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We get technical

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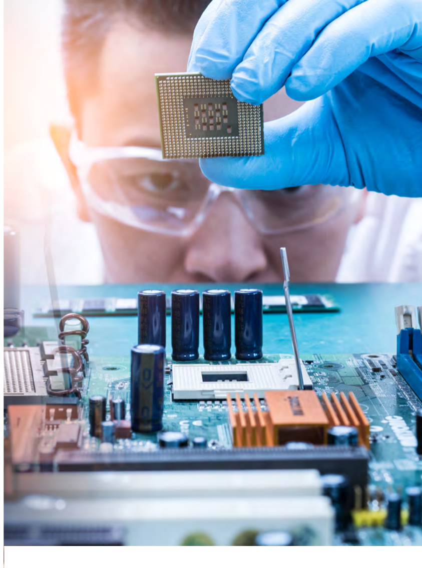

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Editor’s note

Power conversion has always played a major part in the electronics industry. Some of these applications include:

- Phone charging: A power supply is needed to charge our phones, typically in the form of a wall adapter.
- Automotive electronics: Vehicles have become more dependent on computer control that requires a clean power source, typically in the form of a DC/DC converter (or a “Voltage Regulator” if you are in that market).
- Electrical utilities: When looking at the electrical utilities providers, there are electronics deployed at the micro and macro levels to monitor and control the grid.

As all of these applications change over time and as new applications emerge, the technologies behind power conversion have needed to evolve as well.

Today, GaN and SiC semiconductors are playing a larger role in the evolution of power and are at the leading edge of advancements in power switching technology. These technologies are enabling gains in power conversion efficiency.

In a properly designed power supply, efficiency gains can mean a reduction in waste heat, which can reduce thermal stresses on components, which in turn can increase reliability. All of this can enable an increase in power density and a reduction in weight.

In addition to the direct impact that efficiency can have on a power supply, many countries have enacted legislation around minimum efficiency levels. So, whether you are designing a power supply or just purchasing one, having higher efficiency power conversion can help to future proof your design.

How to effectively prevent input overvoltage of switched-mode power supply

By Mornsun

Input overvoltage is caused by a large fluctuation in the grid load. For example, the voltage is often low during peak power consumption and high when equipment is shut down.

The actual variation range of power grid voltage amplitude varies greatly with the power grid capacity, the transmission and distribution equipment quality, the power consumption, and other factors. In cities and industrial areas with a sound power supply, the variation range is usually only about ±15% (with the maximum value not exceeding

264 V_{AC}). If it does exceed 264 V_{AC}, the power supply may be damaged, or even cause equipment to trip and/or start a fire, threatening safety and property.

However, in countries and regions with poor power supply conditions, or on occasions where there is equipment with large load changes in the power grid, such as mountain areas, highway tunnels, charging stations, generator power supply, etc., the change range is much larger. Sometimes the change range could get up to 20%~30% (with the maximum value going up to 274 to 299 V_{AC}).

Voltage stress analysis of power supply components under input overvoltage

Take the flyback switched-mode power supply in Figure 2 as an example to analyze how to select appropriate components according to the voltage stress when the input voltage reaches 305 V_{AC}.

Figure 1. The voltage waveform in harsh working environments. (Image source: Mornsun Power)

1. Nominal voltage selection of fuse F1

The nominal voltage of the fuse must be greater than or equal to the maximum voltage of the turn-off circuit. Due to the very low resistance of the fuse, its nominal voltage becomes important only when attempting to interrupt the current flow. When the fuse element melts, the fuse must be able to quickly disconnect, extinguish the arc, and prevent the open circuit voltage from triggering the arc again through the disconnected fuse element.

The common specifications of fuses are 125 V, 250 V, 300 V, and 400 V. In response to the large fluctuation of input voltage, a 300 V fuse shall be selected.

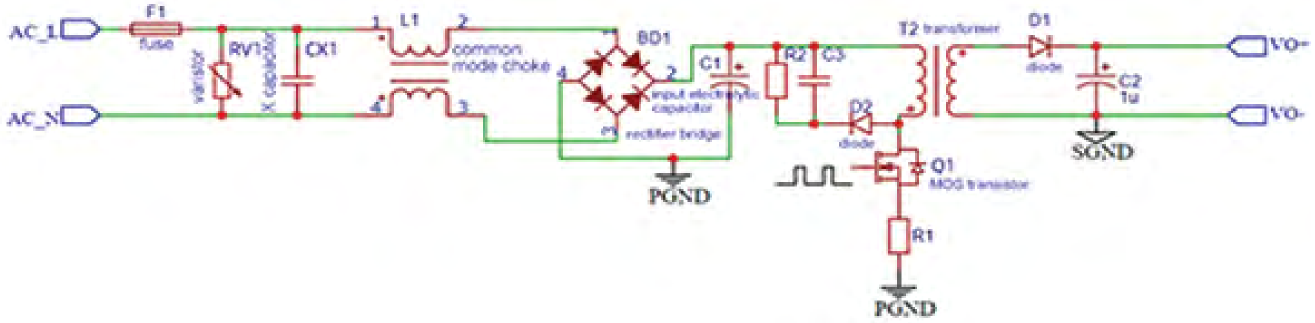


Figure 2: A flyback switched-mode power supply. (Image source: Mornsun Power)

2. The selection of rated voltage of varistor RV1

In practical applications, varistor RV1 is generally connected in parallel in the circuit. When the circuit works normally, it is in a high resistance state, which does not affect the normal operation of the circuit. When the circuit has abnormal instantaneous overvoltage and reaches its turn-on voltage (varistor voltage), the varistor quickly changes from a high resistance state to a low resistance state, discharges the instantaneous overcurrent caused by abnormal instantaneous overvoltage, and clamps the abnormal instantaneous overvoltage within a safe level so as to protect the subsequent circuit from the damage of abnormal instantaneous overvoltage.

Common specifications of varistors are as follows:

The voltage value of the varistor shall be greater than the voltage peak in the actual circuit, which means the power supply voltage that is continuously applied to both ends of the varistor shall be less than the "maximum continuous operation voltage value (AC and DC)" in the varistor specification. As shown in Table 1, 300 V_{AC} (385 V_{DC}) obviously does not meet the long-term operation of 305 V_{AC}. In order to prevent damage to the varistor, it is necessary to select 10D561 varistors in case of large input voltage fluctuation.

3. Nominal voltage selection of X capacitor CX1

The nominal voltage of the X2 safety capacitor is generally 275 V, 305 V or 310 V, which are actually universal. Because of the different nominal voltage requirements in the different countries and different safety regulations, the label of X2 is not always accurate. For example, the nominal voltage required for CQC certification in China is 310 V_{AC}, while that in other countries is 275 V, 305 V_{AC} and 310 V_{AC}. In the case of large input voltage fluctuations, a 310 V X-capacitor is preferred.

4. Nominal voltage selection of bridge rectifiers BD1

When V_{IN} = 264 V_{AC}, the maximum stress of bridge rectifier diodes should be: Vmax1 = 264 × √2 = 373 V.

When V_{IN} = 305 V_{AC}, the maximum stress of bridge rectifier diodes should be: Vmax2 = 305 × √2 = 431 V.

Varistor pPN	Varistor voltage range	Maximum continuous AC operating voltage	Maximum continuous DC operating voltage	Maximum limiting voltage
S10K300	423 V to 517 V	300 V_{AC}	385 V_{DC}	775 V
S10K350	504 V to 616 V	350 V_{AC}	455 V_{DC}	925 V

Table 1: Varistor voltage specifications of the S10K300 and S10K350. (Image source: Mornsun Power)

Since the switching power supply needs to do the lightning surge test, a rectifier bridge that is rated for greater than 600 V is generally selected. In order to meet the harsher surge environment, a 1000 V rectifier bridge can also be selected.

5. Nominal voltage selection of electrolytic capacitor C1

When V_{IN} = 264 V_{AC}, the maximum stress of the electrolytic capacitor should be: Vcmax1 = 264 × √2 = 373 V.

When V_{IN} = 305 V_{AC}, the maximum stress of the electrolytic capacitor should be: Vcmax2 = 305 × √2 = 431 V.

In the case of large fluctuations in the input voltage, a 450 V electrolytic capacitor should be selected.

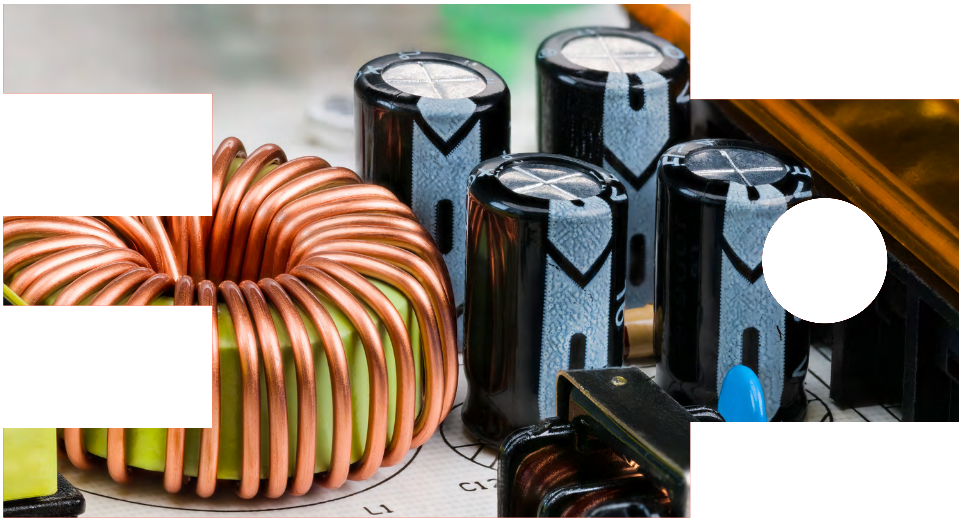
6. Nominal voltage selection of MOS transistor Q1

The voltage stress of the MOS transistor (Vmos) is equal to:

VIN refers to the input voltage with the maximum input voltage being 431 V.

$$V_{mos} = V_{IN} + V_{OR} + V_{PK}$$

VOR is the reflection voltage, generally 60-120 V, which is positively correlated to the turn ratio of primary and secondary. This can be assumed to be 80 V or less through optimal design.



VPK is the peak voltage generated from inductance, generally around 100 V, and can be taken as 80 V or less by optimizing leakage inductance and absorption parameters.

Therefore, the working voltage stress of MOS transistor Q1 should be: 431 + 120 + 100 = 651 V. After optimization, the working voltage stress of Q1 could be: 431 + 80 + 80 = 591 V. Therefore, considering the surge of 305 VAC input, and in order to ensure the reliable operation of the MOS transistor, at least a 700 V MOS transistor should be selected, but a 650 V MOS transistor can also be selected after optimizing the turn ratio and leakage inductance of the transformer.

7. Nominal voltage selection of diode D1

The computational formula of voltage stress of the Diode is:

$$V_D = \frac{V_{IN}}{n} + V_O + V_{D-PK}$$

VD-PK refers to the peak voltage generated by the secondary leakage inductance. Since it is greatly affected by different output voltages and absorption parameters, it is generally calculated as:

$$V_D = \left(\frac{V_{IN}}{n} + V_O\right) \times 1.5$$

Assuming that the output voltage is 12 V (VO = 12 V), the leakage inductance peak of the diode is 30 V (VD-PK = 30 V) and the MOS transistor leakage inductance peak of the MOS transistor is 80 V (VPK = 80 V), the calculation is as follows:

	Turn ratio	10	9	8	7	6
V_{IN} = 373 V	V_D	79.3 V	83.4 V	88.6 V	95.3 V	104.2 V
	V_{mos}	573 V	561 V	549 V	537 V	525 V
V_{IN} = 431 V	V_D	85.1 V	89.8 V	95.8 V	103.5 V	113.8 V
	V_{mos}	631 V	619 V	607 V	595 V	583 V

Table 2: The voltage stress relationship between the turn ratio, MOS transistor, and diode. (Image source: Mornsun Power)

It can be seen from Table 2 that the conventional switched-mode power supply only considers an input voltage of 373 V (VIN = 373 V), and the values of the MOS transistor and diode will be relatively small, which cannot be applied to the input voltage of 431 V. Once the input voltage exceeds 373 V, there is a risk of damage.

To sum up, taking the output voltage of 12 V as an example, in terms of the surge or input of 305 VAC, in order to ensure the reliable operation of the diode, at least 150 V diodes should be selected. However, 100 V diodes can also be selected by optimizing the turn ratio and leakage inductance of the transformer.

Screen printing	Component name	Mainstream power supplies	305RAC power supplies
F1	fuse	250 V	300 V
RV1	varistor	470 V	560 V
CX1	X capacitor	275 V	310 V
BD1	rectifier bridge	600 V or 800 V	1,000 V
C9	big electrolytic capacitor	400 V	450 V
Q1	MOS transistor	600 V	>e;650 V
D22	diode	100 V	150 V

Table 3: Comparison of Mornsun 305RAC and mainstream power supplies for several different rated voltages. (Image source: Mornsun Power)

Protection requirements for input overvoltage

According to the calculation above, the best way to deal with input overvoltage is to optimize the voltage stress of components, such as components selection of Mornsun 305RAC (Reliable under all conditions) power supplies.

At the same time, keeping a safe distance between high-voltage lines can be maintained by increasing the internal electrical gap and creep distance, avoiding arcing damage to the prototype or endangerment of personnel.

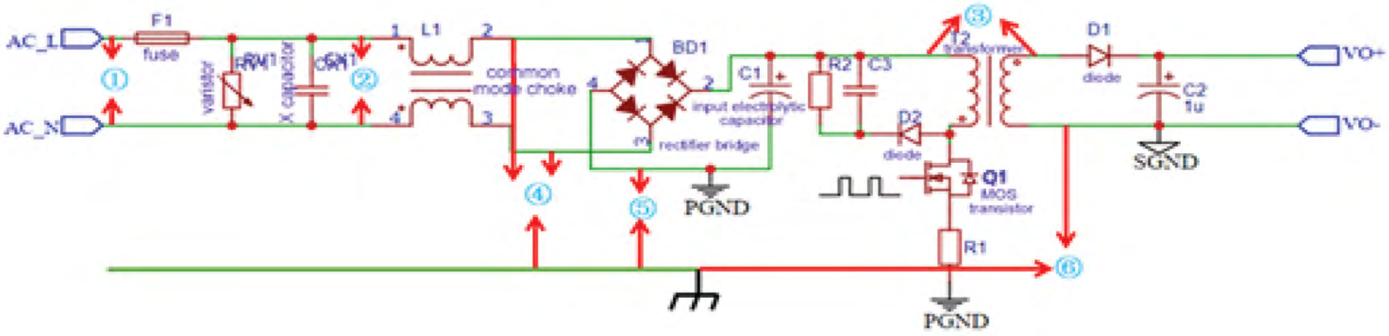


Figure 3: Flyback schematic showing safe distances (see Table 4) for circuit traces to avoid arcing. (Image source: Mornsun Power)

Mark no.	Name	Electrical clearance/creepage distance of mainstream power supply	Electrical clearance/creepage distance of 305RAC power supply
1 & 2	L-N	2.0 mm / 2.5 mm	2.0 mm / 3.2 mm
3	Primary side - Secondary side	4.6 mm / 6.4 mm	4.6 mm / 8.0 mm
4	Before the rectifier bridge, LN-PE	2.0 mm / 2.5 mm	2.0 mm / 3.2 mm
5	After the rectifier bridge, LN-PE	2.0 mm / 2.8 mm	2.0 mm / 3.2 mm
6	VO-PE	3.6 mm / 5.5 mm	4.0 mm / 6.4 mm

Table 4: Comparisons of electrical clearance/creepage distance of mainstream and 305RAC power supplies for the circuit in Figure 3. (Image source: Mornsun Power)

Summary

An input overvoltage can damage a power supply and cause harm to people. How can input overvoltages be avoided? Through the voltage stress analysis of the power supply components, the selection guide of the key components of the switched-mode power supply is determined. At the same time, increasing the internal electric gap and creep distance of the power supply is also beneficial for optimizing the voltage stress.

