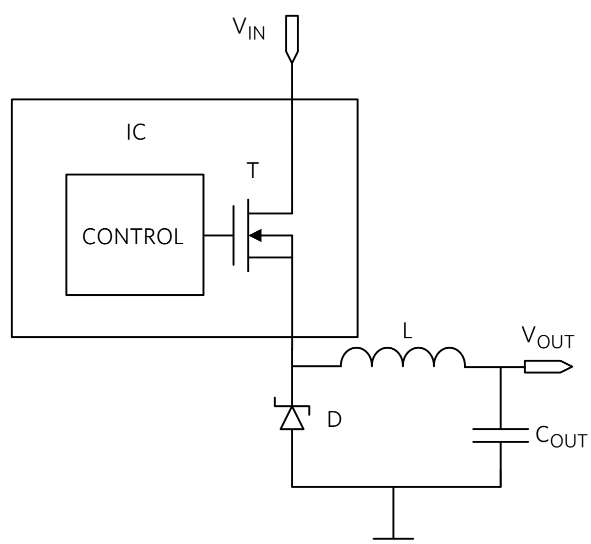

Figure 6. Nonsynchronous Buck Converter

As an example, with a 4A load, a Schottky rectifying diode such as the B560C, exhibits a voltage drop of about 0.64V. Consequently, at 80% duty cycle, the conduction loss (the dominant loss at full load) is approximately equal to (0.64V) x (4A) x (0.80) = 2W.

On the other hand, if we utilize a synchronous architecture ***(Figure 7)***, the diode is replaced with a low-side MOSFET acting as a synchronous rectifier. We can trade off the 0.64V drop across the diode with the drop across the MOSFET transistor's T2 on-resistance, $R_{DS(ON)}$.

In our example, the MOSFET (RJK0651DPB) has an $R_{DS(ON)}$ of only 11mΩ. This leads to a corresponding voltage drop of only (11mΩ) x (4A) = 44mV and a power loss of only (0.044V) x (4A) x (0.80) = 141mW. The MOSFET power loss is about 14 times smaller than the Schottky power loss at full load! Clearly, the logical way to minimize power dissipation is to use synchronous rectification.

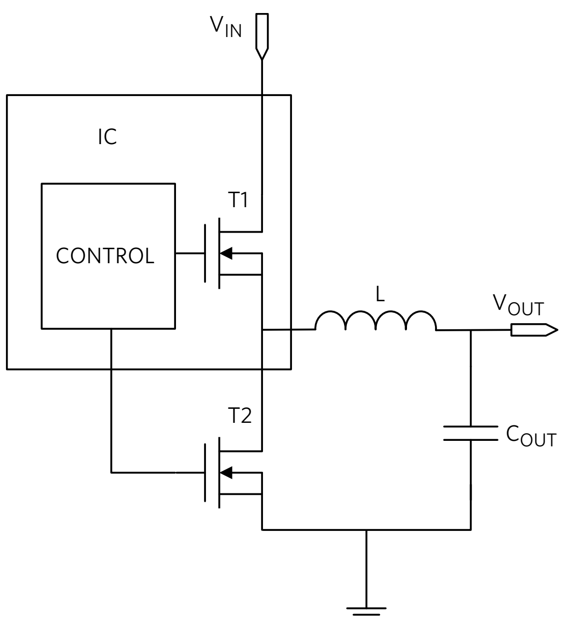

Figure 7. Synchronous Buck Converter

To minimize the overall size of the power-supply circuit, the synchronous rectifier IC should include internal compensation. Newer synchronous rectifiers provide internal compensation for any frequency and output voltage without requiring an oversized output capacitor that hurts bandwidth. The rectifier should also operate at high frequencies to allow the use of small inductors and capacitors.

Naturally, the goal is to fully integrate the entire synchronous rectification half-bridge (T1 and T2) into the IC, as illustrated in *Figure 8*.

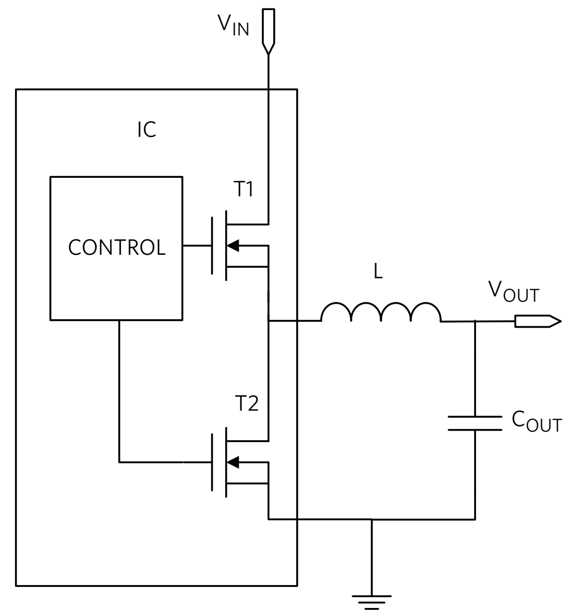

Figure 8. Fully Integrated Synchronous Buck Converter

A Word of Caution on Maximum Input Voltage

While 24V is the nominal rail for factory applications, carefully consider the maximum operating voltage. Select from 28V, 36V, 42V, or 60V input power management solutions available on the market today. With a margin of only 4V, clearly 28V is too close to 24V to provide a reliable margin. Many standards require 60V tolerance, removing the need to make a choice. It is tempting for many designers to choose a device with a 36V maximum input. However, using a 36V input is a high-risk approach for sensors and encoders working on a 24V rail. Even if TVS diodes are used for surge protection, they have a wide tolerance and could still expose equipment to excessive voltages. Unless you know and have modeled every possible surge scenario resulting from long cables and PCB traces, use devices with a 42V or 60V maximum operating voltage even if the standard does not require it.

No Need for Trade-Offs

Our Himalaya family of high-voltage buck converters implements synchronous rectification to obtain the benefit of high efficiency. Himalaya regulators also feature input voltages up to 60V and output currents from 25mA all the way to 50A, with fully integrated dual MOSFETs for devices supporting loads up to 3.5A. Tagged with the slogan "Bye-Bye Schottky," Himalaya buck converters include internal compensation that does not require settling for the trade-offs discussed earlier.

Figure 9 shows the **MAX17503**, 60V, 2.5A fully integrated buck converter, configured for 5V output.

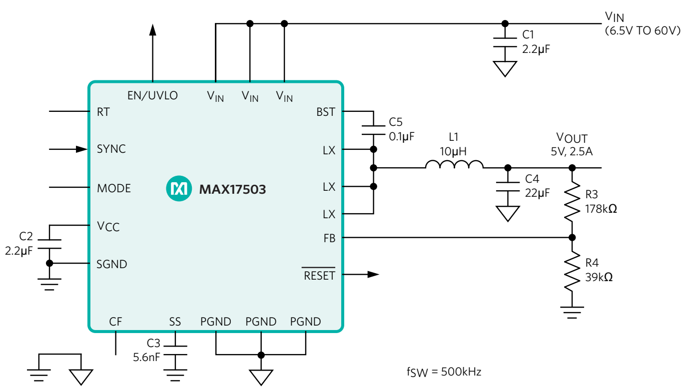

Figure 9. Typical Application Circuit for MAX17503 24V$_{IN}$/5V$_{OUT}$, 2.5A Synchronous Rectification Buck Converter

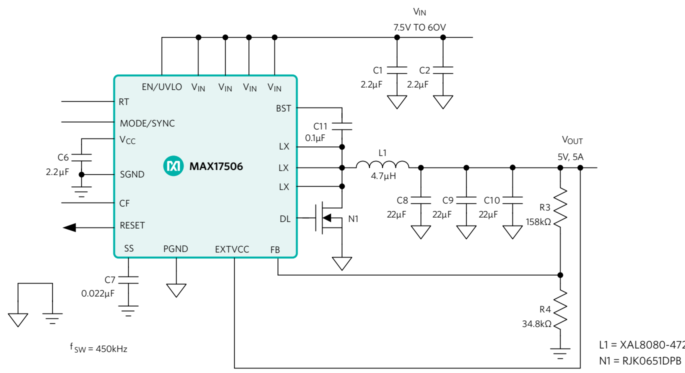

Figure 11. Typical Application Circuit for MAX17506 24V$_{IN}$/5V$_{OUT}$, 4A Synchronous Rectification Buck Converter

An efficiency comparison of the MAX17503 vs. another synchronous solution, based on published specifications, is shown in ***Figure 10***. The MAX17503 shows an efficiency advantage of up to 5%.

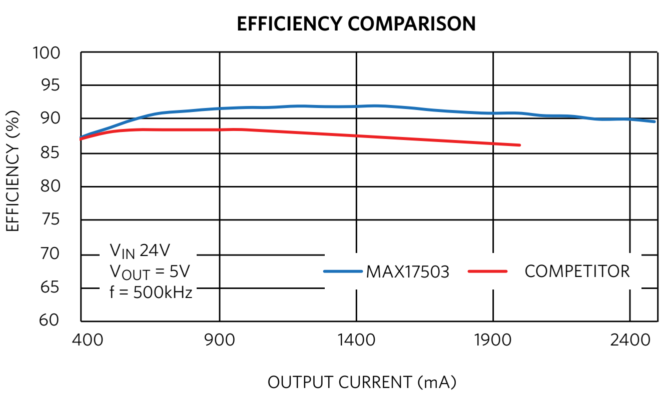

Figure 10. Efficiency Comparison Between MAX17503 and another Synchronous Buck Converter

For higher levels of current, the **MAX17506** synchronous rectification buck converter can be used. ***Figure 11*** shows the MAX17506 application diagram for a 5V, 4A, 20W solution. Pixel rows x Pixel columns x frame rate = Pixel Clock (Hz)

An efficiency comparison of the MAX17506 vs. a nonsynchronous solution, based on published specifications, is shown in ***Figure 12***. For both devices, the test conditions are 24V input and 5V, 4A output. As expected, the synchronous solution exhibits higher efficiency across the entire load current range. At full load (4A), the efficiency of the synchronous solution is above 92% while that of the nonsynchronous device is only about 86%, a difference in efficiency of more than 6%.

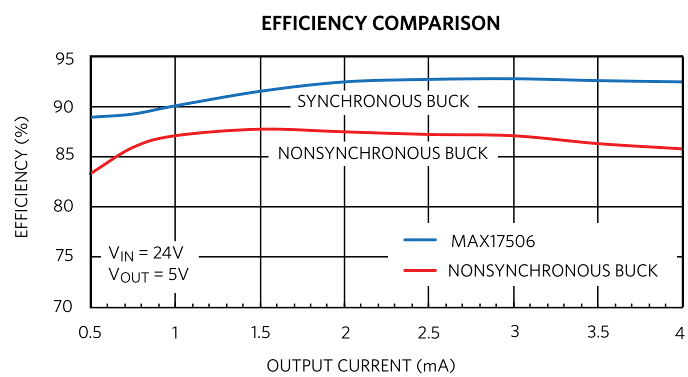

Figure 12. Efficiency Comparison Between MAX17506 and a Nonsynchronous Buck Converter

The MAX17506 synchronous solution demonstrates a clear efficiency advantage that eases thermal management challenges in industrial applications.

With the industry's first 60V synchronous buck regulators, our Himalaya family combines high efficiency and small size to cover a wide range of design requirements.

Case Study: Leverage a power module for faster time to market

Built using Himalaya voltage regulator ICs, the Himalaya power modules series enable cooler, smaller, and even simpler power supply solutions. The **MAXM17504** ***(Figure 13)*** is an easy-to-use, step-down power module that combines a switching power supply controller, dual n-channel MOSFET power switches, a fully shielded inductor, and compensation components in a low-profile, thermally efficient, system-in-package (SiP) framework.

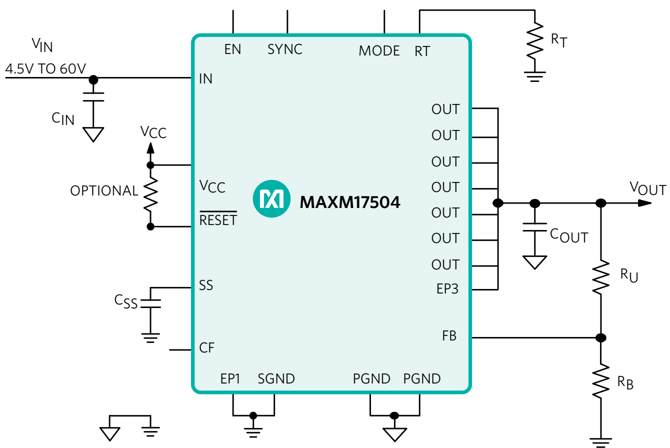

Figure 13. MAXM17504 Power Module

The MAXM17504 operates over a 4.5V to 60V wide input voltage range and delivers up to 3.5A continuous output current with excellent line and load regulation over a 0.9V to 12V output voltage range. The device only requires five external components to complete the total power solution. The device's high level of integration significantly increases reliability, reduces design complexity, reduces manufacturing risks, and offers a true plug-and-play power supply solution that accelerates time-to-market. It can be operated in the pulse-width modulation (PWM), pulse-frequency modulation (PFM), or discontinuous conduction mode (DCM) control schemes. The MAXM17504 is available in a 29-pin, highly thermal-emissive, low-profile 9mm x 15mm x 2.8mm SiP package that reduces power dissipation in the package and enhances efficiency. The package is easily soldered onto a PCB and is suitable for automated circuit board assembly. The device operates over the industrial temperature range from -40°C to +125°C.

Challenge 2
Reduced Solution Size

Case Study: Pack more punch in your small sensor while keeping it cool

Sensors have become ubiquitous in the industrial environment. As they increase in sophistication and shrink in size, sensors enable Industry 4.0 applications. In turn, sensor electronics are becoming more complex, requiring on-board voltage regulators to deliver power more efficiently with minimal heat generation. How do you safely deliver low-voltage power to tiny sensors in high-voltage industrial environments, while minimizing solution size and maximizing efficiency? In this section, we will review a typical industrial sensor architecture and provide a simple solution to this challenge.

Industrial Sensor Applications

Industrial end equipment often operates in harsh electronic environments. Sensors ***(Figure 14)*** detect and diagnose many parameters and make decisions. They must be durable and reliable regardless of the environment. Proximity sensors, temperature sensors, and pressure sensors are used in many industries, including food and beverage, chemical processing, oil, gas, pharmaceutical, manufacturing, construction, water and wastewater, HVAC, and refrigeration systems, and hydraulic and pneumatic applications, to name a few!

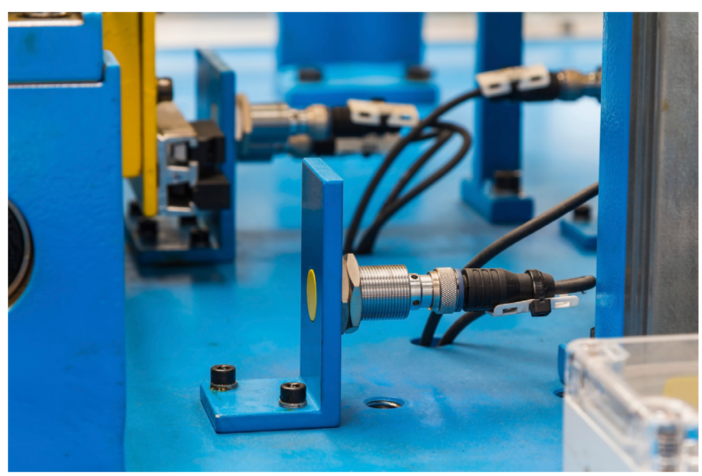

Figure 14. Proximity Sensors in Action

The Sensor System

Sensors may be located anywhere on the factory floor. The sensor "box" includes a front-end transceiver that handles data and routes the power to a step-down voltage regulator, which delivers the appropriate voltage to the ASIC/microcontroller/FPGA and the sensing element.

An example of a digital sensor system is one based on the IO-Link® point-to-point serial communication protocol (*Figure 15*). Numerous point-to-point field bus standards exist in factory automation. IO-Link, used for communicating with sensors and actuators, has been adopted as an international standard (IEC 61131-9) and has been gaining popularity. Like USB, the IO-Link bus carries power (24V) and data. While digital sensors include a transceiver or binary interface, analog sensors work on a 4–20mA loop.

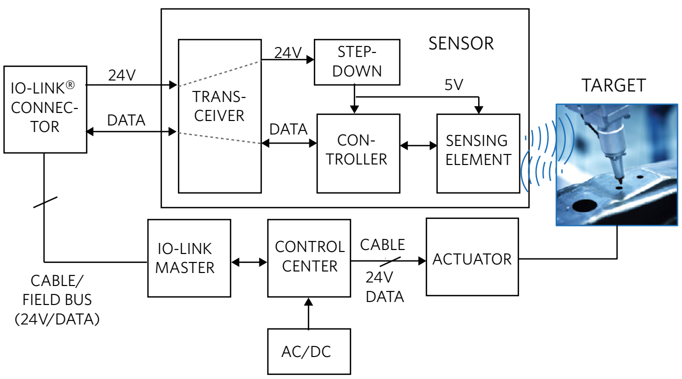

Figure 15. IO-Link-Based Sensor System

The control center receives information from the sensor and sends the appropriate instructions to the actuator via the standard I/O field bus. The sensor "box" includes an IO-Link transceiver interface, which handles data and routes the 24V power to a step-down voltage regulator. The regulator delivers 5V to the microcontroller and to the sensing element.

Safe Low-Voltage Operation

The sensor is typically powered by a 24V DC power source. However, the factory floor can be a very challenging environment, with long cables and strong electromagnetic interference that result in high-voltage transients. Accordingly, the step-down converter inside the sensor must withstand voltage transients of 42V or 60V, which are much higher than the sensor operating voltage. As discussed before, for 24V rails, it is best to rely on devices that have an operating maximum of 42V. According to SELV/PELV/FELV (Safety/Protection/Functional Extra Low Voltage) regulations, an isolated device that handles up to 60V is considered safe to touch. Protection above 60V is provided with the addition of dedicated TVS (transient voltage suppressor) devices.