By comparing the rated voltage, electrical gap and creep distance of components between the mainstream power supply and the Mornsun "305 RAC" power supply, the 305 RAC AC/DC power supply features effectively protect against input overvoltage. It can also be used in harsh and special environments with higher environmental operating requirements such as temperature, humidity, altitude, EMC interference, etc.

Understand and apply supervisory ics to avoid low-voltage power-up glitch headaches

By Bill Schweber
Contributed By DigiKey's
North American Editors

Experienced engineers know that one of the riskiest times for a system is when power is applied. Depending on time constants and how smoothly and quickly the power rail comes up to nominal, the different ICs and parts of the system may start, lock up, or start in an incorrect mode as they attempt to work with each other. Adding to the challenge is that the timing and slew-related performance of the ICs on power-up can be a function of temperature, associated capacitors, mechanical stress, aging, and other factors.

The potential problem is aggravated as operating voltage rails drop to low single-digit values, reducing the amount of "slack" or headroom for functioning with the nominal rail value. All of these factors can lead to inconsistent startup performance and frustrating debug sessions.

For these reasons, analog IC vendors have devised specialized ICs that offer supervisory management features that eliminate the uncertainty and inconsistency of power-up. This article will define and characterize the glitch problem, and then show how it can be avoided through the addition of some small, specialized ICs from Analog Devices.

What is a glitch?

As with many engineering terms such as "buffer" or "programmable," the word "glitch" has different meanings depending on the context. A glitch can be:

- A noise-induced spike on a signal or power line
- A sudden, brief drop in a power supply rail due to a load transient
- A microsecond period when both upper and lower MOSFETs in a bridge are inadvertently turned on simultaneously, as a result of different turn on/off times in their gate drivers (a very bad occurrence)
- A momentary indeterminate signal and race condition due to timing tolerances and differences between components.

This article looks at the glitch that can occur during the "power-up" period when power is turned on, and the ICs are transitioning to their normal operating condition, especially in low-voltage systems. Such power-on glitches are especially frustrating because they can cause intermittent, hard-to-debug problems that have no apparent correlation or consistency. As the glitch-inducing conditions are often "on the edge," their occurrence can vary with temperature, power-rail tolerance (while still within specification),

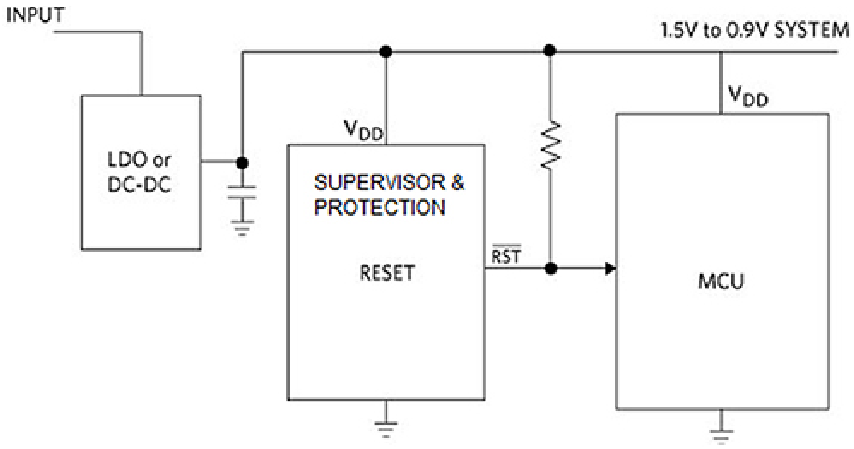


Figure 1: Understanding a glitch source begins with a look at a simple, typical arrangement of a microcontroller and its associated supervisory/protection reset IC, both powered by a battery and its regulator. (Image source: Analog Devices)

individual component variations in a batch of the same device, and other hard-to-determine factors.

What is this glitch, and what is its source? Consider a system with a microcontroller and an associated supervisory/protection reset IC. The role of the latter IC is simple and focused: to maintain reliable system operation during power-up, power-down, and brownout conditions (**Figure 1**).

In a typical battery-powered application, the DC-DC converter generates the supply rail from a small, low-voltage battery. The supervisory IC is generally added between the DC-DC converter and the microcontroller to monitor the supply voltage and enable or disable the microcontroller.

The supervisory IC ensures reliable operation by accurately monitoring the system power supply and then asserting or de-asserting the microcontroller's enable input. The enabling and disabling of the microcontroller is managed via the supervisory IC's reset output pin. This pin is typically an open-drain that is connected to a 10 kilohm (kΩ) pull-up resistor. The supervisory IC monitors the power supply voltage and asserts a reset when the input voltage falls below the reset threshold.

After the monitored voltage rises above the threshold voltage to its nominal value, the reset output remains asserted for a reset timeout period and then de-asserts. This allows the target microcontroller to leave the reset state and begin operating.

But what happens to the reset line before the supervisory IC turns on and pulls it low? The answer is found by looking closely at a typical power-up sequence (**Figure 2**). As supply rail VCC begins to power up, both the microcontroller and the supervisory IC are off. As a consequence, the reset line is floating and the 10 kΩ pullup resistor causes its voltage to track V_{CC}.

This voltage rise can be anywhere

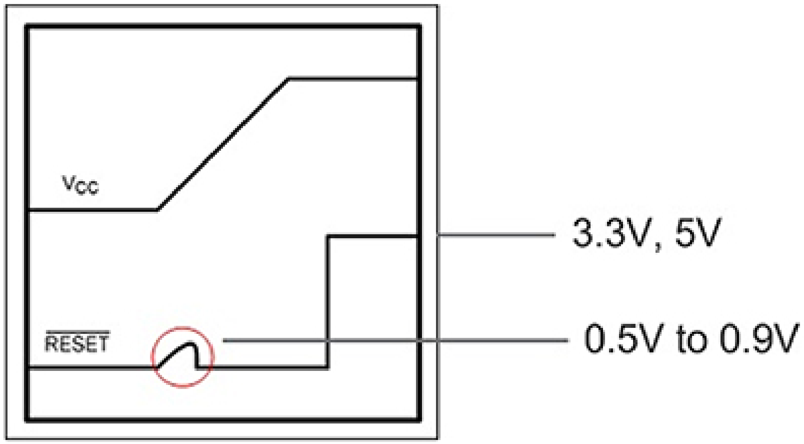


Figure 2: In a typical power-up sequence, the reset line is floating, so its voltage tracks the rise in supply rail VCC. (Image source: Analog Devices)

between 0.5 to 0.9 volts, potentially causing system instability. Once the supervisory IC turns on, the reset line is pulled down to prevent the microcontroller from inadvertently turning on. This glitch is common to all previous generations of supervisory ICs.

Low-voltage systems magnify the problem

This glitch scenario becomes a major concern with the trend toward low-power devices that are operating at ever-lower voltages. Consider systems with three logic levels of 3.3 volts, 2.5 volts, and 1.8 volts (**Figure 3**). For the 3.3-volt system, the output low-voltage threshold (Vol) and the input low-voltage threshold (Vil) are between 0.4 volts and 0.8 volts. If a glitch occurs at 0.9 volts, it would potentially cause the processor to become unstable by switching it off and on.

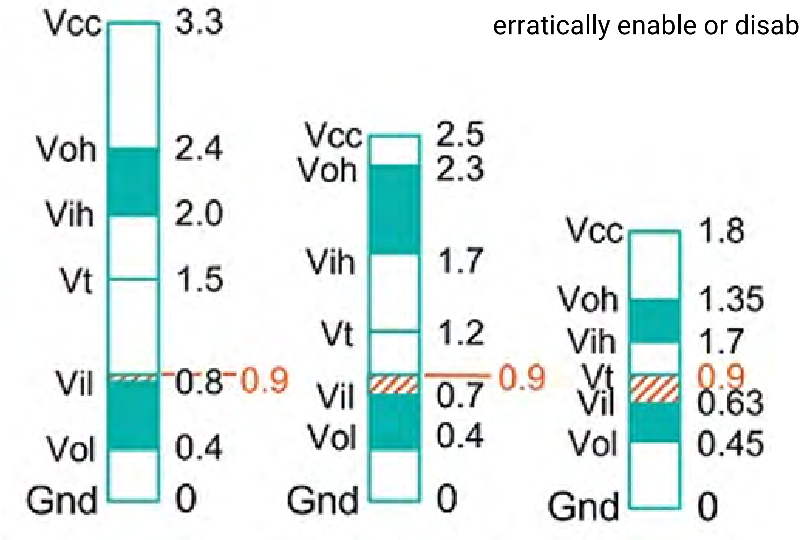


Figure 3: Logic levels have shrunk from 3.3 volts down to 1.8 volts, and so have associated voltage thresholds. (Image source: Analog Devices)

The situation for a nominal 1.8-volt system is more sensitive. Now, Vol and Vil are much lower at 0.45 volts and 0.63 volts. A 0.9 volt glitch in this system represents a larger percentage, giving it a higher potential for error.

How does this situation play out with the glitch impacting system operation? Consider a power supply voltage VDD which ramps up slowly to 0.9 volts and "lingers" there for a short period of time (**Figure 4**). Although this voltage is not enough to turn on the supervisory IC, the microcontroller could still be enabled and running in an unstable state. Since the 0.9-volt value is in an indeterminant state, the glitch can be interpreted by the microcontroller RESET input as either a logic 1 or 0, which would erratically enable or disable it.

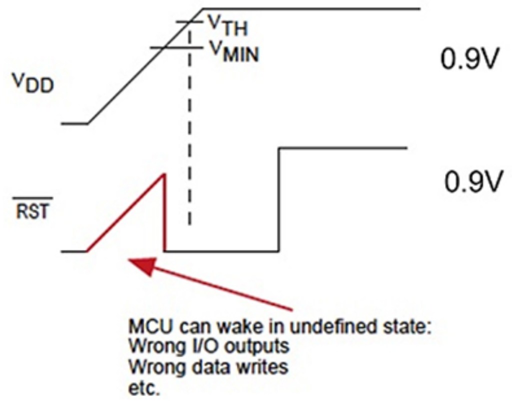


Figure 4: As the power supply voltage VDD ramps up to 0.9 volts and lingers there, the microcontroller can be turned on and off erratically. (Image source: Analog Devices)

This causes the microcontroller to execute partial instructions or incomplete writes to memory, as just two examples of what might happen, likely causing system malfunction and possible catastrophic system behavior.

Solving the glitch problem

Overcoming this problem does not require a return to higher voltage rails, or demand complicated system-level architectures to eliminate its occurrence or minimize its impact. Instead, it requires a new generation of supervisory ICs that recognize the unique aspects of the problem and prevent glitches from forming, regardless of the voltage level during power-up or brown-out conditions.

Achieving this result requires a proprietary circuit and IC such as the MAX16162, a nanopower supply supervisor with glitch-free power-up. With this tiny IC—available in four-bump WLP and four-pin SOT23 packages—the reset output is held low whenever VDD is lower than the threshold voltage, preventing a voltage glitch on the reset line. Once the voltage threshold is reached and the delay period is completed, the reset output de-asserts and enables the microcontroller (**Figure 5**).

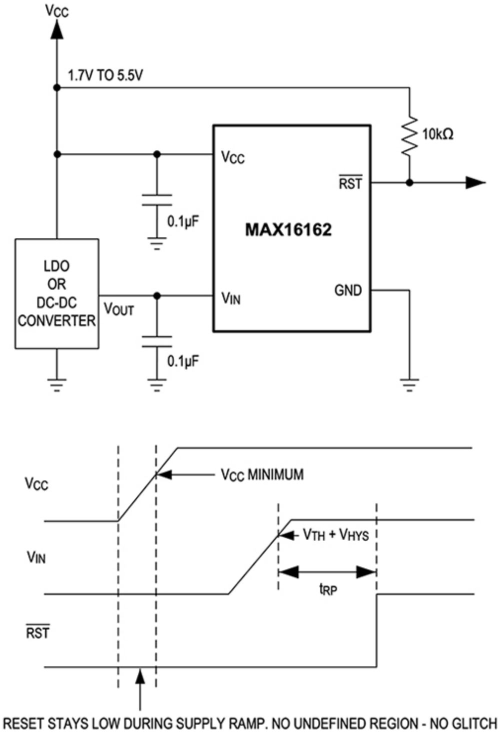


Figure 5: The MAX16162 holds the reset output low whenever VDD is lower than the threshold voltage, preventing a voltage glitch on the reset line. (Image source: Analog Devices)

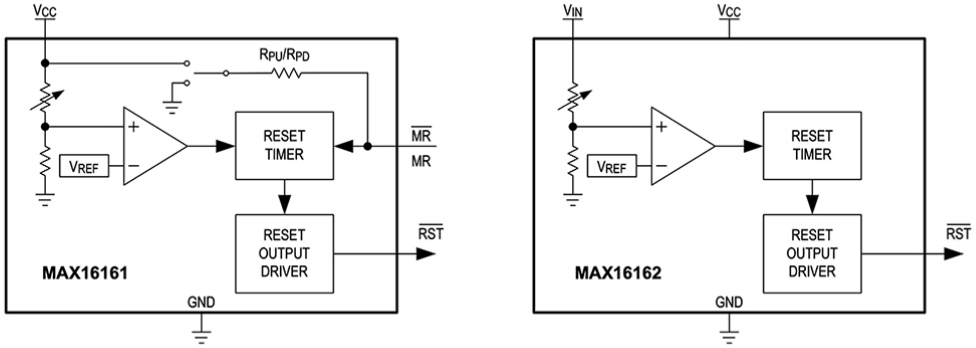


Figure 6: The MAX16161 and MAX16162 are similar but with a small functional and pinout difference: the MAX16161 has an MR input that asserts a reset when it receives an appropriate input signal, while the MAX16162 has separate VCC and VIN pins. (Image source: Analog Devices)

Unlike conventional supervisory ICs that are unable to control the reset output state when VCC is very low, the MAX16162 reset output is guaranteed to remain asserted until after a valid VCC level is achieved.

The MAX16161 is a close sibling of the MAX16162 with nearly identical specifications, but with one functional difference and some redefining of pin assignments (**Figure 6**). It features a manual reset (MR) input that asserts a reset when it receives an appropriate input signal, which can be either active-low or active-high, depending on the option selected. In contrast, the MAX16162 has no MR input but instead has separate VCC and VIN pins, allowing threshold voltages as low as 0.6 volts.

Sequencer versus supervisor

Another pair of terms that have some overlap and ambiguity are supervisor and sequencer. A supervisor monitors a single power supply voltage and asserts/releases reset under defined circumstances. In contrast, a sequencer coordinates the relative resets and "power OK" assertions among two or more rails.

The MAX16161 and MAX16162 can be used as simple power supply sequencers (**Figure 7**). After the output voltage of the first regulator becomes valid, the MAX16161/MAX16162 insert a delay and generate the enable signal for the second regulator after the reset timeout period. Because the MAX16161/MAX16162 never de-assert reset until the supply voltage is correct, the controlled supply is never incorrectly enabled.

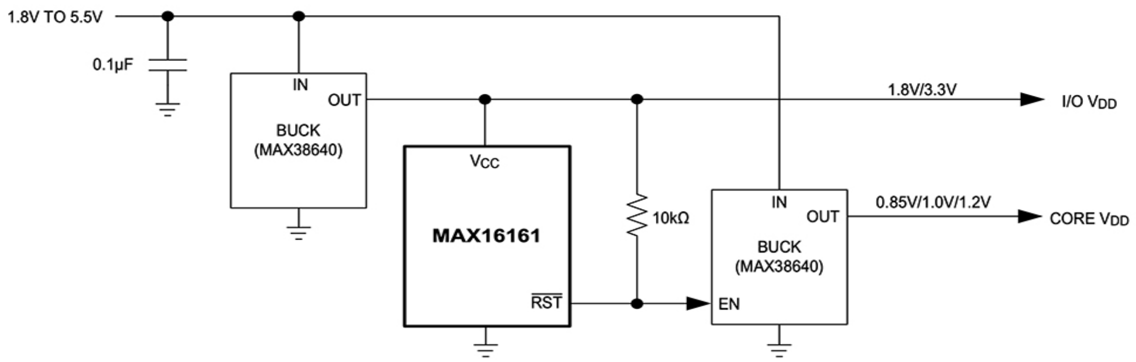


Figure 7: A circuit using the MAX16161 can be configured so the device not only ensures glitch-free power-up but also manages power-rail sequencing between two rails. (Image source: Analog Devices)

There are also many designs that have multiple rails and more complex sequencing needs. In these situations, the Analog Devices LTC2928 Multichannel Power Supply Sequencer and Supervisor offers a solution (**Figure 8**).