Sensor Current Consumption

Tables 1a to 1d include a list of the most common sensors and motor encoders and their typical current consumption. These sensors and encoders are more intelligent with microcontrollers and interfaces, and have increased current consumption. Proximity sensors **(Table 1a)** are by far the most common and are categorized as optical, inductive, capacitive, photoelectric, and ultrasonic.

Table 1a. Proximity Sensor Typical Current Consumption

Proximity Sensor	I (mA) Traditional	I (mA) Intelligent
Optical	80	200
Inductive	300	600
Capacitive	100	300
Photoelectric	100	300
Ultrasonic	45	100

Pressure sensors **(Table 1b)** are based on the piezolelectric effect or on strain gauge. In piezoelectric sensors, the crystal produces a voltage proportional to the pressure. In a strain gauge sensor, the silicon resistance varies with pressure.

Table 1b. Pressure Sensor Typical Current Consumption

Pressure Sensors	I (mA) Traditional	I (mA) Intelligent
Piezo-Resistive or Silicon Strain Gauge	20	100

Rotary or linear encoders **(Table 1c)** are widely used in sensing speed and position of electric motors. Plus, due to the proximity to the motor's moving parts, encoder electronics need to operate up to +125°C.

Table 1c. Motor Encoder Typical Current Consumption

Motor Encoder	I (mA) Traditional	I (mA) Intelligent
Rotary Optical	20	500
Linear	10	300

Temperature is often measured with a 100Ω platinum resistor (RTD) as the sensing element **(Table 1d)**.

Table 1d. Resistance Temperature Detector

RTD	R (Ω)
R	100

Powering the Sensing Elements

Most industrial sensing elements need an input voltage significantly lower than that supplied by the system to power digital and analog ICs. With increasing currents, as illustrated earlier, traditional LDO regulators are not viable solutions due to excessive heat dissipation. *Figure 16* shows the case in which an LDO is used to step-down a 24V system voltage to 5V to power the microcontroller and the sensing elements. This is a lossy process (η = 21%) that ends up costing 1.3W of input power.

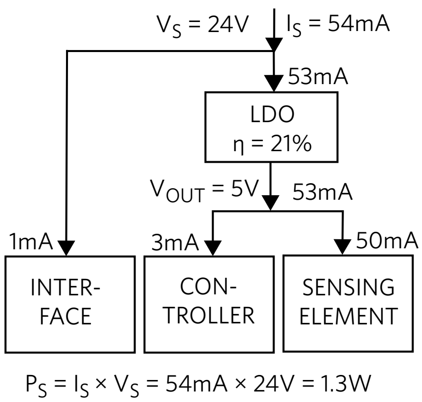

Figure 16. LDO-Powered Sensor

In *Figure 17*, the voltage step-down is performed by a simple switching regulator with 85% efficiency at 50mA.

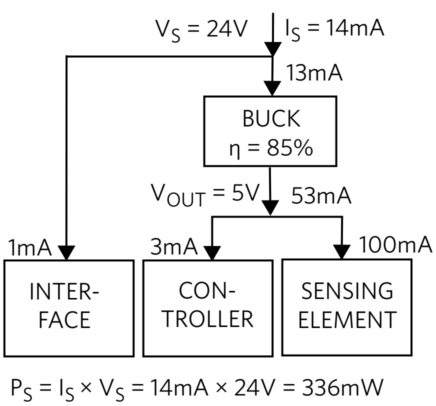

Figure 17. Buck-Powered Sensor

Here, the buck converter transfers power with efficiency higher than an LDO, resulting in an input power of only 336mW.

A Tailor-Made Buck Converter Family

The **MAX15062** and **MAX15462** high-efficiency, high-voltage, synchronous step-down DC-DC converters are part of the Himalaya family. They save space with integrated MOSFETs and operate over the 4.5V to 60V and 4.5 to 42V input voltages, respectively. Delivering output current up to 300mA, the devices are ideal for sensor applications. The low-resistance, on-chip MOSFETs ensure high efficiency at full load and simplify PCB layout. The devices offer programmable switching frequency to optimize solution size and efficiency and are available in compact 8-pin (2mm x 2mm) TDFN packages. Simulation models are also available. We will further examine the MAX15462 in our discussion. Since both the MAX15462 and MAX15062 are pin-compatible, they have the same performance—the only difference is the maximum input voltage they support.

Figure 18 shows the typical application circuit for the 5V fixed configuration—optimized for small PCB size—that delivers 5V to a load up to 300mA.

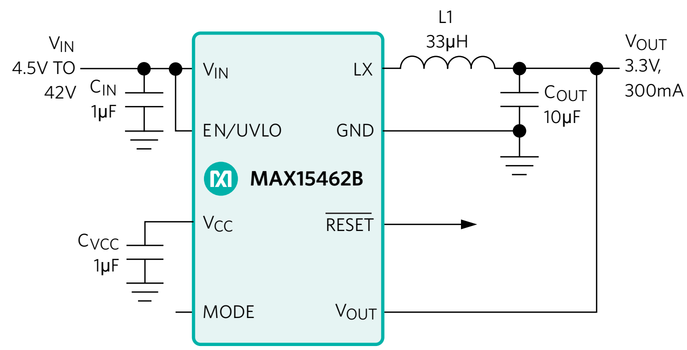

Figure 18. MAX15462B Typical Application Circuit

The A version has a 3.3V fixed output voltage and the C version supports adjustable output voltages.

Figure 19 shows the typical efficiency curves at various input voltages with 5V output. With a 24V input, the peak efficiency is 90%. As shown earlier, these devices decisively outperform any LDO-based solution in terms of power savings.

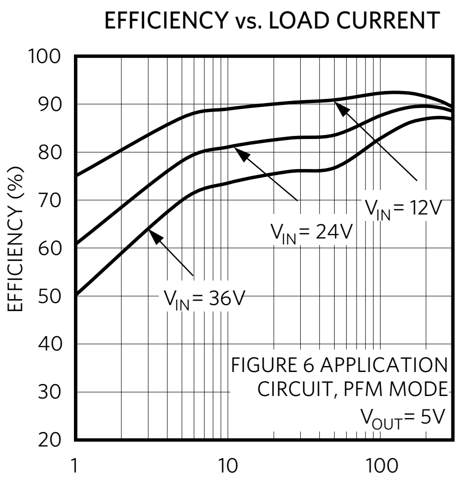

Figure 19. MAX15462B Typical Efficiency Curves

A PCB layout for the MAX15462 operating at $24V_{IN}$ with a 300mA output is shown in *Figure 20*. While Himalaya ICs have transformed the industry with their small size, the constraints of the one-dimensional layout and size of the passives still stress utilization (net component area of 28.12mm²). Compared to a traditional synchronous buck regulator solution that only delivers 150mA, this solution is 12.5% smaller.

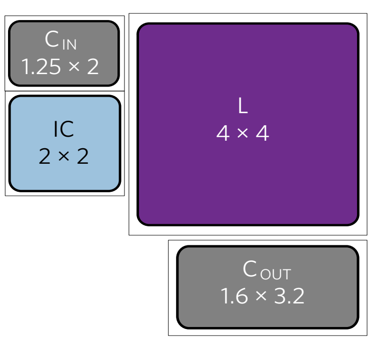

Figure 20. MAX15462 Buck Converter Layout (Net Component Area 28.12mm²)

Note that the manufacturing guidelines on the clearance between components will add additional area. This approach requires some knowledge of switching regulator design/testing to optimize component value/size.

Traditional Module Solutions Fall Short

To specifically address ease of use and reduce time to design and testing, many vendors have developed switching regulator modules. A typical switching regulator module that houses the buck converter IC and the inductor in a single package is shown in *Figure 21.* This solution attempts to address the ease-of-design and efficiency requirements, but clearly falls short in the PCB area utilization. In this example, at a net component area of 47.2mm², the module solution takes up 68% more area than the discrete DC-DC regulator solution shown in *Figure 20*.

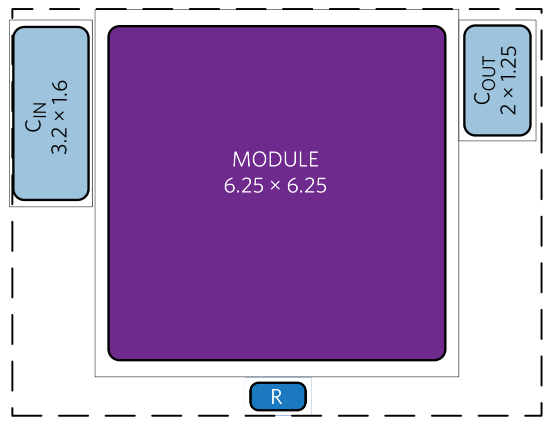

Figure 21. Traditional Buck Converter Module Layout (Net Component Area 47.2mm²)

Case Study: Add more power density than ever to your small sensor

The electronics industry continues to find ways to pack more data in the same space, first with Moore's Law for silicon, and then beyond ("More than Moore") with sophisticated multidimensional IC packaging techniques. These techniques help push the power density envelope by packing more Watts in the same square millimeters. In this section, we introduce a disruptive approach in pushing the power density envelope for industrial sensors even further with a novel, miniaturized, easy-to-design, high-performance solution.

Himalaya uSLIC™ Packaging Technology

Can more power be delivered in a solution size even smaller than Himalaya-based power supply solutions without sacrificing the efficiency and reliability benefits? Effectively, the quest is for LDO-like size with all the benefits of a switching regulator! A revolutionary technology has been developed which co-packages a state-of-the-art Himalaya buck converter with passive components in a micro-sized system-level IC (uSLIC). The Himalaya uSLIC power module delivers more power in a smaller space than ever before, with high efficiency, ease of use, and faster time to market.

uSLIC Power Module Specifications

The uSLIC power module vertically integrates the inductor and the buck converter IC, dramatically reducing the PCB space occupied by the standard buck converter solution. This still meets expectations of high-voltage tolerance and high-temperature operation. The **MAXM17532** module ***(Figure 22)*** is available in a low-profile, compact 10-pin, 2.6mm x 3mm x 1.5mm uSLIC package. The device operates over a wide temperature range from -40°C to +125°C. ***Figure 22*** shows the dramatic size reduction achieved with the MAXM17532, 100mA, 42V buck converter uSLIC module. The ability to meet 42V maximum operating voltage (not just absolute maximum) and support output voltages below 1.8V (to support the latest digital ICs), distinguishes a highly reliable product from other run-of-the mill varieties. For higher loads, the **MAXM15462** provides up to 300mA output in the same form factor.

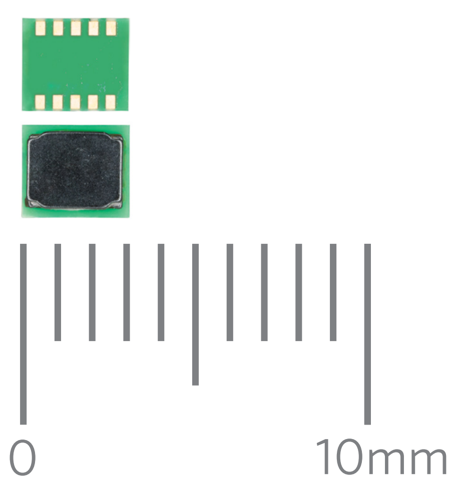

Figure 22. Less than 8mm² Footprint of the MAXM15462 uSLIC Buck Converter

Miniaturized Size

Figure 23 shows the PCB for a complete power supply solution using the MAXM17532 switching regulator module. Thanks to the vertical integration of the inductor, the net component area is a mere 14.3mm².

Compared to the IC solution of Figure 20, the uSLIC module solution's net component area is 2x smaller. Compared to the traditional module of ***Figure 21***, the uSLIC module solution is 3.3x smaller.

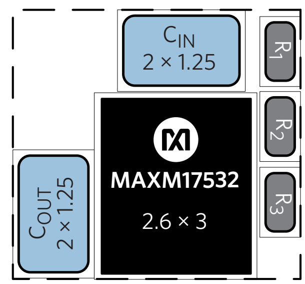

Figure 23. MAXM17532 uSLIC 5V$_{OUT}$, 100mA Buck Solution (Net Component Area 14.3mm²)

Figure 24 shows the uSLIC housed in a small, M8-sized proximity sensor. Clearly, the uSLIC module consumes minimal space in this application.

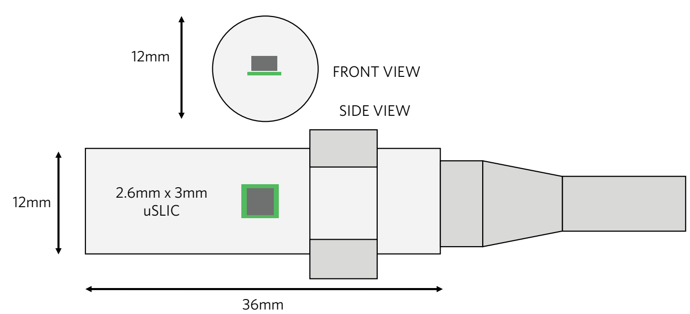

Figure 24. Buck IC, Inductor, and Sensor Size Comparison in a Proximity Sensor Application

High Efficiency

Figure 25 shows the efficiency of the MAXM17532 with 5V output and various input voltages. Despite the small size, the buck converter delivers high efficiency with peaks up to 90%.

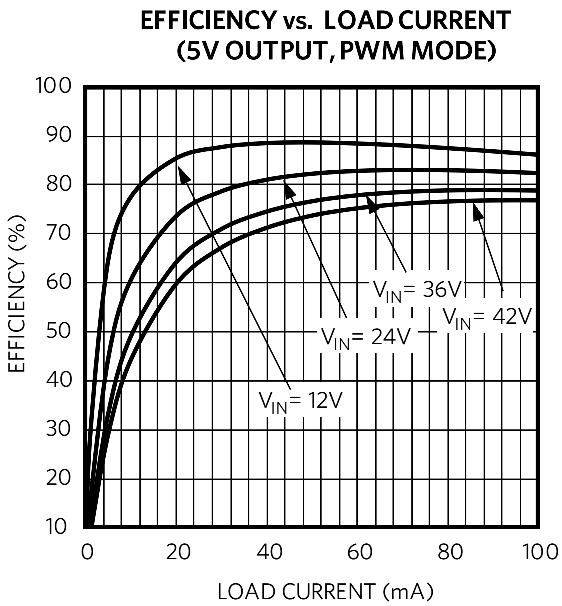

Figure 25. MAXM17532 uSLIC Power Module Efficiency

Low Emissions

The module's PCB layout is designed to minimize trace lengths and eliminate ground loops for minimum radiated emissions. The use of high-frequency ceramic capacitors minimizes conducted emissions. *Figure 26* shows that the MAXM17532 radiated emission comfortably meets the CISPR22 CLASS B specification.

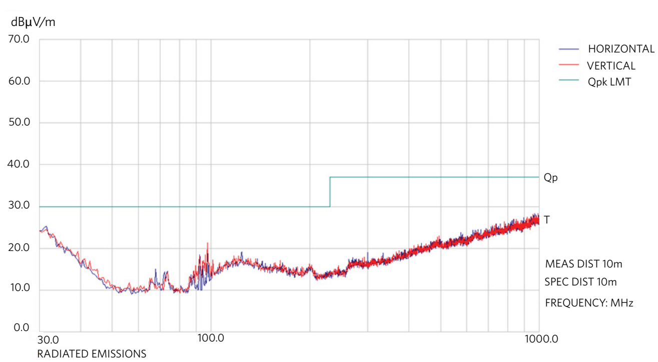

Figure 26. MAXM17532 Radiated Emission

Figure 27 shows that the MAXM17532-conducted emission also comfortably meets the CISPR22 CLASS B specification.

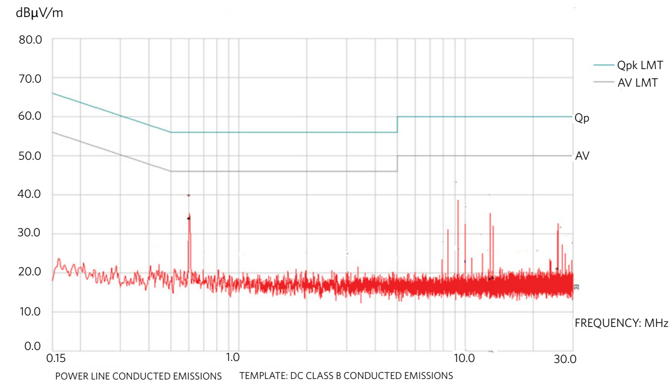

Figure 27. MAXM17532 Conducted Emission

Drop, Shock, and Vibration Tolerance

Beyond thermal, electrical, and electromagnetic performance, it is important that power supplies are tolerant of mechanical stresses. Himalaya uSLIC modules meet JESD22-B103/B104/B111 standards for drop, shock, and vibration guaranteeing fool-proof operation in sensors deployed in harsh industrial, medical, defense, and consumer applications.

For Higher Current

For higher loads, the MAXM15462 Himalaya uSLIC module outputs up to 300mA with the same package footprint and provides similar benefits for solution size, efficiency, CISPR 22 compliance and shock, drop, and vibration tolerance.

Challenge 3
Increased Safety and Reliability

Case Study: Design smaller, more reliable, more efficient isolated power supplies

Isolated DC-DC voltage regulators are found in the most diverse applications. Although an isolated solution is more complex than a non-isolated one, there is still an expectation for it to fit in a small space and be highly efficient. In this case study, we discuss the reasons for isolation in low-voltage power conversion systems and review an isolated digital I/O module as an example.

Low-Voltage Isolated Systems

According to SELV/FELV regulations, input voltages below 60V are considered inherently safe to touch, but the need for isolation in this operating range is still pervasive for functional safety and reliability reasons. In this voltage range, the power-supply electronic load, typically a very delicate and expensive microcontroller, needs protection. It could readily self-destruct if accidentally exposed to high voltage.

Isolation also prevents ground loops, which occur when two or more circuits share a common return path. Ground loops produce parasitic currents that can disrupt the output voltage regulation as well as introduce galvanic corrosion of the conducting traces. This is a phenomenon that degrades equipment reliability. Accordingly, isolated power supplies are routinely utilized in industrial, consumer, and telecom applications concerned with the protection of sensitive loads and the long-term reliability of equipment.