This four-channel cascadable power supply sequencer and high-accuracy supervisor allows designers to configure power-management sequencing thresholds, order, and timing using just a few external components. It ensures that power rails are enabled in the desired order. In addition to power-on sequencing, it can manage the complementary and often equally critical power-down sequencing.

The sequence outputs are used to control supply-enable pins or N-channel pass gates. Additional supervisory functions include undervoltage and overvoltage monitoring and reporting, as well as microprocessor reset generation. The type and source of faults are reported for diagnosis. Individual channel controls are available to exercise the enable outputs and supervisory functions independently. For systems with more than four rails, multiple LTC2928s can be easily connected to sequence an unlimited number of power supplies.

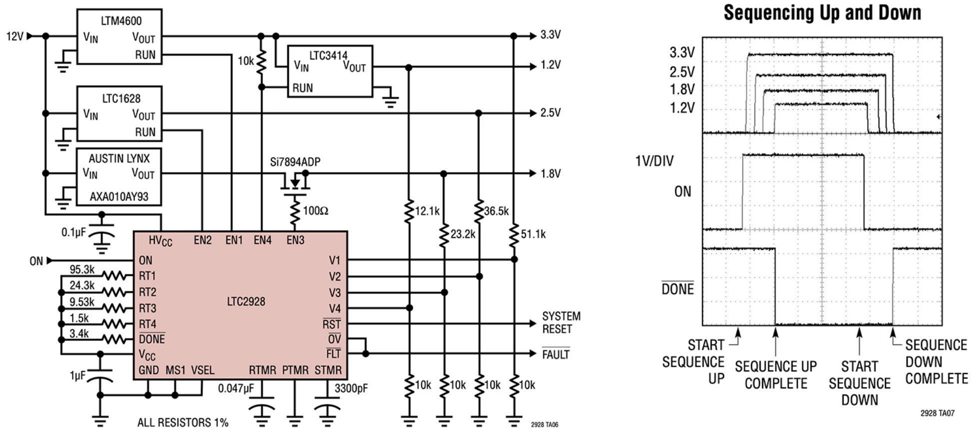
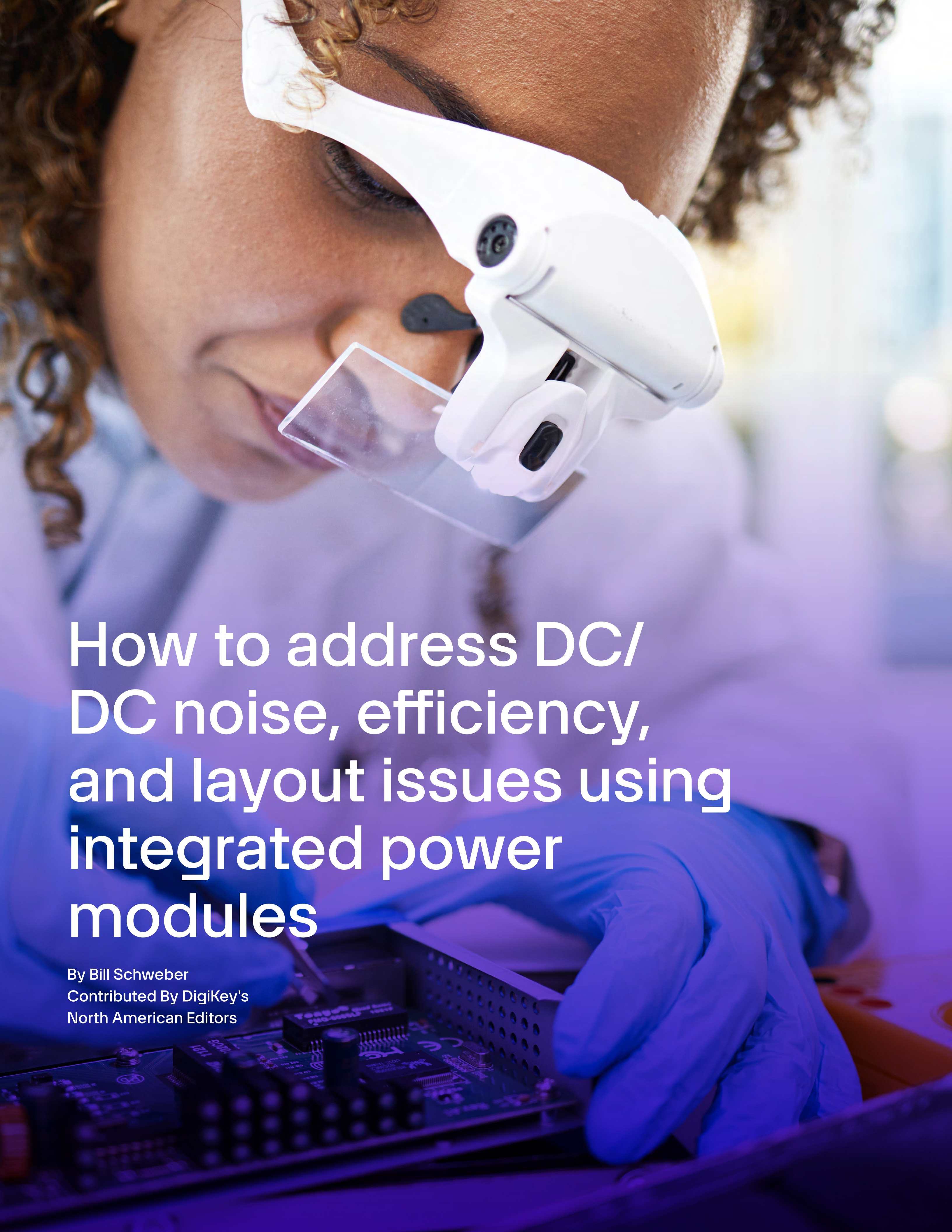


Figure 8: The LTC2928 power sequencer manages power-up and power-down sequencing among four independent rails, and enables user control over key parameters. (Image source: Analog Devices)

Conclusion

Glitches are present in every application, but they have not posed a significant issue for higher voltage applications which dominated until recently. Now, power supply voltages are moving lower, making system turn-on less reliable due to 0.9-volt glitches.

As shown, designers can improve reliability using newer supervisory ICs that offer glitch-free operation to provide the highest degree of system protection for low-power/low-voltage applications.



How to address DC/DC noise, efficiency, and layout issues using integrated power modules

By Bill Schweber
Contributed By DigiKey's
North American Editors

It doesn't seem difficult to build a basic step-down (buck) DC/DC regulator for low voltages of 10 volts (typical) or less and modest current levels of about 2 to 15 amperes (A). The designer just needs to select a suitable switching regulator IC and add a few passive components using the example circuit on the datasheet or application note. But is the design really done and ready to release to pilot run, or even to production? Probably not.

While the regulator provides the desired DC rail, it still has several potential problems and issues. First, the efficiency may not meet project objectives or regulatory requirements, thereby adding to thermal impact, as well as shorter battery life. Second, additional components may be needed to ensure proper start-up, transient performance, and low ripple, which in turn affects size, time to market, and the overall bill of material (BOM). Finally, and perhaps most challenging, the design may not meet the increasingly stringent limitations on electromagnetic interference (EMI) or radio frequency interference (RFI) as defined by the various regulatory mandates, thus requiring a redesign or further additional components and testing.

This article describes the gap between expectations and performance between a basic DC/DC regulator design and a superior one that meets or exceeds requirements for efficiency, low radiated and ripple noise, and overall integration. The article then introduces Analog Devices' Silent Switcher μModules and shows how to use them to solve multiple DC/DC buck regulator problems.

ICs make it look easy, at first

Step-down DC/DC (buck) regulators are widely used to provide DC rails. A typical system may have tens of these providing different rail voltages or physically separated rails at the same voltage. These buck regulators commonly take a higher voltage, typically between 5 and 36 volts DC, and regulate it down to a single-volt value at a few or low double-digit amperes (**Figure 1**).

There's good news and bad news when constructing a basic buck regulator. The good news is that building one that provides nominally "good-enough" performance is generally not difficult. There are many switching ICs available to do the bulk of the task that need only a single field effect transistor (FET) (or none at all) and a few

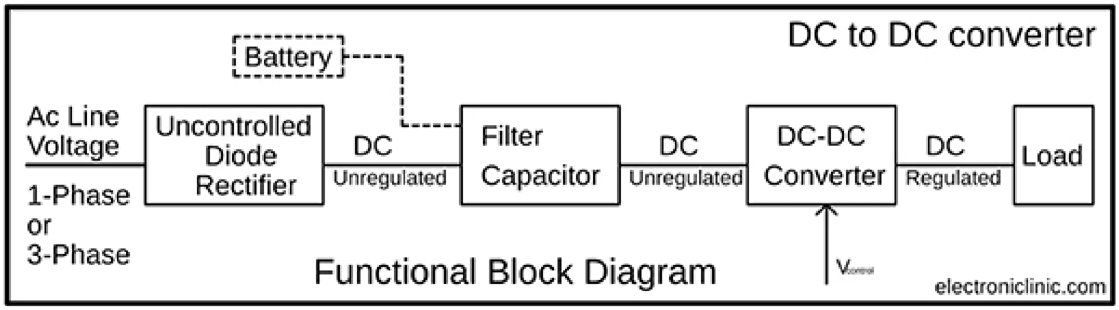


Figure 1: The role of the DC/DC regulator (converter) is straightforward: Take an unregulated DC source which may be from a battery or a rectified and filtered AC line, and provide a tightly regulated DC rail as the output. (Image source: Electronic Clinic)

passive components to complete the job. The task is made even easier as the datasheet for the regulator IC almost always shows a typical application circuit with a schematic, a board layout, and a BOM that may provide component vendor names and part numbers.

The engineering dilemma is that a "good" level of performance may not be adequate with respect to some non-obvious regulator performance parameters. While the output DC rail may deliver enough current with adequate line/load regulation and transient response, those factors are only the beginning of the story for power rails.

The reality is that in addition to those basic performance criteria, a regulator is also assessed by other factors, some of which are driven by external imperatives. The three critical issues which most regulators must address are not necessarily apparent, solely from the simplistic perspective of a functional block that accepts an unregulated DC input and provides a regulated DC output. They are (**Figure 2**):

- Cool: High efficiency and associated minimal thermal impact.
- Quiet: Low ripple for error-free system performance, plus low EMI to meet radiated noise standards (non-acoustic).
- Complete: An integrated solution that minimizes size, risk, BOM, time to market, and other "soft" concerns.

Addressing these issues brings a set of challenges, and solving them can become a frustrating experience. This is in line with the "80/20 rule", where 80% of the effort is devoted to getting the last 20% of the task done. Looking at the three factors in more detail:

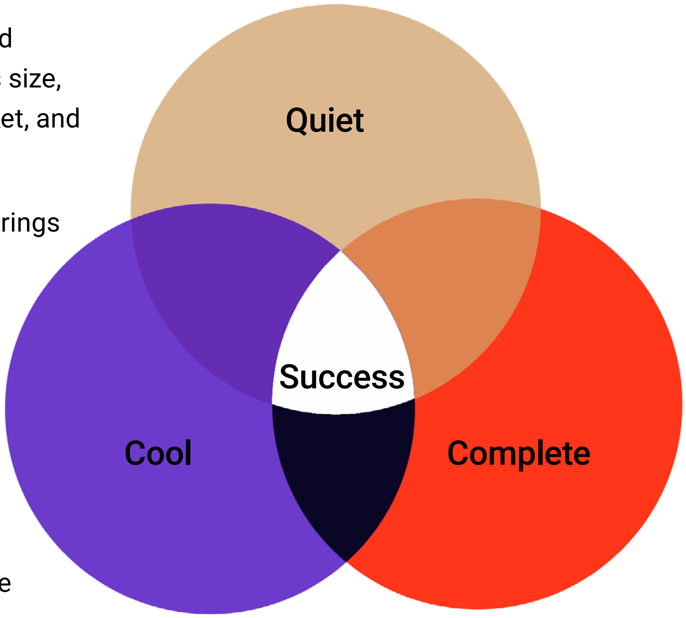


Figure 2: A DC/DC regulator must do more than just deliver a stable power rail; it must also be cool and efficient, be EMI "quiet," and be functionally complete. (Image source: Math.stackexchange.com; modified by author)

Cool: Every designer wants high efficiency, but exactly how high, and at what cost? The answer is the usual one: it depends on the project and its tradeoffs. Higher efficiency is important for three main reasons:

- It translates into a cooler product that enhances reliability, may allow for operation at a higher temperature, may eliminate the need for forced air (fan) cooling, or may simplify setting up effective convection cooling if feasible. At the high end, it may be needed to keep specific components that run particularly hot below their maximum allowed temperature and within their safe operating area.
- Even if these thermal factors are not a concern, efficiency translates to longer run time for battery-operated systems or a reduced burden on the upstream AC-DC converter.
- There are now many regulatory standards mandating specific efficiency levels for each class of end product. While these standards do not call out efficiency for individual rails in a product, the designer's challenge is to ensure that the overall aggregate efficiency meets the mandate. This is easier when each contributing rail's DC/DC regulator is more efficient, as that provides for headroom in the summation with the other rails and other sources of loss.

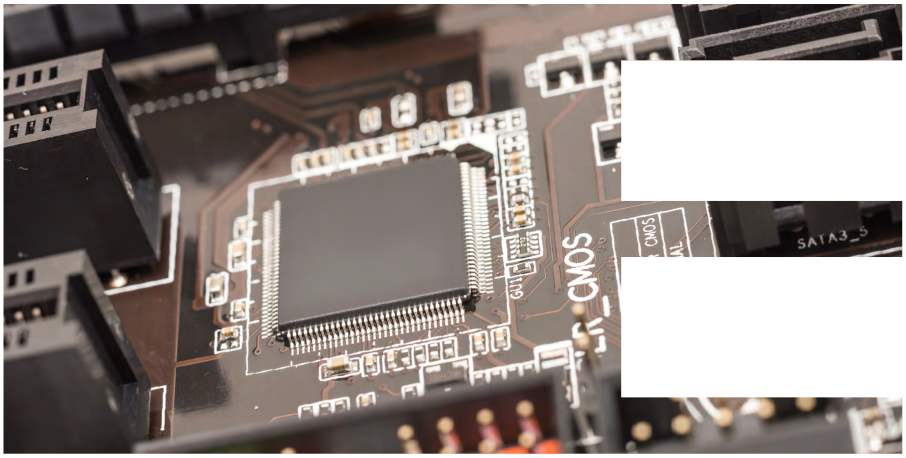
Quiet: There are two broad classes of noise that concern designers. First, the noise and ripple on the output of the DC/DC regulator must be low enough so that it does not adversely affect system performance. This is an increasing concern as rail voltages drop to low single digits in digital circuits, as well as for precision analog circuits where ripple of even a few millivolts can degrade performance.

The other major concern is related to EMI. There are two types of EMI emissions: conducted and radiated. Conducted emissions ride on the wires and traces that connect to a product. Since the noise is localized to a specific terminal or connector in the design, compliance with conducted emissions requirements can often be assured relatively early in the development process with a good layout and filter design.

Radiated emissions, however, are more complicated. Every conductor on a circuit board that carries current radiates an electromagnetic field: every board trace is an antenna, and every copper plane is a mirror. Anything other than a pure sine wave or DC voltage generates a wide signal spectrum.

The difficulty is that even with careful design, a designer never really knows how bad the radiated emissions are going to be until the system gets tested, and radiated emissions testing cannot be formally performed until the design is essentially complete. Filters are used to reduce EMI by attenuating the levels at specific frequencies or over a range of frequencies using various techniques.