Digital I/O System Example

The I/O modules of automated factories (*Figure 28*) are at the heart of factory process control and are prime examples of low-voltage isolated systems.

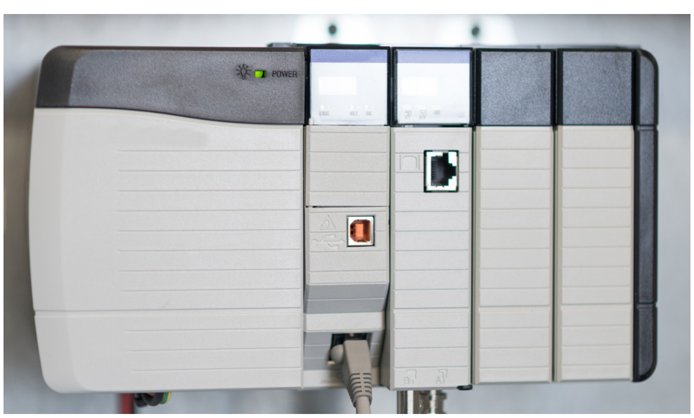

Figure 28. Digital I/O Module

Figure 29 illustrates a generic digital I/O module and factory system block diagram. A central hub takes the AC line power and converts it to 24V DC, delivered to the I/O module together with the corresponding digital input (DI) and digital output (DO) data. With electric and magnetic interference and overvoltages, the factory environment is harsh and requires additional protection for sensitive electronics. Each module's PLC is powered via an isolated step-down voltage regulator. At the digital input module (DIM), a rugged voltage-level translator interface powers the sensor, receives its information, and passes it along to the PLC via a digital isolator or optocoupler. A similar power, signal, and isolation chain on the digital output module (DOM) leads to the on-board driver, which interfaces to the external actuator. A power-efficient and compact implementation of the isolated step-down converter in the input and output modules is necessary for modern systems.

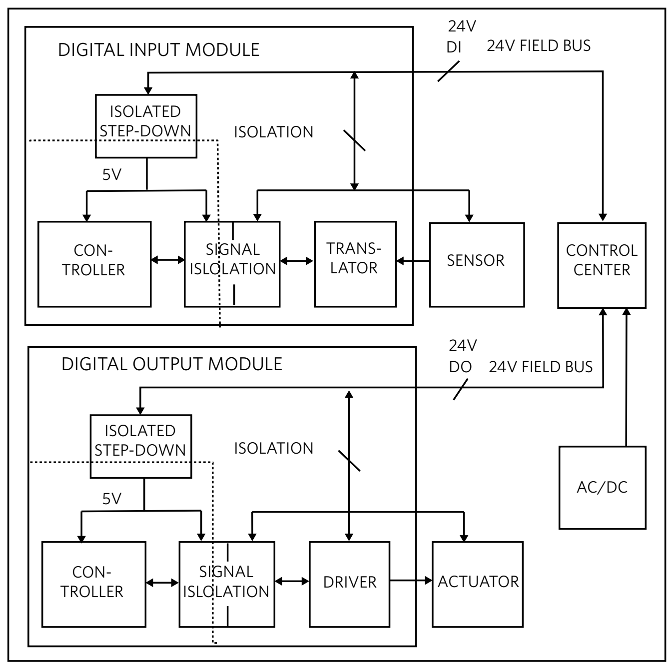

Figure 29. Digital I/O Module and Factory System Block Diagram

Traditional Implementation

Using galvanically isolated transformers with PWM control is the most common architecture for an isolated DC-DC power supply. The flyback converter is the classic architecture that produces an isolated output. ***Figure 30*** shows the traditional implementation. During the "ON" time of the transistor T1, the voltage across the primary winding is positive (equal to V_{IN}) and the voltage across the secondary winding is negative. Consequently, the Shottky diode (SD) prevents energy from passing to the output and the energy is stored in the transformer. During the "OFF" time of T1, the primary winding inverts its voltage, which allows the energy to be released to the output. The control loop is quite complex, often requiring a shunt regulator (TL431A) on the secondary to regulate the voltage at the output. An optocoupler and error amplifier on the secondary-side of the transformer provide the isolated feedback signal needed to close the PWM control loop to the primary side.

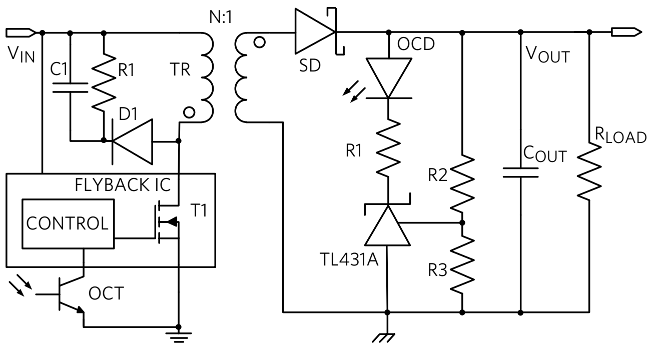

Figure 30. Flyback with Optocoupler

This solution, which utilizes two ICs and many passive components, is typically expensive, inefficient, and space consuming.

No-Opto Flyback Implementation

The patented **MAX17690** is a peak current-mode, fixed-frequency switching controller, that is part of our Rainier isolated "Bye Bye Optocoupler" solutions. It is specifically designed for the isolated flyback topology operating in discontinuous conduction mode (DCM). Since the transformer is magnetically coupled, the secondary winding voltage is reflected on the primary winding. The MAX17690 samples and senses this isolated output voltage on the secondary-side directly from the primary-side flyback waveform during the off-time of the primary switch. No auxiliary winding or optocoupler is required for output voltage regulation. Similar to a traditional flyback, 3% to 5% regulation accuracy is possible. However, with the no-opto implementation the solution size is reduced by 30%. ***Figure 31*** shows a typical application of a shunt regulator (TL431A) on the secondary that regulate the voltage at the output. An optocoupler and error amplifier on the secondary-side of the transformer provide the isolated feedback signal needed to close the PWM control loop to the primary side.

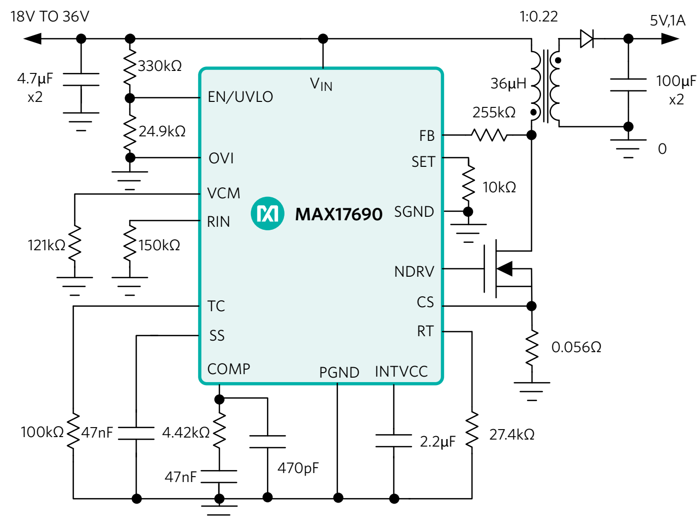

Figure 31. No-Opto Flyback Controller

The MAX17690 is designed to operate over a wide supply range from 4.5V to 60V. The switching frequency is programmable from 50kHz to 250kHz. The EN/UVLO pin allows the user to precisely turn on/off the power supply at the desired input voltage. The MAX17690 provides input overvoltage protection through the OVI pin. The 7V internal LDO output of the MAX17690 makes it suitable for switching both logic-level and standard MOSFETs used in flyback converters. With 2A/4A source/sink currents, the MAX17690 is ideal for driving low $R_{DS(ON)}$ power MOSFETs with fast gate transition times. The MAX17690 provides an adjustable soft-start feature to limit the inrush current during startup. Application Note 6394: *How to Design a No-Opto Flyback Converter with Secondary-Side Synchronous Rectification* is available to provide additional understanding of the topology.

The MAX17690 provides temperature compensation for the output diode forward-voltage drop. With robust hiccup protection and thermal protection schemes, it is available in a space-saving, 16-pin, 3mm x 3mm TQFN package with a temperature range from -40°C to +125°C.

If tight regulation accuracy is not critical and a small, compact, isolated power supply solution is required, a novel iso-buck topology is an option, as outlined in the blog, *Why Iso-Buck Converters are Better than Flyback Converters.*

Case Study: Choose the right protection for your smart load for improved system safety and reliability

Protection circuits are the unsung heroes of today's electronics. The long electrical chain, from the AC line to the digital load, no matter the application, is interspersed with fuses and transient voltage suppressors (TVS) of all sizes and shapes. While common issues like ESD protection and pin-to-pin short circuits are handled within ICs, there are additional aspects to consider for safety and reliability. Along the electrical path, electrical stressors—such as inrush currents due to storage capacitors, reverse currents due to power outages, overvoltages, and undervoltages induced by inductive load switching or lightning—can damage precious electronic loads. This is true for microprocessors and memories, which are built with fragile sub-micron, low-voltage technologies. Layers of protection are necessary to handle these potentially catastrophic events ***(Figure 32)***.

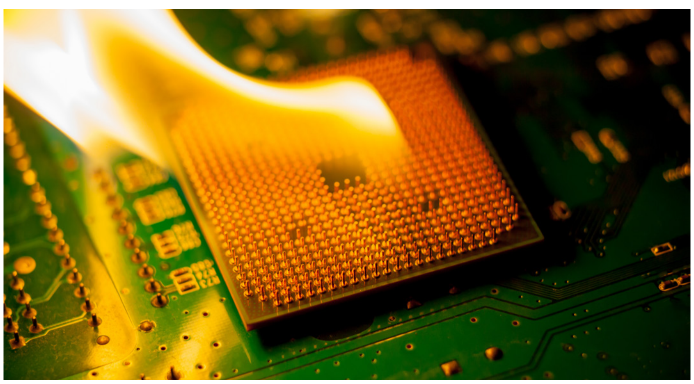

Figure 32. Unprotected CPU on Fire

Typical System Protection

Figure 33 shows a typical system protection scheme around the smart load, for example, a microprocessor. A DC-DC converter—complete with control (IC_2), synchronous rectification MOSFETs (T_3, T_4), associated intrinsic diodes (D_3, D_4), and input and output filter capacitors (C_{IN}, C_{OUT})—powers the microprocessor. A voltage surge coming from the 48V power bus (V_{BUS}), if directly connected to V_{IN}, would have catastrophic consequences for the DC-DC converter and its load. For this reason, front-end electronic protection is necessary. Here the protection is implemented with a controller (IC_1) that drives two discrete MOSFETs, T_1 and T_2. Some control scheme designs use discrete components or a CPLD/microcontroller.

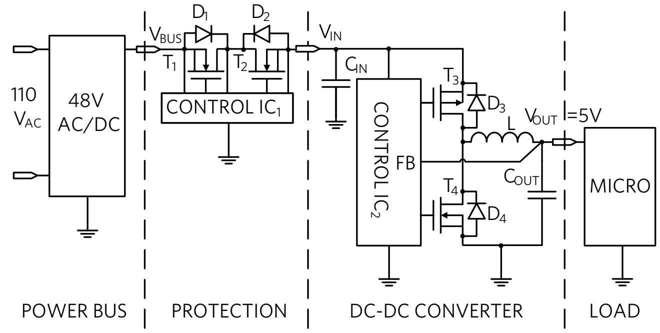

Figure 33. Typical Electronic System with Protection

The protection electronics must handle fault conditions such as overvoltage/undervoltage, overcurrent, and reverse-current flow within the limits of its voltage and current rating. If the expected voltage surge exceeds the protection electronics ratings, additional layers of protection are added, in the form of filters and TVS devices.

Overvoltage Protection

Figure 34. Hot Plug-In Causes Voltage Surges

Arc fault protectors and TVS diodes protect against lightning surges and catastrophic high-voltage events. But protection is still needed when you get down to the main input bus (48V in the example above) or a typical 24V in industrial applications. Hot plugging ***(Figure 34)*** causes supply bounce while ringing, due to long cable inductance ***(Figure 35)***, also causes voltage surges.

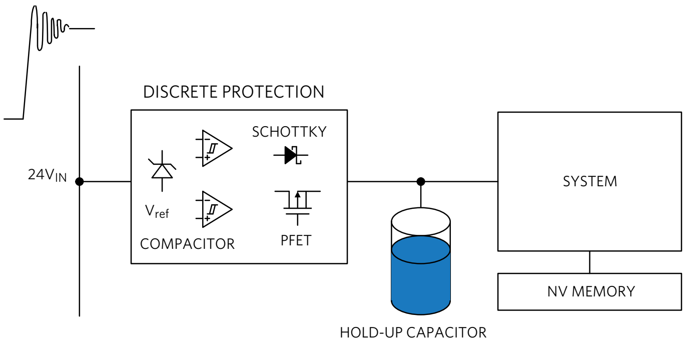

Figure 35. Cable Ringing Causes Voltage Surges

Overcurrent Protection

Figure 36. Heat-Damaged Electric Wires — Cable Faults Result in Short-Circuit Faults

Even when the incoming voltage is confined within the allowed operating range, problems can persist. Upward voltage fluctuations and large storage capacitors generate high CdV/dt inrush currents that can blow a fuse or overheat the system ***(Figure 36)***, which reduces its reliability. Accordingly, the protection circuit ***(Figure 37)*** must be equipped with a current-limiting mechanism. Also, while in operation, it is not uncommon to face both hard and soft short-circuit faults, which need to be protected against.

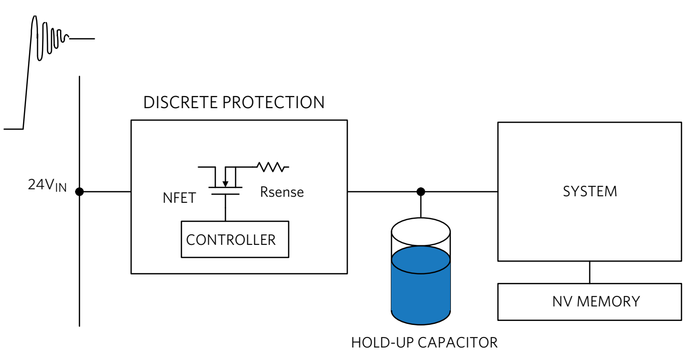

Figure 37. Current-Limit Protection Illustration

Reverse-Voltage/Reverse-Current Protection

Supply reversal can also occur due to improper cabling or operator errors that require reverse-polarity protection. Reverse-current protection is also an important need. In motor drive applications, the DC motor current is PWM-controlled with a MOSFET bridge driver. During the OFF portion of the PWM control cycle, the current recirculates back to the input capacitor. Similar applications exist in other factory automation equipment, which result in sinking current that cause equipment failures.

Discrete Protection Circuits

Protection in most systems starts as a simple discrete circuit, typically designed to minimize component costs ***(Figure 38)***. However, as the final system goes through multiple phases of type testing and field deployments, more and more protection must be added. This increases costs and PCB area. A smart design practice is to first choose intelligent system protection ICs to mitigate problems late in the product development cycle.

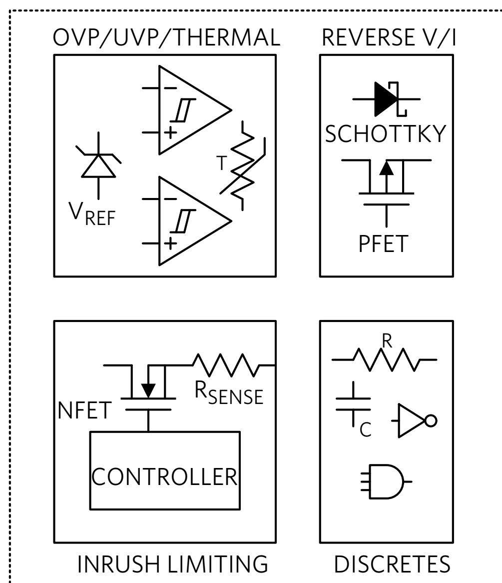

Figure 38. Discrete Protection Circuits Found in Most Systems

Integrated Solution

Figure 39 shows an integrated protection circuit that addresses overvoltage, reverse polarity, current limiting, reverse current, and short-circuit protection with all the benefits of an e-fuse and surge stopper. Designers can easily implement robust protection in their smart factory equipment and pass compliance with configurable pins to set UVLO/OVLO, current limit, real-time voltage and current monitoring, current thermal foldback, thermal shutdown, and other features.

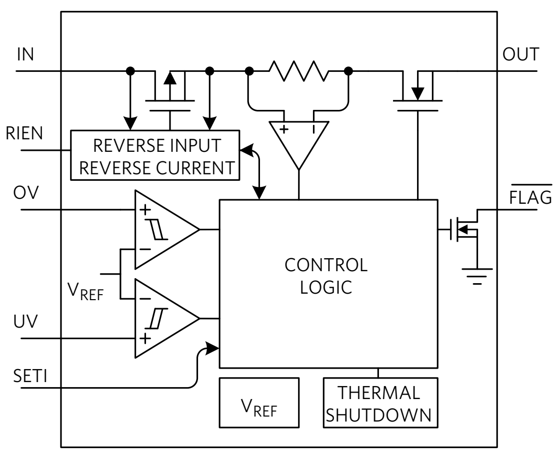

Figure 39. Integrated Protection in a Single IC

Integrated Protection Family

The Olympus family of protection ICs provides adjustable overvoltage and overcurrent protection. These devices protect downstream circuitry from positive and negative input voltage faults up to ±60V. The overvoltage lockout threshold (OVLO) is adjusted with optional external resistors to any voltage between 5.5V and 60V. The undervoltage lockout threshold (UVLO) may be adjusted with optional external resistors to any voltage between 4.5V and 59V. Olympus devices feature programmable current-limit protection up to 1A. The current-limit threshold is programmed by connecting a suitable resistor to the SETI pin. Uniquely, the same SETI pin is used to read out the current at any time during operation. Both the **MAX17608** and **MAX17610** block current flowing in the reverse direction, whereas, the **MAX17609** allows current to flow in the reverse direction while still maintaining the reverse-voltage protection feature. The devices also feature thermal shutdown protection against internal overheat. They are available in a small, 12-pin (3mm x 3mm) TDFN-EP package. The devices operate over the -40°C to +125°C extended temperature range. Multiple devices in the Olympus family can be concatenated together to support protection against higher currents. For example, two **MAX17525** 4.5V to 60V, 6A protection ICs can be connected to support up to 12A. Many devices also support a novel thermal foldback feature that limits current delivered by using temperature as a guide.