Some of the energy radiating through space is attenuated by using sheet metal as a magnetic shield. The lower frequency part that rides on pc board traces (conducted) is controlled using ferrite beads and other filters. Shielding works but brings a new set of problems. It must be well-designed with good electromagnetic integrity (often surprisingly difficult). It adds cost, increases real estate, makes thermal management and testing more difficult, and introduces additional assembly costs.



Another technique is to slow down the switching edges of the regulator. However, this has the undesired effect of reducing the efficiency, increasing minimum on and off times as well as the required dead times, and compromising the current-control-loop speed.

Still another approach is to adjust the regulator design to radiate less EMI by careful selection of the key design parameters. The task of balancing these regulator tradeoffs involves assessing the interaction of parameters such as switching frequency, footprint, efficiency, and resultant EMI.

For example, a lower switching frequency generally reduces switch loss and EMI and improves efficiency, but requires larger components with associated increases in footprint. The quest for greater efficiency is accompanied by low minimum on and off times, resulting in higher harmonic content due to the faster switch transitions. In general, with every doubling of switching frequency, the EMI becomes 6 decibels (dB) worse, assuming all other parameters such as switch capacity and transition times, remain constant. The wideband EMI behaves like a first-order high-pass filter with 20 dB higher emissions when the switching frequency increases by a factor of ten.

To overcome this, experienced pc board designers will make the regulator's current loops ("hot loops") small, and use shielding ground layers as close to the active layer as possible. Nevertheless, pinout, package construction, thermal design requirements, and package sizes needed for adequate energy storage in decoupling components dictate a certain minimum hot-loop size.

To make the layout problem even more challenging, the typical planar pc board has magnetic or transformer-style coupling between traces above 30 megahertz (MHz). This coupling will attenuate the filtering efforts since the higher the harmonic frequencies, the more effective unwanted magnetic coupling becomes.

Which standards are relevant?

There is no single guiding standard in the EMI world, as it is largely determined by the application and relevant governing mandates. Among the most cited ones are EN55022, CISPR 22, and CISPR 25. EN 55022 is a modified derivative of CISPR 22 and applies to information technology equipment. The standard is produced by CENELEC, the European Committee for Electrotechnical Standardization, and is responsible for standardization in the electrotechnical engineering field.

These standards are complex and define the test procedures, probes, instrumentation, data analysis, and more. Among the many limits defined by the standard, the Class B radiated emission limit is often of most interest to designers.

Complete: Even when the design situation is fairly well understood, selecting and employing the needed support components in just the right way is a challenge. Slight differences in component placement and specifications, pc board grounds and traces, and other factors can adversely affect performance.

Modeling and simulation are necessary and can help, but it's very difficult to characterize the parasitics associated with these components, especially if their values shift. Further, a change in vendors (or unannounced change by the preferred vendor) may induce a subtle shift in second- or third-tier parameter values (such as inductor dc resistance (DCR)), which could have significant and unanticipated consequences.

Further, even slight repositioning of the passive components or adding "just one more", can change the EMI scenario and result in emissions exceeding allowable limits.

SilentSwitcher μModules resolve the issues

Anticipating and managing risk is a normal part of a designer's job. Reducing the number and intensity of these risks is a standard end-product strategy. A solution is to use a functionally complete DC/DC regulator that, through good design and implementation, is cool, quiet, and complete. Using a known device reduces uncertainty while addressing size, cost, EMI, BOM, and assembly risks. Doing so also accelerates time to market and reduces regulatory compliance angst.

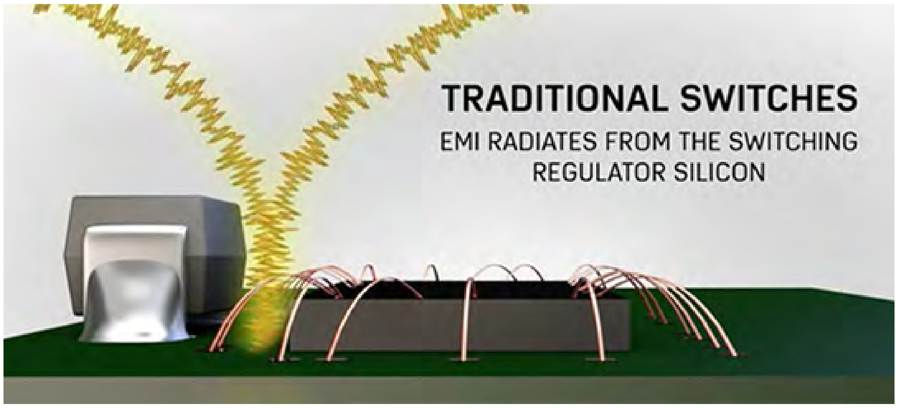


Figure 3: The bond wires from the IC die to the package function as miniature antennas and radiate undesired RF energy. (Image source: Analog Devices)

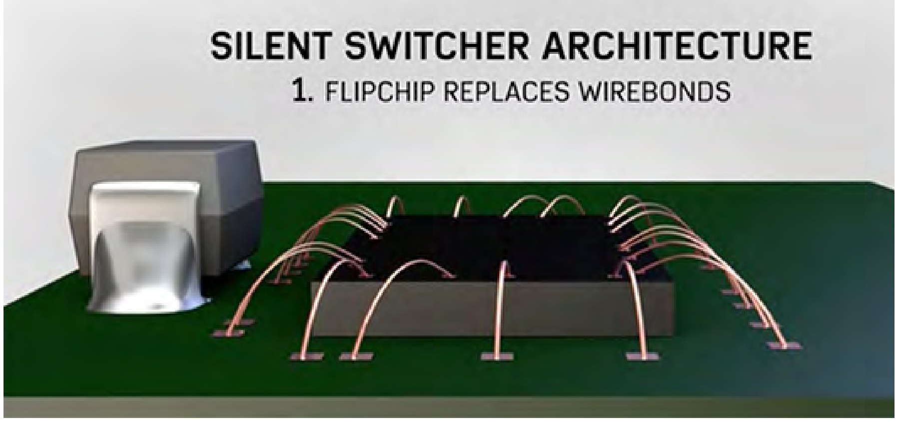


Figure 4: The Silent Switcher assembly begins by replacing the wire bonds with flipchip technology, thus eliminating the energy-radiating wires. (Image source: Analog Devices)

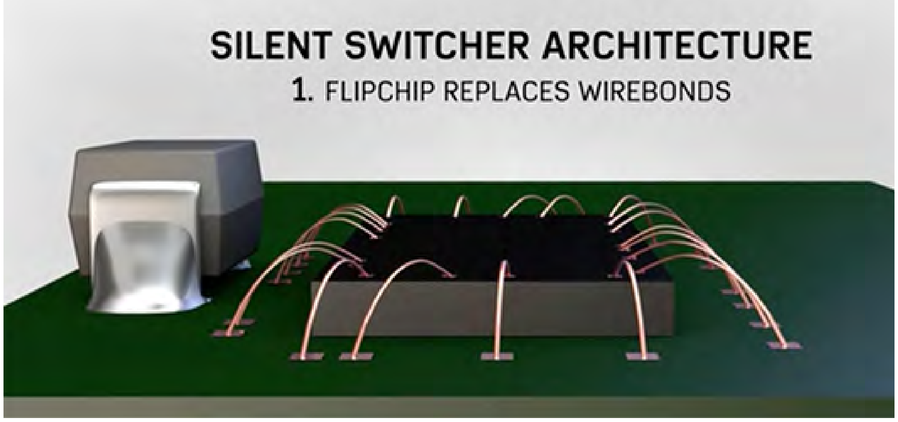


Figure 5: The flipchip approach effectively eliminates the antennas and minimizes radiated energy. (Image source: Analog Devices)

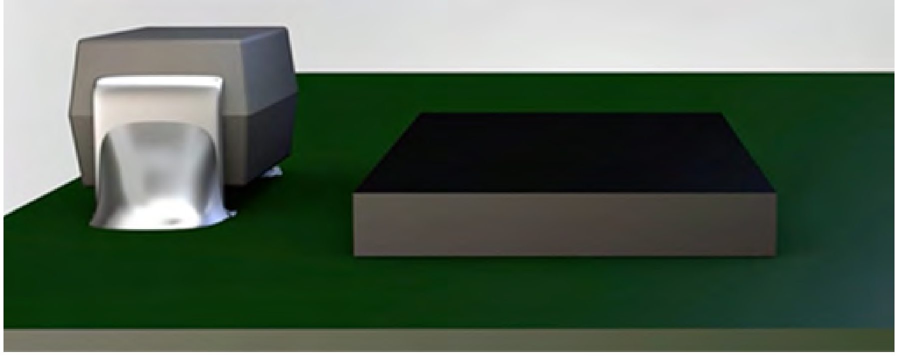


Figure 6: Dual, mirrored input capacitors are also added to constrain EMI. (Image source: Analog Devices)

By looking at a complete family of such regulators, such as the Silent Switcher µModules from Analog Devices, designers can choose a DC/DC regulator matched to the needed voltage and current rating, while being assured that EMI mandates will be met, size and cost will be known, and there will be no surprises.

These regulators incorporate much more than innovative schematics and topologies. Among the techniques they use are:

- Technique #1: The switching of the regulator acts as an RF oscillator/source and combines with the bond wires, which act as antennas. This turns the assembly into an RF transmitter with undesired energy that may exceed allowed limits (**Figures 3, 4, and 5**).
- Technique #2: The use of symmetrical input capacitors bounds EMI by creating balanced, opposing currents (**Figure 6**).
- Technique #3. Finally, the use of opposite current loops to cancel magnetic fields (**Figure 7**).

These Silent Switcher µModules represent the evolution of step-down regulator design and packaging from an IC with support components to an LQFN IC with integral capacitors to a µModule with requisite capacitors and inductors (**Figure 8**).

Broad offering addresses needs, tradeoffs

The Silent Switcher µModules comprise many individual units with different ratings for input voltage range, output voltage rail, and output current. For example, the LTM8003 is a 3.4 to 40-volt input, 3.3-volt output, 3.5 A continuous (6 A peak) µModule that meets CISPR 25 Class 5 limits, yet measures just 9 × 6.25 millimeters (mm) and 3.32 mm high (**Figure 9**).

It is offered in a pinout which is failure mode effects analysis (FMEA) compliant (LTM8003-3.3), meaning that the output stays at

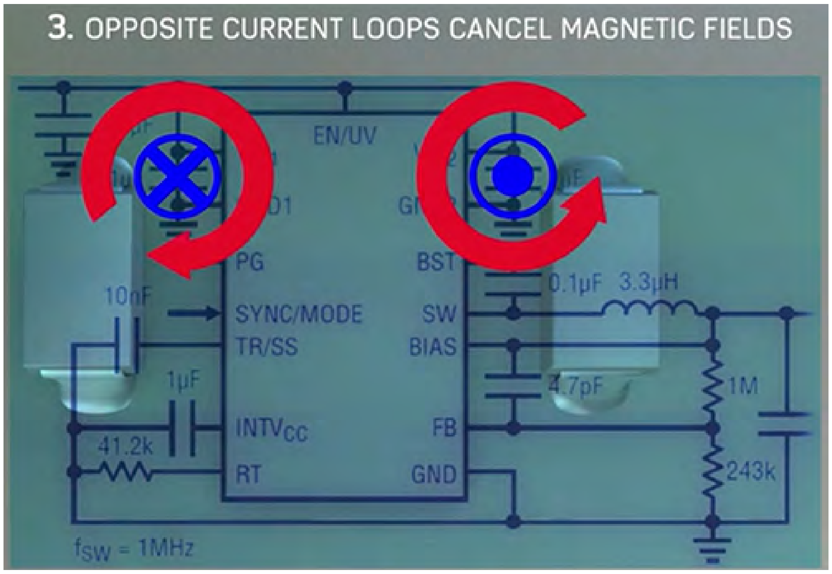


Figure 7: An internal layout with current loops in opposite directions also cancels undesired magnetic fields. (Image source: Analog Devices)

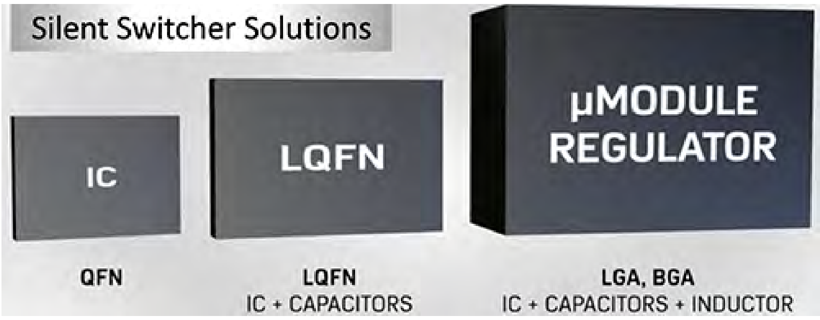
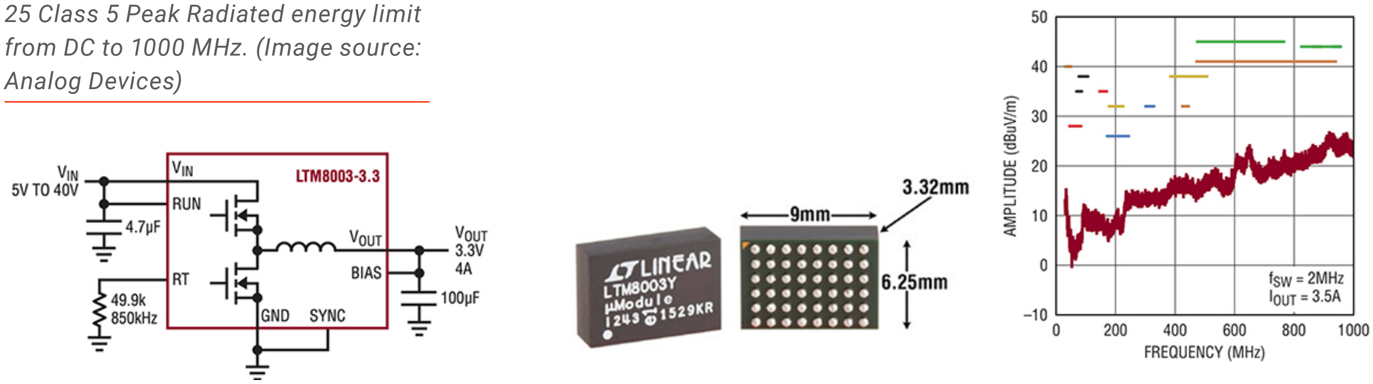
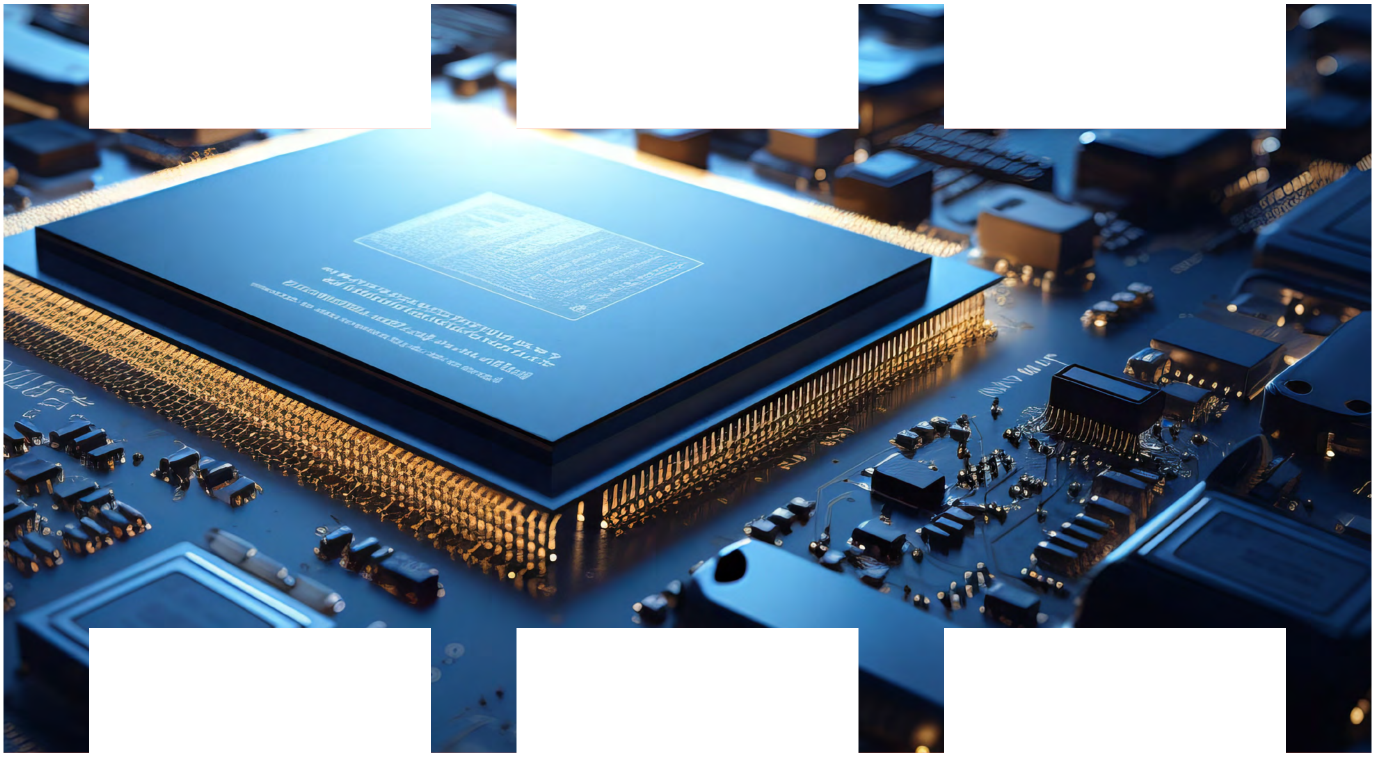


Figure 8: By incorporating capacitors and an inductor in the package, the Silent Switcher µModules are the third stage in the advancement of IC-centric switching regulators. (Image source: Analog Devices)

Figure 9: The LTM8003 Silent Switcher is a tiny, self-contained package that easily meets the CISPR 25 Class 5 Peak Radiated energy limit from DC to 1000 MHz. (Image source: Analog Devices)





or below the regulation voltage during an adjacent-pin short circuit or if a pin is left floating. The typical quiescent current is just 25 microamperes (µA), and the H-grade version is rated for 150°C operation.

The DC2416A demonstration (demo) board is available for designers to exercise the regulator and assess its performance for their application (**Figure 10**).

Two nominally similar Silent Switcher µModule family members, the LTM4657 (3.1 to 20-volt input; 0.5 to 5.5 volt @8 A output) and the LTM4626 (3.1 to 20-volt input; 0.6 to 5.5 volt at 12 A output), show the nature of the tradeoffs that the devices offer. The LTM4657 uses a higher value inductor than the LTM4626, allowing it to operate at lower frequencies to decrease switching loss.

Figure 10: The DC2416A demo board simplifies connection with and evaluation of the LTM8003 Silent Switcher device. (Image source: Analog Devices)

The LTM4657 is a better solution for high switching losses and low conduction losses, such as in applications where the load current is low and/or the input voltage is high. Looking at the LTM4626 and LTM4657 operating at the same switching frequency, and with the same 12-volt input and 5-volt output, the superior switching loss of the LTM4657 can be seen (**Figure 11**). Additionally, its higher-value inductor reduces the output voltage ripple. However, the LTM4626 can supply more load current than the LTM4657.

Users can assess the performance of the LTM4657 using the DC2989A demo board (**Figure 12**), while for those who need to evaluate the LTM4626, the DC2665A-A board is available (Figure 13).

The Silent Switcher µModules are not restricted to single-output modules. For example, the LTM4628 is a complete, dual 8 A

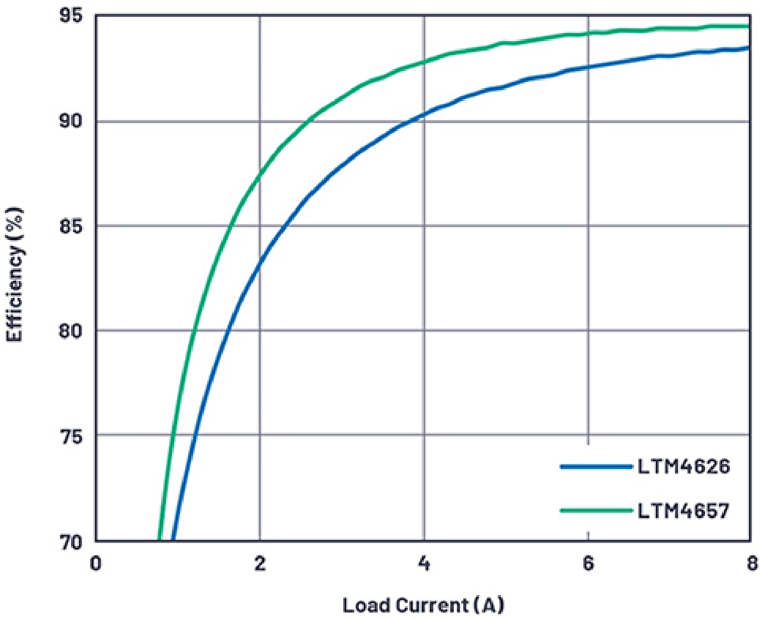


Figure 11: The efficiency comparison of the LTM4626 and LTM4657 at 1.25 MHz with the same configuration on a DC2989A demonstration board shows modest but tangible differences. (Image source: Analog Devices)

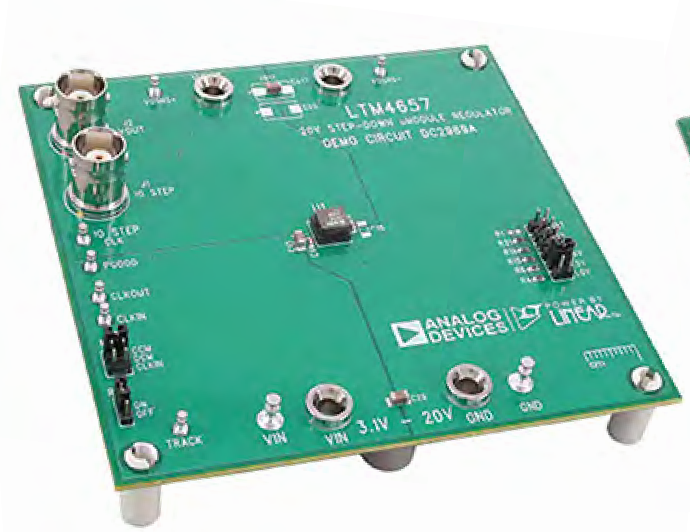


Figure 12: The DC2989A demo board is designed to speed the evaluation of the LTM4657 Silent Switcher. (Image source: Analog Devices)

Figure 13: For the LTM4626 Silent Switcher module, the DC2665A-A demo board is available to facilitate exercise and evaluation. (Image source: Analog Devices)

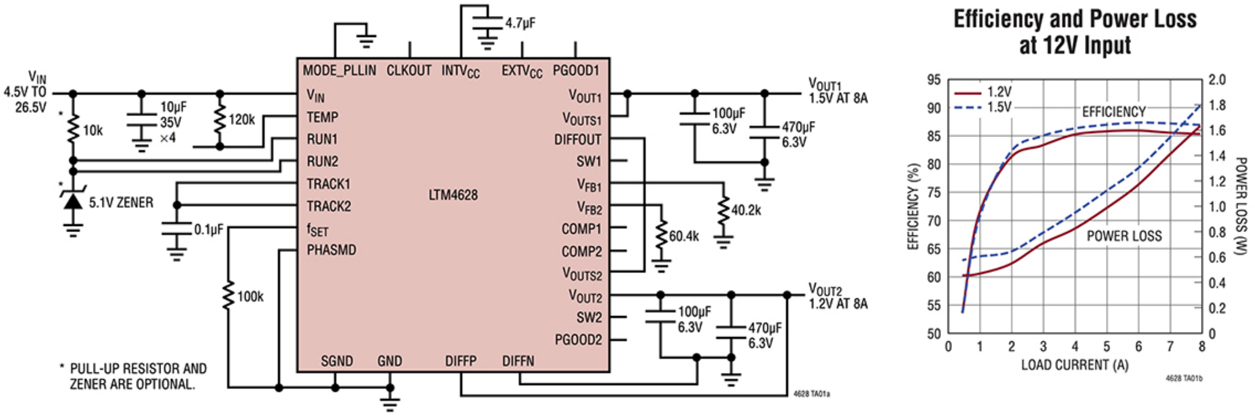


Figure 14: The LTM4628 can be configured as a dual-output, 8 A per channel switching DC/DC regulator, or in a single-output, 16 A output configuration. (Image source: Analog Devices)

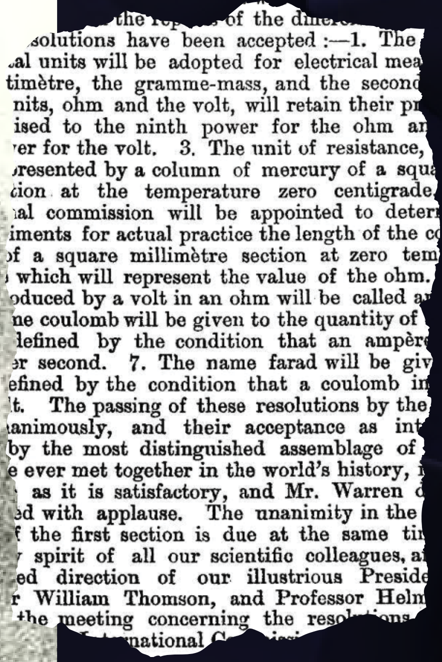
output switching DC/DC regulator that can be easily configured to provide a single 2-phase 16 A output (**Figure 14**). The module is offered in 15 mm × 15 mm × 4.32 mm LGA and 15 mm × 15 mm × 4.92 mm BGA packages. It includes the switching controller, power FETs, inductor, and all supporting components.

The module operates over an input voltage range of 4.5 to 26.5 volts and supports an output voltage range of 0.6 to 5.5 volts, set by a single external resistor. Users can investigate its performance as a single or dual-output device using the DC1663A demo board (**Figure 15**).

Conclusion

Designing a functioning DC/DC regulator is fairly easy with available ICs. However, designing a regulator that simultaneously excels in efficiency, is functionally complete, and meets the often various confusing and stringent regulator mandates is not. The Silent Switcher µModules from Analog Devices simplify the design process. They eliminate risk by meeting the goals for cool and efficient operation, EMI emissions below allowed limits, and drop-in completeness.

Figure 15: Evaluation of the single/dual-output LTM4628 is accelerated with the use of its DC1663A demo board. (Image source: Analog Devices)



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Ohm's Day

March 16

By David Ray
Cyber City Circuits

March 16: Ohm’s Day

March 16, 2024 marks Georg Ohm’s 235th Birthday. As you already know, the ohm is the unit of electrical resistance in a conductor such that a constant current of one ampere produces a potential difference of one volt.

The international standardization of the 'ohm' to denote the practical unit of electrical resistance dates to the first International Electrical Congress of 1881 in Paris. It was here that the units we are all fond of today… amperes, volts, farads… were all etched in stone.

That is the ending of this story. It started many years earlier.

1840s - The dashes and dots of the telegraph

With the dissolution of the Holy Roman Empire in the recent past, Europe was quickly becoming full of unrest and military action. The superpowers of the time knew that fast and reliable communication would win the upcoming conflicts for territory. By the 1840s, the electrical telegraph had become the cutting edge of technology. Quickly, all over Europe, telegraph lines were installed on overhead poles, along railways and highways, and through mountains and fields.

Overhead cable only required little in the way of planning or measurement. In 1843, Sir Charles

Wheatstone used a copper wire of 'one foot in length and weighing one hundred grains' as an electrical resistance standard. In the same building, an engineer designing telegraph cables used a standard of 'a mile of copper wire with a diameter of one-sixteenth inch' . Early telegrapher manuals may list the length and weight of the copper used as the only useful measurements.

The cable manufacturing industry experienced a surge during this period. With numerous players joining the market, there was a buzz of innovation and competition, driving the new electrical industry forward. You could go to any cable manufacturer, and they all sold 'the best and purist of copper cable', but there was no established standard to measure this claim against. At the time, this wasn't a big issue because telegraph messages could be sent through almost any length of overhead lines without difficulty.

1850s - The trans-Atlantic cable

By the mid-1850s, man's telegraphy hubris became an insurmountable obstacle. Between 1850 and 1853, submarine cables were laid from France to Britain and then from Britain to Ireland. In 1854, the concept of a trans-Atlantic cable was becoming trivial in the minds of some. Several attempts were made to connect the New World to the Old World, but their limited understanding of electrical theory and measurements caused one issue after another.

Running two thousand miles of heavy conductors through three-mile-deep ocean water at very low temperatures and shoveling two thousand volts of electricity through them may cause problems.

Ohm's Law had been recognized as accurate and practical, so they knew that if they could reckon an absolute measure of resistance, they could model voltaic currents (amperes), electromotive force (voltage), and electrical quantity (charge). Domestically, each country had its own 'standard.' Some countries used iron wire in their standard, some used copper wire, and others used gold-alloy wire. It became clear that standardizing the measurement of electrical resistance would be necessary to figure out how to solve the trans-Atlantic cable problem.

1860s - The British Association for the Advancement of Science

The year was 1861.

After years of work as a cable engineer, including efforts that lead to improvements on the trans-Atlantic cable, Latimer Clark found himself in front of the British Association for the Advancement of Science in Manchester. Being accompanied

Fun Fact: The first transatlantic cable weighed 1,600 tons, used over 26,000 nautical miles of wire, and took 250 workers a year to make.

> "The science of electricity, and the art of telegraphy, have both now arrived at a stage of progress at which it is necessary that universally received standards of electrical quantities and resistance should be adopted, in order that precise language and measurement may take the place of the empirical rules and ideas now generally prevalent"
> – Latimer Clark, 1861

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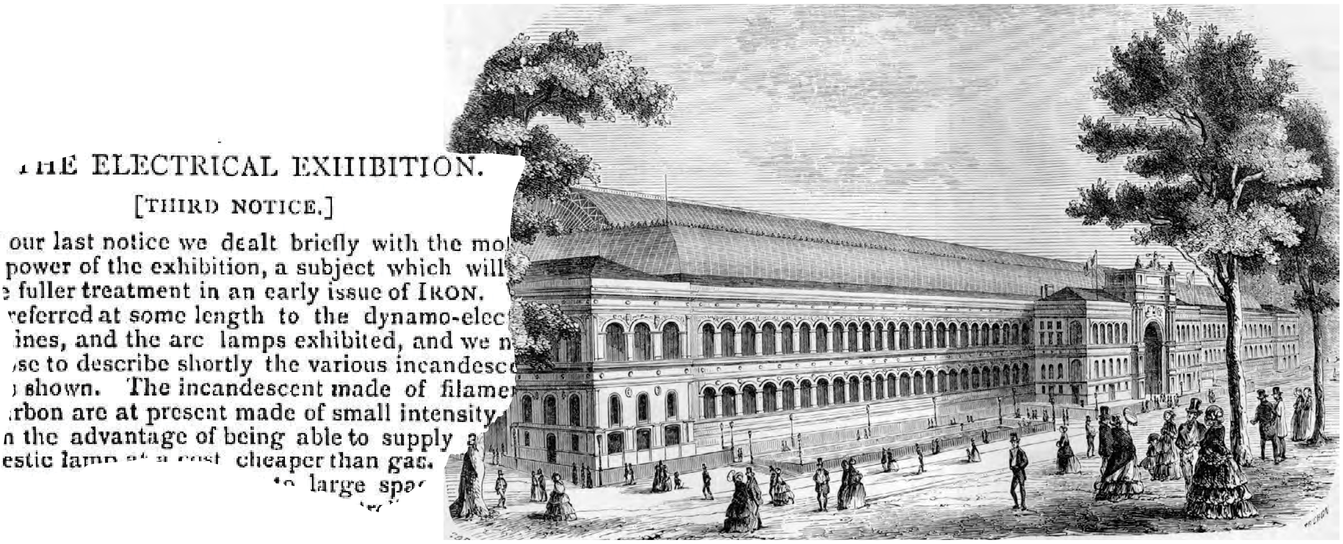
by Sir Charles Bright, he starts down the path that will lead to the immortalization of Georg Ohm in the minds of designers, on the tongues of electricians, and within the hearts of every high school physics teacher in the time since by proposing a new committee to study and standardize the measurement of electrical resistance.