Electronic loads require protection from the effects of power outages and fluctuations, inductive load switching, and lightning. A typical protection solution with a low level of integration leads to inefficiencies in terms of PCB space and a large bill of materials. The MAX17608–MAX17610 integrated, highly flexible, low $R_{DS(ON)}$ protection ICs provide direct and reverse-voltage/current protection with minimal BOM and PCB space.

Summary

Table 2 is a summary of an example power management approach for the smart factory.

Table 2. Power Management for the Smart Factory

Challenge	Application	Products	Product Type
Energy Efficiency	Actuators, PLC, I/O, Motion Control	MAX17503, 60V, 2.5A MAX17506 60V, 5A	IC
		MAXM17504 60V, 3.5A	SIP Module
Small Size	Sensors, Encoders, I/Os	MAX15062 60V, 300mA MAX15462 42V, 300mA	IC
		MAXM17532 100mA MAXM15462 300mA	uSLIC Module
Safety and Reliability	Isolation	MAX17690 60V, 5Vout, 1A No-Opto	IC
	Protection	MAX17608 60V, 1A MAX17525 60V, 6A	IC

Conclusion

As the current trend of automation and data exchange in manufacturing technologies, also known as smart factories or Industry 4.0, continues unabated, it will rely on new technologies and approaches to achieve higher manufacturing efficiencies. The adoption of these technologies introduces challenges in terms of energy efficiency, miniaturization, and system reliability. For each challenge we presented, we also showed examples of how power management can effectively help users realize smart factories in their industry. For energy efficiency, we proposed two highly integrated, high-power buck converter ICs for high-performance systems (MAX17503 and MAX17506 from the Himalaya IC family) and a power module for ease of design and fast time-to-market (MAXM17504 from the Himalaya SiP module family). Similarly, for sensors, we proposed two low-power, highly integrated ICs (MAX15062 or MAX15462 from the Himalaya IC family), and two fully integrated power modules for highly space-constrained applications (MAXM17532 and MAXM15462 from the Himalaya uSLIC power module family). Finally, for safety and reliability, we presented a no-opto isolated flyback converter IC (MAX17690 from the Rainier isolated family) and two highly integrated protection ICs (MAX17608 and MAX17525 from the Olympus protection family). These power management solutions overcome the critical challenges faced by today's smart factories.

Glossary

Augmented Reality: A technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view that improves production tasks like assembly and maintenance.

FELV: Functional Extra Low Voltage. A non-isolated circuit below 60V.

Industry 4.0: The current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of Things and cloud computing. Industry 4.0 creates what has been called a "smart factory."

Industrial Internet of Things (IIoT): The networking of manufacturing equipment for real-time quality control, sustainable and green practices, supply chain traceability, and overall supply chain efficiency.

Internet of Things (IoT): The network of physical objects that feature an IP address for internet connectivity and the communication that occurs between them.

PLC: Programmable logic controller. An industrial computer that monitors and controls a single manufacturing process. A PLC board is comprised of a CPU, I/O modules, memory/programming, and power supply.

SCADA: Supervisory, Control and Data Acquisition. A hardware and software framework that monitors and controls multiple interfaces and peripherals through PLCs and other control systems.

SELV: Separated Extra Low Voltage. An isolated circuit below 60V. Such circuits are considered safe to the touch.

Product Selector Tables

Himalaya Wide Input Synchronous Voltage Regulators

<table>
<tr><th rowspan="2">Part</th><th>I_{OUT} (A)</th><th colspan="2">V_{IN} (V)</th><th colspan="2">V_{OUT} (V)</th><th rowspan="2">Frequency Range (MHz)</th><th rowspan="2">PFM Option</th><th rowspan="2">Package Type</th><th rowspan="2">Package Size (mm)</th></tr>
<tr><th>Max</th><th>Min</th><th>Max</th><th>Min</th><th>Max</th></tr>
<tr><td colspan="10">4.5V to 60V/76V Single-Output, Step-Down Regulators</td></tr>
<tr><td>MAX17761</td><td>1.0</td><td>4.5</td><td>76.0</td><td>0.8</td><td>68.4</td><td>0.2 to 0.6</td><td>Yes</td><td>TDFN</td><td>3.0 x 3.0</td></tr>
<tr><td>MAX17550</td><td>0.025</td><td rowspan="3">4.0</td><td rowspan="3">60.0</td><td rowspan="3">0.8</td><td rowspan="3">54.0</td><td rowspan="3">0.1 to 2.2</td><td rowspan="3">Yes</td><td rowspan="3">TDFN/µMAX</td><td rowspan="3">2.0 x 3.0/3.0 x 5.0 pin-compatible</td></tr>
<tr><td>MAX17551</td><td>0.050</td></tr>
<tr><td>MAX17552</td><td>0.1</td></tr>
<tr><td>MAX15062[1]</td><td>0.3</td><td rowspan="11">4.5</td><td rowspan="11">60.0</td><td rowspan="11">0.9</td><td>53.0</td><td>0.5</td><td>Yes</td><td>TDFN</td><td>2.0 x 2.0</td></tr>
<tr><td>MAX17501[1]</td><td>0.5</td><td rowspan="2">55.0</td><td>0.3/0.6</td><td>Yes[3]</td><td>TDFN (TSSOP[3])</td><td>2.0 x 3.0 (3.0 x 3.0)</td></tr>
<tr><td>MAX17502[1]</td><td>1.0</td><td>0.3/0.6</td><td rowspan="3">No</td><td>TDFN/TSSOP</td><td>2.0 x 3.0 / 4.4 x 5.0</td></tr>
<tr><td>MAX17572</td><td>1.0</td><td rowspan="8">54.0</td><td rowspan="2">0.4 to 2.2</td><td rowspan="2">TDFN</td><td rowspan="2">3.0 x 3.0</td></tr>
<tr><td>MAX17575</td><td>1.5</td></tr>
<tr><td>MAX17505</td><td>1.7</td><td>0.2 to 2.2</td><td rowspan="6">Yes</td><td rowspan="6">TQFN</td><td rowspan="2">4.0 x 4.0 pin-compatible</td></tr>
<tr><td>MAX17503</td><td>2.5</td><td rowspan="2">0.1 to 2.2</td></tr>
<tr><td>MAX17574</td><td>3.0</td><td>4.0 x 5.0</td></tr>
<tr><td>MAX17504</td><td>3.5</td><td>0.2 to 2.2</td><td>5.0 x 5.0</td></tr>
<tr><td>MAX17536</td><td>4.0</td><td rowspan="2">0.1 to 2.2</td><td rowspan="2">5.0 x 5.0 pin-compatible</td></tr>
<tr><td>MAX17506</td><td>5.0</td></tr>
<tr><td colspan="10">4.5V to 42V/60V Dual-Output, Step-Down Regulators</td></tr>
<tr><td>MAX17521</td><td>1.0 per output</td><td rowspan="4">4.5</td><td rowspan="3">60.0</td><td>0.9</td><td>55.0</td><td>0.3/0.56</td><td>Yes</td><td rowspan="2">TQFN</td><td>4.0 x 5.0</td></tr>
<tr><td>MAX17558[2]</td><td rowspan="3">10.0 per output</td><td rowspan="3">0.8</td><td rowspan="3">24.0</td><td rowspan="3">0.1 to 2.2</td><td rowspan="3">No</td><td>5.0 x 5.0</td></tr>
<tr><td>MAX17559[2]</td><td>TQFP</td><td>7.0 x 7.0</td></tr>
<tr><td>MAX17548[2]</td><td>42.0</td><td>TQFN</td><td>5.0 x 5.0</td></tr>
<tr><td colspan="10">4.5V to 42V Single-Output, Step-Down Regulators</td></tr>
<tr><td>MAX17530</td><td>0.025</td><td rowspan="3">4.0</td><td rowspan="3">42.0</td><td rowspan="3">0.8</td><td rowspan="3">37.0</td><td rowspan="3">0.1 to 2.2</td><td rowspan="3">Yes</td><td rowspan="3">TDFN/µMAX</td><td rowspan="3">2.0 x 3.0/3.0 x 5.0 pin-compatible</td></tr>
<tr><td>MAX17531</td><td>0.050</td></tr>
<tr><td>MAX17532</td><td>0.1</td></tr>
<tr><td>MAX15462[1]</td><td>0.3</td><td rowspan="7">4.5</td><td rowspan="7">42.0</td><td rowspan="7">0.9</td><td rowspan="7">37.0</td><td>0.5</td><td>Yes</td><td>TDFN</td><td>2.0 x 2.0</td></tr>
<tr><td>MAX17541G</td><td>0.5</td><td rowspan="2">0.6</td><td rowspan="2">Yes[3]</td><td rowspan="2">TDFN (TSSOP[3])</td><td rowspan="2">2.0 x 3.0 pin-compatible</td></tr>
<tr><td>MAX17542G</td><td>1.0</td></tr>
<tr><td>MAX17545</td><td>1.7</td><td rowspan="4">0.1 to 2.2</td><td rowspan="4">Yes</td><td rowspan="4">TQFN</td><td rowspan="2">4.0 x 4.0 pin-compatible</td></tr>
<tr><td>MAX17543</td><td>2.5</td></tr>
<tr><td>MAX17544</td><td>3.5</td><td rowspan="2">5.0 x 5.0</td></tr>
<tr><td>MAX17546</td><td>5.0</td></tr>
</table>

Notes:
1. Fixed 3.3V and 5.0V pin-compatible options available for even more compact designs.
2. Controller ICs for use with external MOSFETs to support high current applications.
3. Contact **Maxim Technical Support**.