The following year, the British Association for the Advancement of Science (BAAS) appointed 'The Committee on Standards of Electrical Resistance'. Members of this committee included Sir William Thomson (Lord Kelvin), James Clerk Maxwell, Carl Siemens, Sir Charles Wheatstone, and Sir Charles Bright, along with people instrumental in metallurgy, mineralogy, and the design of cable-laying ships.

After three years of extensive experimentation, the 1865 Report of the Committee on Standards of Electrical Resistance starts with 'The Committee has the pleasure of reporting that the object for which they were first appointed has now been accomplished.' By 1867, the committee had completed the bulk of their work, and these new standards for resistance revolutionized the entire supply chain, top to bottom. They could now determine the purity of copper based on the length, weight, temperature, and resistance, thus could better model and predict how wire will act in different environments. In 1873, after twelve years of working on this problem, a committee of the British Association for the Advancement of Science formally proposed the 'ohm' as the standard unit of measure for electrical resistance.



HE ELECTRICAL EXHIBITION.

[THIRD NOTICE.]

our last notice we dealt briefly with the mo
power of the exhibition, a subject which will
fuller treatment in an early issue of IRON.
eferred at some length to the dynamo-elec
ines, and the arc lamps exhibited, and we n
se to describe shortly the various incandesce
shown. The incandescent made of filame
rbon are at present made of small intensity
n the advantage of being able to supply a
estic lamp at a cost cheaper than gas.
large spa

1827

Ohm's principal work, 'The Galvanic Circuits Investigated Mathematically,'is published.

1854

The work on the Transatlantic Cable begins.

1861

Latimer Clark reads his proposal in Manchester.

1865

The committee creates the first standardized system for measuring electrical resistance.

1873

The B.A.A.S announces the 'ohm' as the standard unit of measure for electrical resistance.

1881

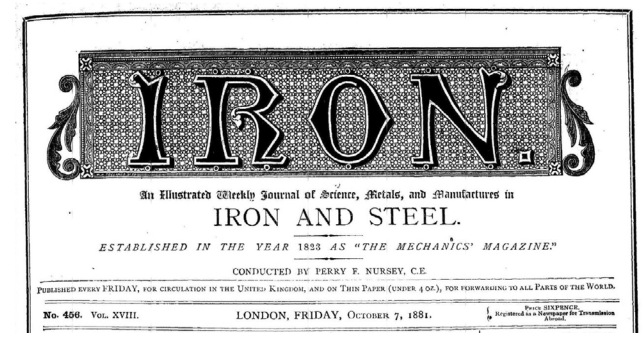
The 'ohm' is formalized for international use by the First International Electrical Congress.

This was a watershed moment for civilization. Never could a manufacturer take a specification and be assured that a comparable piece could be found, tested, and verified before running it through a mountain range or putting it miles below the ocean.

1881 - The first international electrical congress

Even though the British Association for the Advancement of Science mostly completed their work for a standard unit of electrical resistance, some nations did not accept the standard at first. It took a concerted effort to create an international consensus.

In 1881 the world's greatest minds converged on Paris for the First International Electrical Congress. From the fifteenth of September through the fifth of October, a jury of one hundred forty-four representatives from fifteen different countries came together to standardize electrical units for measurement, but also discuss business at hand concerning machines, motors, weights, coils, electrical lamps, sewing machines, etc.



IRON.

An Illustrated Weekly Journal of Science, Metals, and Manufactures in

IRON AND STEEL.

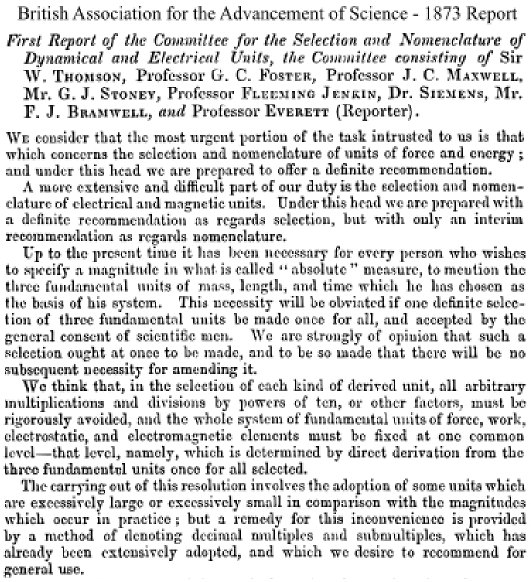
ESTABLISHED IN THE YEAR 1823 AS "THE MECHANICS' MAGAZINE."

CONDUCTED BY PERRY F. NURSEY, C.E.

PUBLISHED EVERY FRIDAY, FOR CIRCULATION IN THE UNITED KINGDOM, AND ON THIN PAPER (UNDER 4 OZ.), FOR FORWARDING TO ALL PARTS OF THE WORLD.

No. 456. VOL. XVIII. LONDON, FRIDAY, OCTOBER 7, 1881. PRICE SIXPENCE. Registered as a Newspaper for Transmission Abroad.

> The 'ohm,' as represented by the original standard coil, is approximately 109 C. G. S. units of resistance; the 'volt' is approximately 108 C.G.S. units of electro-motive force; and the 'farad' is approximately 1/109 of the C.G.S. unit of capacity."
> - The Committee for the Selection and Nomenclature of Dynamical and Electrical Units, 1873



British Association for the Advancement of Science - 1873 Report

First Report of the Committee for the Selection and Nomenclature of Dynamical and Electrical Units, the Committee consisting of Sir W. Thomson, Professor G. C. Foster, Professor J. C. Maxwell, Mr. G. J. Stoney, Professor Fleeming Jenkin, Dr. Siemens, Mr. F. J. Bramwell, *and* Professor Everett (Reporter).

We consider that the most urgent portion of the task intrusted to us is that which concerns the selection and nomenclature of units of force and energy; and under this head we are prepared to offer a definite recommendation.

A more extensive and difficult part of our duty is the selection and nomenclature of electrical and magnetic units. Under this head we are prepared with a definite recommendation as regards selection, but with only an interim recommendation as regards nomenclature.

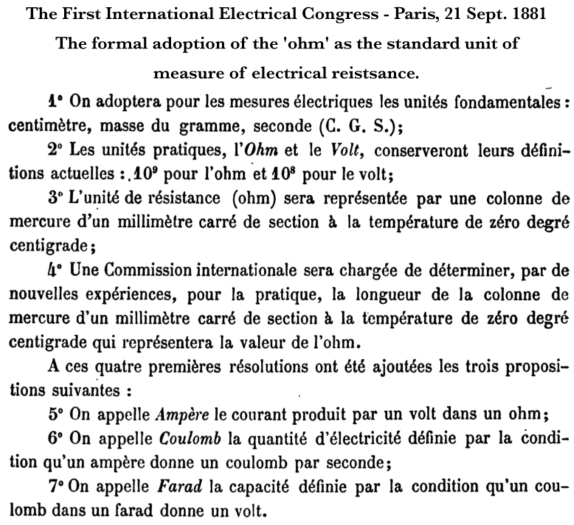
Up to the present time it has been necessary for every person who wishes to specify a magnitude in what is called "absolute" measure, to mention the three fundamental units of mass, length, and time which he has chosen as the basis of his system. This necessity will be obviated if one definite selection of three fundamental units be made once for all, and accepted by the general consent of scientific men. We are strongly of opinion that such a selection ought at once to be made, and to be so made that there will be no subsequent necessity for amending it.

We think that, in the selection of each kind of derived unit, all arbitrary multiplications and divisions by powers of ten, or other factors, must be rigorously avoided, and the whole system of fundamental units of force, work, electrostatic, and electromagnetic elements must be fixed at one common level—that level, namely, which is determined by direct derivation from the three fundamental units once for all selected.

The carrying out of this resolution involves the adoption of some units which are excessively large or excessively small in comparison with the magnitudes which occur in practice; but a remedy for this inconvenience is provided by a method of denoting decimal multiples and submultiples, which has already been extensively adopted, and which we desire to recommend for general use.

The news reached London the last week of September and was first published in the London Week News, where it was said: "the passing of these resolutions by the Congress today unanimously, and their acceptance as international decisions by the most distinguished assemblage of physicists which have ever met together in the world's history, i s quite as remarkable as it is satisfactory."

The International Electrical Congresses in the late 19th and early 20th centuries established electrical standards that drove the Second Industrial Revolution's growth and innovation. These meetings brought together the brightest minds in electrical engineering and were instrumental in propelling rapid technological advancements and industrial expansion.



The First International Electrical Congress - Paris, 21 Sept. 1881

The formal adoption of the 'ohm' as the standard unit of measure of electrical reistsance.

1° On adoptera pour les mesures électriques les unités fondamentales: centimètre, masse du gramme, seconde (C. G. S.);

2° Les unités pratiques, l'*Ohm* et le *Volt*, conserveront leurs définitions actuelles: 10^9 pour l'ohm et 10^8 pour le volt;

3° L'unité de résistance (ohm) sera représentée par une colonne de mercure d'un millimètre carré de section à la température de zéro degré centigrade;

4° Une Commission internationale sera chargée de déterminer, par de nouvelles expériences, pour la pratique, la longueur de la colonne de mercure d'un millimètre carré de section à la température de zéro degré centigrade qui représentera la valeur de l'ohm.

A ces quatre premières résolutions ont été ajoutées les trois propositions suivantes:

5° On appelle *Ampère* le courant produit par un volt dans un ohm;

6° On appelle *Coulomb* la quantité d'électricité définie par la condition qu'un ampère donne un coulomb par seconde;

7° On appelle *Farad* la capacité définie par la condition qu'un coulomb dans un farad donne un volt.

An immortal legacy

Two hundred years after he first published 'The Galvanic Circuit Investigated Mathematically,' Georg Ohm is still in the back pocket of every engineer and technician worldwide. Latimer Clark honored Ohm by proposing a unit of measure for him, immortalizing his work in ways that very few people ever could be.

This year, on Ohm's Day, while you're celebrating with your friends and loved ones, let us not forget the people like Sir William Thomson (Lord Kelvin), James Maxwell, Sir Charles Wheatstone, Latimer Clark, and Sir Charles Bright, who lifted him above the pantheon of the giants who made our understanding of the movement of electrons possible.

How to design effective power supply thermal management in industrial and medical systems

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Efficient and cost-effective thermal management for power supply units (PSUs) is important when designing industrial and medical systems to ensure reliability. Designing an effective thermal management system for a PSU is a complex activity, and much depends upon whether the PSU is enclosed or open frame.

If an enclosed PSU is used, the type of enclosure has an impact on airflow and thermal dissipation. While fans help, designers need to consider fan reliability as well as the back pressure caused by system fans that can significantly reduce the effectiveness of the PSU fan(s), potentially increasing PSU operating temperatures.

PSUs often have lower efficiencies at low input line voltage conditions. As a result, units that are operated for extended periods under low input line conditions can result in higher thermal dissipation and the need for additional cooling. Finally, PSUs often require derating if operated at elevated temperatures that can be experienced in industrial and medical systems.

To speed the implementation of effective thermal management systems, designers can turn to PSUs specifically designed for use in industrial and medical applications that offer a range of thermal management options.

This article reviews the thermal management challenges when designing industrial and medical systems and offers guidance for designing effective thermal management solutions. It then presents options when integrating PSUs into industrial and medical equipment using PSUs from Bel Power Solutions as real-world examples, and closes with some practical steps designers can follow when integrating a PSU into the overall system thermal design.

Power supply thermal management challenges

PSU thermal management challenges include system airflow and the impact that system fans can have on the performance of any fans integrated into PSUs, the ambient operating temperature, the need for peak power delivery, and the impact the input voltage range can have on power dissipation. These are first-order considerations; this article does not touch on second-order thermal management considerations related to rack mount systems or special environments such as data centers.

One of the first considerations is the direction of PSU airflow; normal airflow creates positive pressure exiting the system and reverse airflow creates positive pressure entering the system (**Figure 1**).

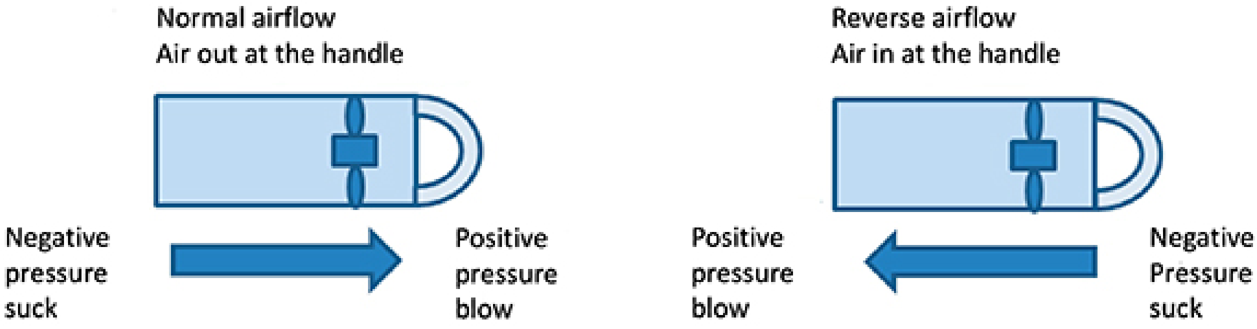


Figure 1: In normal airflow, positive pressure exits the system (left). With reverse airflow, positive pressure enters the system (right). (Image: Bel Power Solutions)

A fan is not enough

Many PSUs include a cooling fan. Rather than simplifying the thermal design, a PSU with a fan can complicate thermal design with considerations of airflow direction as well as the system or chassis airflow impedance and pressure. Complications include:

- System fans can compete with and reduce the effectiveness of PSU fans, reducing airflow through the PSU.
- The entry to the PSU fan can have an unexpectedly high impedance, reducing airflow through the PSU.
- Cables or other obstacles can block the PSU airflow, reducing the effectiveness of the fans.

There are several ways that system and PSU fans can interact, examples are shown in **Figure 2** below:

- The PSU fan(s) produce normal airflow, but the higher performance of the system fan(s) results in a lower (negative) pressure inside the chassis, thereby reducing PSU fan effectiveness.
- The PSU fan(s) produce reverse airflow and the system fan(s) are helping the PSU cooling, not fighting it. However, if the air entering the PSU is coming from the system exhaust plenum, that can create issues that include a reduction in net airflow, as well as recirculation issues that cause the accumulation of heat in the PSU.
- The air entry to the PSU is isolated from the main chassis airflow protecting the PSU fans from interference from the system fan(s). To realize the maximum benefit, the airflow channel for the PSU should have a low resistance.

Peak vs. nominal power rating and derating

Derating is often different for peak power versus nominal power. Peak power needs vary widely from a few milliseconds (ms) up to 10 seconds or more, and it's an important consideration in many industrial and medical systems. Consider two 600-watt PSU series optimized for different peak power delivery; the ABC601 series of industrial and medical AC-DC power supplies from Bel Power Solutions that is rated for 10 seconds of peak power delivery, and the VPS600 series that's rated for 1 ms of peak power.