Himalaya Power Modules

<table>
<tr><th rowspan="2">Part Number</th><th colspan="2">V_{IN} (V)</th><th colspan="2">V_{OUT} (V)</th><th>I_{OUT} (A)</th><th colspan="2">Frequency (MHz)</th><th rowspan="2">Package Type</th><th rowspan="2">Size (mm)</th></tr>
<tr><th>Min</th><th>Max</th><th>Min</th><th>Max</th><th>Max</th><th>Min</th><th>Max</th></tr>
<tr><td colspan="10">2.4V to 5.5V Step-Down Power Modules</td></tr>
<tr><td>MAXM17514</td><td rowspan="3">2.4</td><td rowspan="3">5.5</td><td rowspan="3">0.75</td><td rowspan="3">5.5</td><td>4.0</td><td rowspan="3">1.0</td><td rowspan="3">1.0</td><td rowspan="3">SiP 28-pin</td><td rowspan="3">6.5 x 10 x 2.8</td></tr>
<tr><td>MAXM17515</td><td>5.0</td></tr>
<tr><td>MAXM17516</td><td>6.0</td></tr>
<tr><td colspan="10">4.5V to 42V Step-Down Power Modules</td></tr>
<tr><td>MAXM17532</td><td>4.0</td><td rowspan="5">42.0</td><td rowspan="5">0.9</td><td>5.5</td><td>0.10</td><td>0.1</td><td>0.9</td><td rowspan="2">µSLIC 10-pin</td><td rowspan="2">2.6 x 3.0 x 1.5</td></tr>
<tr><td>MAXM15462</td><td rowspan="4">4.5</td><td>5.0</td><td>0.30</td><td>0.47</td><td>0.53</td></tr>
<tr><td>MAXM17545</td><td rowspan="3">12.0</td><td>1.7</td><td rowspan="3">0.1</td><td rowspan="3">1.8</td><td rowspan="3">SiP 29-pin</td><td rowspan="3">9 x 15 x 2.8</td></tr>
<tr><td>MAXM17543</td><td>2.5</td></tr>
<tr><td>MAXM17544</td><td>3.5</td></tr>
<tr><td colspan="10">4.5V to 60V Step-Down Power Modules</td></tr>
<tr><td>MAXM17502</td><td rowspan="5">4.5</td><td rowspan="5">60.0</td><td rowspan="5">0.9</td><td>5.0</td><td>1.0</td><td>0.3</td><td>0.6</td><td>SiP 28-pin</td><td>6.5 x 10 x 2.8</td></tr>
<tr><td>MAXM17505</td><td rowspan="2">12.0</td><td>1.7</td><td rowspan="4">0.1</td><td rowspan="2">1.8</td><td rowspan="2">SiP 29-pin</td><td rowspan="4">9 x 15 x 2.8</td></tr>
<tr><td>MAXM17503</td><td>2.5</td></tr>
<tr><td>MAXM17574</td><td>15.0</td><td>3.0</td><td>2.2</td><td>SiP 33-pin</td></tr>
<tr><td>MAXM17504</td><td>12.0</td><td>3.5</td><td>1.8</td><td>SiP 29-pin</td></tr>
</table>

Rainier Isolated DC-DC Power Solutions

Part Number	Supply Voltage Min	Supply Voltage Max	Feedback	FET	Frequency Range (MHz)	Package Type	Package Size L (mm) x W (mm)
DC-DC Peak Current-Mode Flyback Converters							
MAX17498B	4.5	36	Opto	Integrated	500	TQFN	3x3
MAX17498C					250		
High-Efficiency, Iso-Buck DC-DC Converter							
MAX17681/A	4.5	42	Primary Side	Integrated	200	TDFN	2x3
MAX17682					100 to 500	TQFN	4x4
No-Opto Flyback Controller							
MAX17690	4.5	60	Primary Winding*	External	50 to 250	TQFN	3x3
Peak-Current-Mode Controllers for Flyback Applications							
MAX17596	4.5	36	Opto	External	100 to 1000	TQFN	3x3
MAX17597							
Peak-Current-Mode Controllers for Active-Clamp Forward Applications							
MAX17598	8.0	29	Opto	External	100 to 1000	TQFN	3x3
MAX17599	4.5	36					

Output voltage regulated using the primary winding of transformers.

Part Number	V_{IN} (V) Min	V_{IN} (V) Max	Drive Source/Sink Current (A)	Turn-On Prop. Delay (nS)	Turn-Off Prop. Delay (nS)	Package Type	Package Size L (mm) x W (mm)
Secondary-Side Synchronous MOSFET Driver for Flyback Converters							
MAX17606	4.5	36	2/4	26	32	TSOT	2x3

EV Kit	Configuration	Input	Output	
MAX17681EVKITA	Iso-Buck	17V to 32V	±15V	100mA
MAX17681EVKITB		17V to 36V	±7V	100mA
MAX17681EVKITC			+15V	200mA
MAX17681EVKITD			+7V	200mA
MAX17681EVKITE			±15V	75mA
			±7V	75mA
MAX17681EVKITF			+24V	100mA
MAX17682EVKIT		16V to 42V	+12V	750mA

EV Kit	Configuration	Input	Output	
MAX17598EVKIT	Active-Clamp	36V to 72V	3.3V	8A
MAX17498BEVKIT	Flyback	18V to 36V	+5V	1.5A
MAX17596EVKIT	Flyback		+24V	833mA
MAX17597FBEVKIT	Flyback		+24V	833mA
MAX17690EVKITB	Flyback		+5V	1A
MAX17690EVKITC	Flyback		±15V	200mA
MAX17606SFBEVKIT	Sync. Flyback		+5V	3A
MAX17690EVKITA	Sync. Flyback		+5V	1A

Overvoltage and Overcurrent Protectors

Part Number	V_{IN} (V)		Current Limit (A)		Fault Response	Dual-Stage Current Limiting[1]	Features	Package-Pin
	Min	Max	Min	Max				
MAX14571	4.5	36	0.7	4.2	Autoretry			TSSOP-EP/14
MAX14572	4.5	36	0.7	4.2	Latch-off			TSSOP-EP/14
MAX14573	4.5	36	0.7	4.2	Continuous			TSSOP-EP/14
MAX14588	4.5	36	0.15	1	Latch-off			TQFN-CU/16
MAX14691	5.5	58	0.6	6	Pin-selectable (latch-off, autoretry, continuous)	1.0x	OV, UV, OC, OT, reserve current (external FET)	TQFN-CU/20
MAX14692	5.5	58	0.6	6	Pin-selectable (latch-off, autoretry, continuous)	1.5x	OV, UV, OC, OT, reserve current (external FET)	TQFN-CU/20
MAX14693	5.5	58	0.6	6	Pin-selectable (latch-off, autoretry, continuous)	2.0x	OV, UV, OC, OT, reserve current (external FET)	TQFN-CU/20
MAX14721	5.5	60	0.2	2	Pin-selectable (latch-off, autoretry, continuous)	1.0x	OV, UV, OC, OT, reserve current (with external FET)	TQFN/20
MAX14722	5.5	60	0.2	2	Pin-selectable (latch-off, autoretry, continuous)	1.5x	OV, UV, OC, OT, reserve current (with external FET)	TQFN/20
MAX14723	5.5	60	0.2	2	Pin-selectable (latch-off, autoretry, continuous)	2.0x	OV, UV, OC, OT, reserve current (with external FET)	TQFN/20
MAX17525	5.5	60	0.6	6	Latch-off			TQFN-CU/20
MAX17561	4.5	36	0.7	4.2	Autoretry			TSSOP-EP/14
MAX17562	4.5	36	0.7	4.2	Latch-off			TSSOP-EP/14
MAX17563	4.5	36	0.7	4.2	Continuous			TSSOP-EP/14
MAX17608	4.5	60	0.1	1	Pin-selectable (latch-off, autoretry, continuous)		OV, UV, OC, OT, reverse-current protection (internal FET), FLAG and UVOV, signals	TDFN-EP/12
MAX17609	4.5	60	0.1	1	Pin-selectable (latch-off, autoretry, continuous)		OV, UV, OC, OT, FLAG and UVOV signals	TDFN-EP/13
MAX17610	4.5	60	0.1	1	Pin-selectable (latch-off, autoretry, continuous)			TDFN-EP/14

1. During initial startup period, the current limit is increased by the indicated ratios.

Related Resources

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