The ABC601 series provides up to 600 watts of regulated output power over an input voltage range from 85 to 305 volts alternating current (VAC) in single outputs

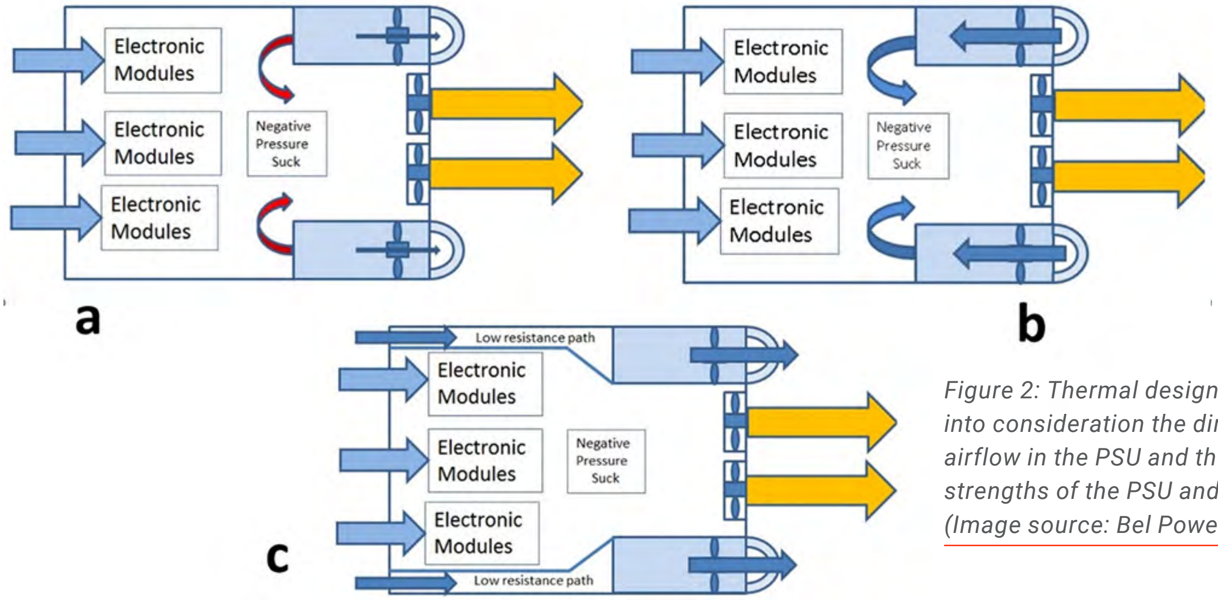


Figure 2: Thermal design must take into consideration the direction of airflow in the PSU and the relative strengths of the PSU and system fans. (Image source: Bel Power Solutions)

of 24, 28, 36, or 48 volts direct current (VDC). For example, the ABC601-1T48 has a 48 VDC output. These PSUs are rated for 600 watts of continuous power or peak power up to 800 watts for up to 10 seconds at up to 60°C for the enclosed front-mounted fan models (**Figure 3**). They have a 5 VDC standby power output rated for 1.2 amperes (A) for U chassis models and 1.5 A for front-mounted fan models, and a 12 volt, 1 A, fan output.

The ABC601 series comes in two packages, U-frame chassis or enclosed with a front-mounted fan (**Figure 4**). The ABC601 series features an internal current share circuit for parallel operation between units to enhance total power.

The EOS Power VPS600 series of open frame PSUs from Bel Power Solutions feature a narrower input range of 85 to 264 V_{AC} and deliver

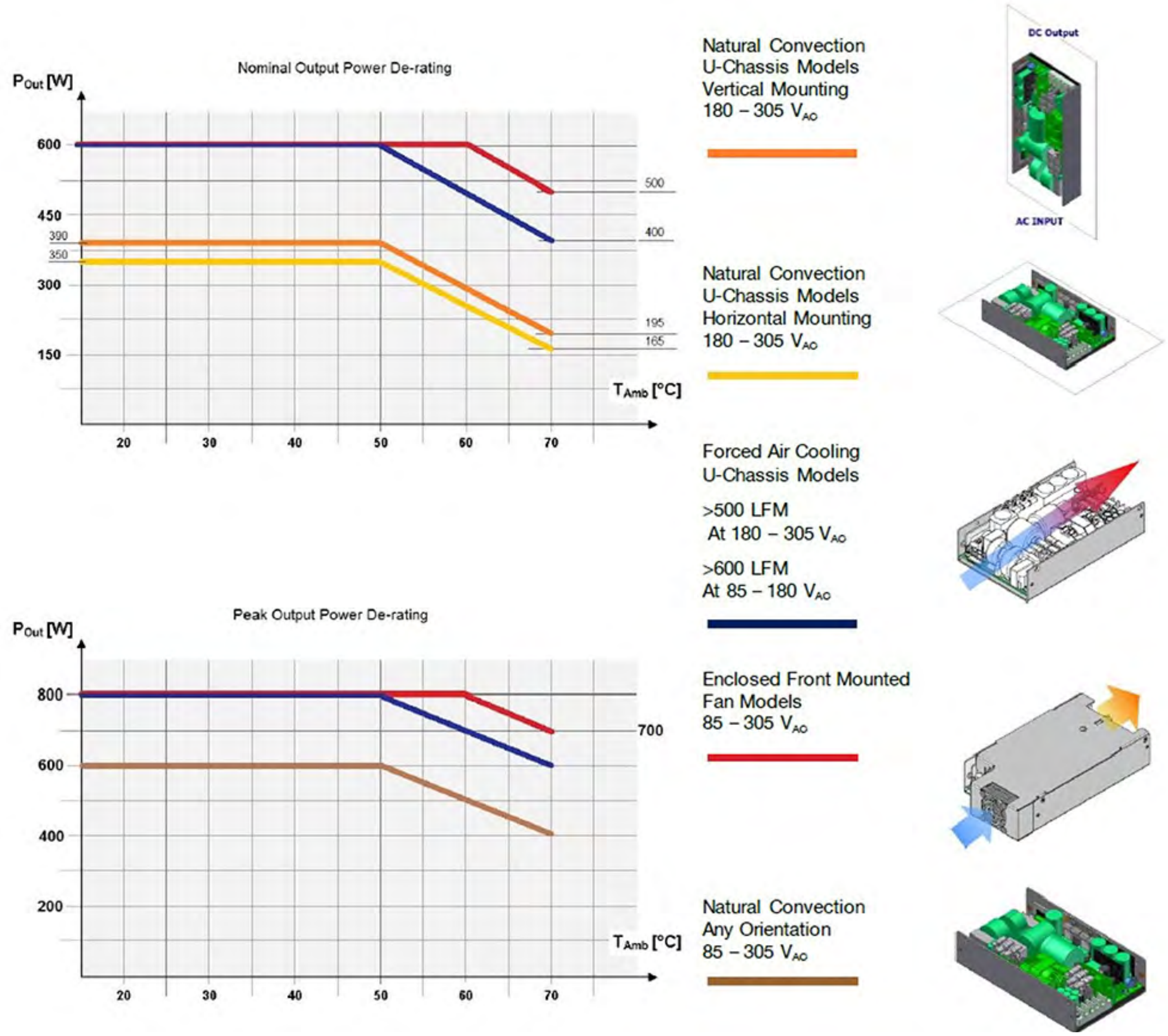


Figure 3: The enclosed front-mounted fan models of the ABC601 series deliver 600 watts of continuous power (red line on top graph) or up to 800 watts for up to 10 seconds (red line on bottom graph) at up to 60°C. (Image source: Bel Power Solutions)

Figure 4: ABC601 PSUs are available with fan cooling (top) or convection cooling (bottom). (Image source: Bel Power Solutions)

up to 600 watts of continuous output power and peak power of 720 watts for 1 ms (**Figure 5**). These PSUs are available with output voltages of 12, 15, 24, 30, 48, and 58 V_{DC}. For example, the VPS600-1048 has an output of 48 VDC. These units include a 5 V_{DC}, 500 milliamperes (mA), standby power output and a 12 volt, 500 mA, fan output. While the ABC601 series is offered in two package styles, the VPS600 series is available in three with different power ratings: convection cooled U channel rated for 600 watts, slotted cover units rated for 420 watts, and plain cover units rated for 360 watts.

The various output voltage options and package styles have different derating curves. For example, the derating for 24 V_{DC} output units is:

- Open frame
    - Convection load, 600 watts continuous up to 30°C
- Slotted cover
    - Convection load, 420 watts continuous up to 30°C
- Plain cover
    - Convection load, 360 watts continuous up to 30°C
- For all cover styles
    - Derate between 30 and 50°C by 0.833% per °C
    - Derate above 50°C by 2.5% per °C to a maximum of 70°C

Figure 5: The VSP600 series is available in three package configurations with different nominal power ratings; 600-watt convection cooled U channel units, 420-watt slotted cover units, and 360 watt plain cover units. (Image source: Bel Power Solutions)

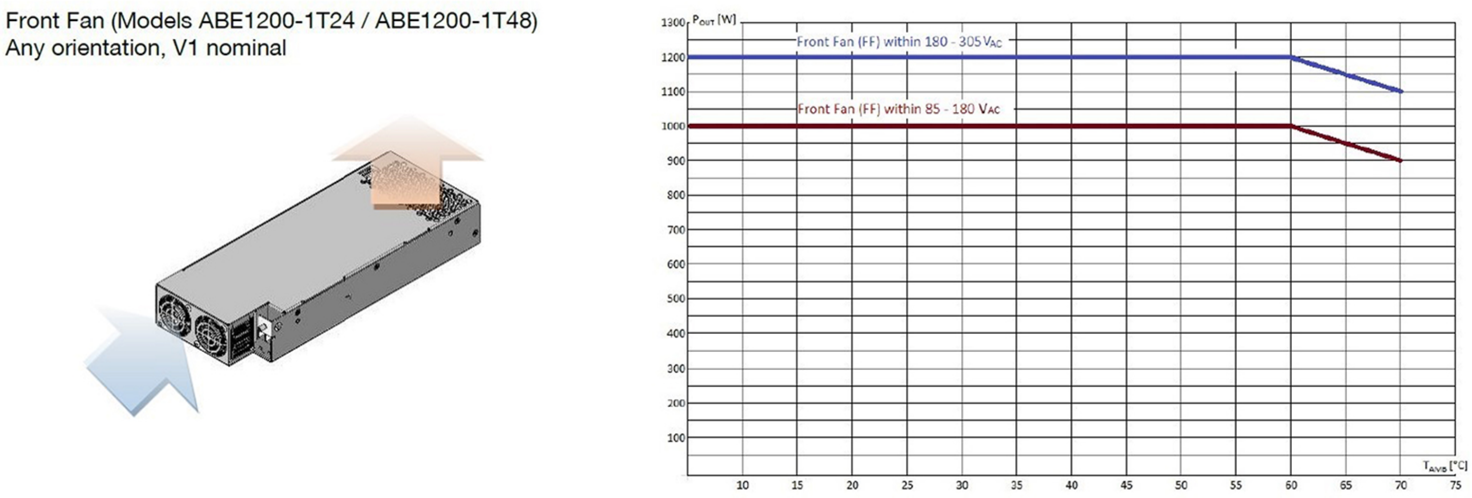


Figure 6: The ABE1200/MBE1200 PSUs deliver 1200 watts with input voltages from 180 to 305 VAC and 1000 watts with input voltages from 85 to 180 VAC. (Image source: Bel Power Solutions)

The input voltage effect

PSU efficiency can be reduced at lower input voltages, resulting in derating of the nominal output power. For example, the ABE1200/MBE1200 series of AC-DC power supplies provide 1200 watts with an input of 180 to 305 V_{AC}, and 1000 watts with an input range of 85 to 180 V_{AC} (**Figure 6**). These nominal ratings are from 0 to 60°C. At 70°C, they derate linearly from 1200 to 1100 watts and from 1000 to 900 watts, respectively.

These PSUs include a fan speed control to minimize audible noise when maximum airflow is not needed. They are available in three 1U height compatible packages, including an enclosed model with two fans (24 V_{DC} models only), and a U-shaped chassis with two protective cover options (**Figure 7**).

Figure 7: The ABE1200 PSUs are available with dual fans (24 VDC models only), and two choices of protective covers. (Image source: Bel Power Solutions)

DIN is different

The LEN120 series PSUs have a nominal power rating of 120 watts and are designed for standard DIN-rail mounting. For example, the LEN120-12 delivers an output of 12 V_{DC} over nominal input voltage ranges of 90 to 264 V_{AC} (universal) or 127 to 370 V_{DC} (**Figure 8**).

When derating DIN-rail PSUs, the datasheets often simultaneously consider input and output voltages, in addition to the operating temperature. For the LEN120 series:

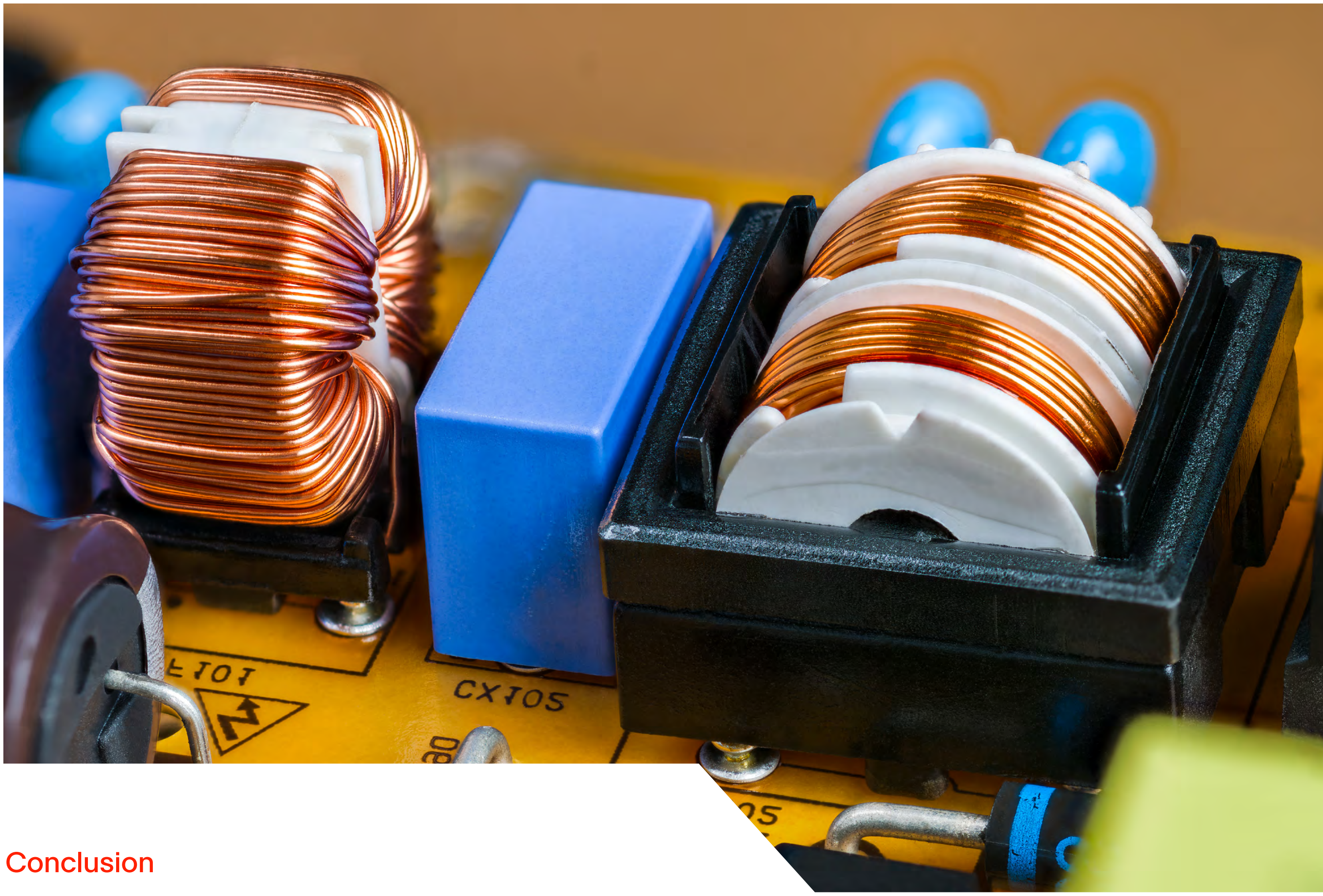
- All models
  - From -20°C to -10°C, with a nominal 115 V_{AC} input, output power derates 2%/°C
  - From -20°C to -10°C, with a nominal 230 V_{AC} input, no derating is required
  - From +40°C to +60°C, with a nominal 115 V_{AC} input, output power derates 2.5%/°C
  - For input voltages between 115 and 264 V_{AC} and between 162 and 370 V_{DC}, no derating is required
  - For input voltages between 115 and 90 V_{AC} and between 162 and 127 V_{DC} (low line conditions), output power derates 1%/V
- Model LEN120-12 (12 V_{DC} output)
  - From +45°C to +60°C, with a nominal 230 V_{AC} input, output power derates 3.33%/°C
- Models LEN120-24 and LEN120-48 (24 and 48 V_{DC} output, respectively)
  - From +50°C to +60°C, with a nominal 230 V_{AC} input, output power derates 5%/°C

Figure 8: The LEN120 series DIN-rail PSUs are rated 120 watts and are convection cooled. (Image source: Bel Power Solutions)

Practical steps toward better thermal designs

As shown, the integration of a PSU into a system involves complex thermal design issues. There are several practical steps designers can follow to help avoid unpleasant surprises:

- The PSU maker can provide detailed information on the relationship between fan air flow and static pressure (the P-Q curve), enabling designers to know what airflow to expect if the PSU fan will be operating with or against internal back pressure in the system.
- Some PSU makers can supply FlowTHERM thermal models of the PSU that can be used in the overall system model to assess PSU thermal performance and identify potential concerns.
- Have the PSU maker review a system thermal design and make recommendations for further analysis, or confirm the validity of the design.



Conclusion

There are several issues to consider when designing a PSU thermal management system for medical or industrial applications. They include system airflow, the impact that system fans can have on the performance of any fans integrated into the PSU, the specified operating temperature range, the need to support peak power delivery, and the impact the input voltage range can have on power dissipation.

To help solve these issues, designers can turn to PSU designs from Bel Industrial Power that are optimized for different thermal environments and application scenarios. Additionally, thermal management tools are available from PSU makers that can help speed the design process.

Maintaining electrical power quality within automated systems

By Lisa Eitel
Contributed By DigiKey's
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As covered in a previous Digi-Key article on the specifics of dirty utility power, there are half a dozen power-quality issues (including voltage surges, outages, frequency instabilities, and noise) that can arise from fluctuations in the local utility power grid. Further complicating matters is that variations can also originate from within each piece of electrically powered automation equipment. Fortunately, components abound to address such electric-power consistency issues. These power supplies and other power components make machinery perform its best and prevent machinery from having a negative impact on the local utility power grid.

The two main types of power-quality problems arising from within equipment are noise and harmonic disturbances.

Electrical noise in electrical power refers to high-frequency voltage variations. High frequency is relative — but always indicates frequencies considerably higher than the system ac frequency. Viewed in the time domain, an ac current should appear as a smooth sinusoidal wave. Noise makes the wave ragged and rough.

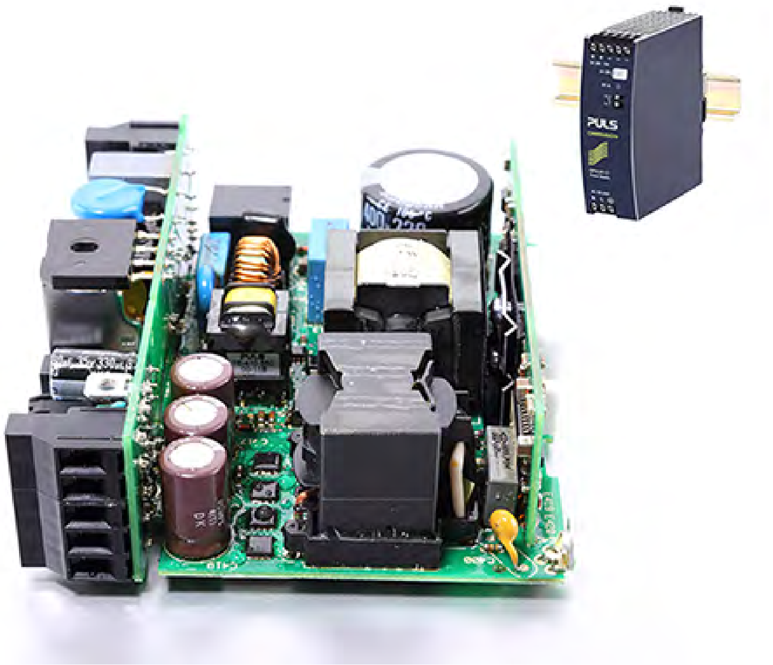


Figure 1: This PULS CP-Series single-phase power supply mounts to DIN rail so common in industrial automation. Features include high immunity to transients and power surges as well as low electromagnetic emission, a DC-OK relay contact, 20% output power reserves (covered later in this article), and minimal inrush current surge. The specially coated power supply also executes active power factor correction or PFC functions. (Image source: EE World)

There is always some noise in the electrical supplies of machinery caused by the resistance of the conducting wires involved. Such noise is called thermal noise and is generally a negligible disturbance. More significant and potentially detrimental noise is caused by local loads such as welders and electric motors. Noise from such components and systems can often be difficult to quantify — and pose the most risk of causing affected equipment subcomponents to overheat, wear, and even fail.

Electrical harmonics are voltage or current disturbances at frequencies that are integer multiples of the system ac frequency. They are caused by nonlinear loads such as rectifiers, computer power supplies, fluorescent lighting, and certain types of variable-speed electric motors. Current harmonics tend to be larger than voltage harmonics and actually tend to drive the latter.

These electrical harmonics (due to the way they induce heat generation) can dramatically degrade the efficiency and life of electric motors. They may also cause vibrations and torque pulsations in the mechanical output of electric motors, which shortens the life of the power-transmission subcomponents integrated into the motors — especially the shaft-supporting bearings.

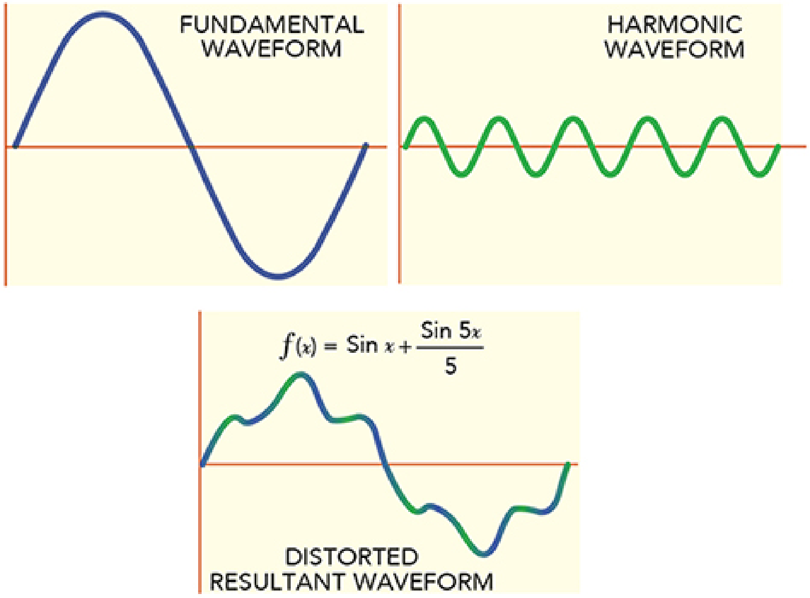


Figure 2: Harmonic waveforms are frequency integer multiples of some fundamental waveform that (in electrical power systems) can combine with the fundamental waveform and cause problems. Harmonics typically originate from some electrical load or within an attached piece of machinery. (Image source: Design World)

Key power-system parameters

Two important specifications for power supplies include the *power factor* and *holdup time*.

Power factor is a dimensionless ratio used to describe the difference between true power and apparent power in ac systems. Apparent power is the combination of the true power and the reactive power. Reactive power in turn is drawn from the network, stored momentarily, and then returned without being consumed. This is typically caused by inductive or capacitive loads, which leads to the current and voltage being out of phase. Reactive power increases the load on distribution systems, reduces power quality, and leads to higher energy bills.

Ideally a system will have a power factor of one — meaning there's no reactive power in the system. Designs with power factors below 0.95 cause increased load on the distribution system and may incur reactive-power charges.

Holdup time is how long a power supply can continue to supply power within its specified voltage after a power outage. Consider the case of uninterruptible power supplies (UPSs) and generators — types of backup power used to ensure continuity of automated operations during blackouts and brownouts. As detailed more fully

Figure 3: Shown here is a TML 100C Series, 85-100 Watt AC-to-DC power module from Traco Power. Active power-factor correction (PFC) ensures a power factor of better than 0.95 (for 230 VAC) and better than 0.99 (for 115 VAC). (Image source: Traco Power)

in this article's final section, a UPS must supply power for any significant period. But depending on the UPS design, these may introduce a delay of up to 25 msec between a utility-power failure and the UPS initiation of power delivery.

Power-supply holdup time allows the power supply to bridge this gap, largely using power stored in capacitors. In fact, switch-mode power supplies tend to have longer holdup times than linear power supplies due to their higher-voltage capacitors.

Other features to address machine-induced power problems

Grounding, isolation, and filtered power converters provide the foundation for a quality power supply.

Grounding: Proper grounding is essential for a power supply to function correctly. It provides a reference voltage (from which all other voltages are measured) and a return path for electrical current. Read the Digi-Key article *What You Need to Know about Ground Fault Sensing and Protection* for more on this topic.

Isolation: Although non-isolated power supplies can be more energy efficient and compact, isolation between the input and output voltage protects against dangerous voltages passing to the output in the event of a component failure. Isolation may also be required to protect operators from dangerous voltages or to protect equipment from transients and swells.

Forms of isolation include:

- Physical insulation between components
- Inductive coupling through a transformer — power converters that change the voltage of a power system
- Optical couplings — which are most suitable for signal transfer between different parts of a power system while ensuring a very high level of isolation

Figure 4: Power supplies often function as power converters to either 1) change an ac source's voltage or frequency or 2) rectify or otherwise convert ac power into dc. Case in point: This 48-V 400-W AC-to-DC pulse-frequency-modulated (PFM) converter from Vicor Corp. has integrated filtering and transient surge protection. One caveat: The Vicor Integrated Adapter (VIA) converter only accepts input from an external rectified sinusoidal ac source — with a power factor maintained by the module. Harmonics conform to IEC 61000-3-2 and internal filtering enables compliance with applicable surge and EMI requirements. (Image source: Vicor Corp.)

Electrical filters and surge suppression: Surge suppression removes transients and swells, protecting electrical equipment from the effects of these overvoltage conditions. In contrast, electrical filters smooth the system voltage to remove noise and harmonics. Read about the filters on industrial power supplies used in large aircraft (with 400 Hz electrical sources) in the digikey.com article *Power Supply Operation on a 400 Hz Source.* Or consider another electrical-filter type that's especially common in automated installations near the point of use — LC filters – to complement motor drives. LC filters are a type of tank or resonant circuit (also called a tuned circuit) with an inductor L and a capacitor C to generate output at a set frequency. LC filters for motors usually serve the purpose of converting a drive's rectangular PWM output voltage into a smooth sine wave with low residual ripple. Benefits include the extension of motor life through avoidance of high dv/dt, overvoltage, overheating, and eddy-current losses.

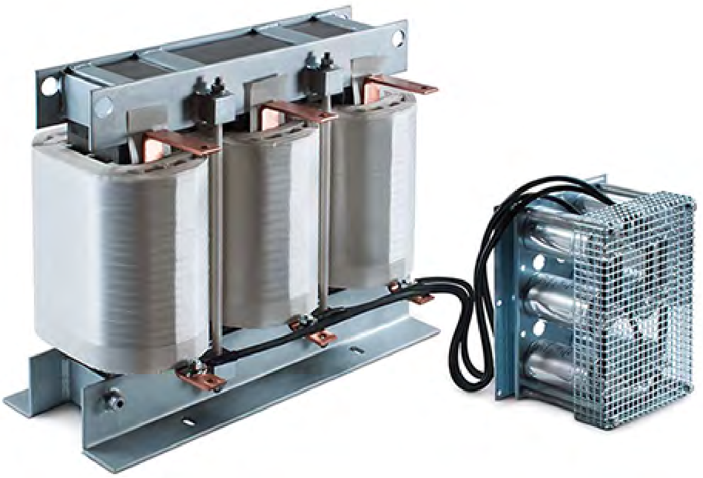


Figure 5: This is a Schaffner EMC Inc. LC sine-wave filter to help motor drives deliver smooth sine waves into attached motor windings without voltage peaks. The filter also allows for installations with longer motor-cable lengths. (Image source: Schaffner EMC Inc.)

Surge protectors work by either blocking or shorting current — or combining surge-blocking and shorting measures.

Surge protecting via blocking: Current can be blocked with inductors that damp sudden current changes. However, most surge protectors short when overvoltage occurs, diverting current back into the power distribution lines where it's dissipated by resistance in the circuit's wires.

Surge protecting via shorting: Rapid shorting (triggered when voltage exceeds a set level) is done with a spark gap, a discharge tube, or a semiconductor device. Only rarely (during large or very prolonged surges) do surges melt the surge protector's power lines or internal components. Capacitors may also damp out sudden voltage changes.

Key specifications for surge protectors include clamping voltage, response time, and energy rating. The clamping voltage — also known as *let-through voltage* — is the maximum voltage allowed to pass through the surge protector. It's typical for 120 V devices to have a clamping voltage of 220 V.

The energy rating (typically in joules) is the maximum power that can be absorbed before components within the surge protector burn out and fail.

An important but often overlooked specification for surge protectors is what happens when the surge protector fails. If a surge exceeds the protector's energy rating and internal subcomponents fail, that protector will no longer be able to protect against further surges. But this doesn't mean that power is cut off: some surge protectors (such as some designed to protect server or other electronic memory) will continue to supply power after failure. The only indication that surge protection no longer exists may be a warning light. Other surge protectors do indeed cut power or reduce power transmission when they fail.

UPSs complement generators in critical applications

UPSs and generators for backup power ensure continuity of operations during blackouts and brownouts. UPSs use batteries and are typically designed to provide power for periods of a few minutes to a few hours. Generators use an engine to generate power for prolonged periods, limited only by the fuel available.

UPSs provide an instant response to a power outage, ensuring that the power supply is uninterrupted. Generators on the other hand have a startup time of at least several seconds. For applications where continuous power is required, a UPS must be combined with a generator to supply power while the generator starts up.

Figure 6: This 24 V_{DC} 5 A uninterruptible power supply (UPS) mounts on DIN rail and provides up to 25 minutes of backup power at full load. (Image source: Phoenix Contact)

UPSs protect equipment from power outages. Offline or voltage and frequency-dependent UPSs are the most cost effective but have two major shortcomings:

- Under normal conditions, offline UPSs pass current directly past the battery to the output. When the UPS circuitry detects a power outage, a switch connects the battery to the output via an inverter. This means that the power may be interrupted by as much as 25 msec.
- Offline UPSs also provide little to no protection against other power-quality issues such as surges and noise.

In contrast, a line-interactive or voltage-independent (VI) UPS works in essentially the same way as a voltage and frequency-dependent UPS, but it has an additional voltage stabilizer to improve power-output quality under normal operation. Such systems still exhibit a switchover time during which power is interrupted — but it's usually just 5 msec or so, which is well within the holdup time of most power supplies.

Taking power-supply sophistication one step further to provide the greatest protection are online UPSs, also known as voltage and frequency independent UPSs. In UPSs, the load isn't directly connected to the mains supply but is always drawn from the system battery, which is continuously charged by the mains supply. The mains ac power is transformed to battery voltage and rectified to dc, so it can charge the battery. Power from the battery is then inverted to produce ac and stepped up by another transformer to mains voltage. This means that power quality issues in the supply do not affect the output and very high levels of power quality and protection are provided. However, it also results in considerably lower energy efficiency and higher upfront UPS cost.

For all but the most sensitive and critical loads, an offline UPS coupled with a power supply with sufficient holdup time is a better choice.

Conclusion

Determining a design's requirements for power quality is the first step to preventing downtime and maintenance costs from dirty utility power, electrical noise, and harmonics. These requirements significantly vary depending on the machine design and its functions. However, once these parameters are defined, design engineers can properly specify power supplies with filters, surge suppression, backup power, and power conditioning. This can profoundly improve the reliability of automated equipment.

How to implement galvanic isolation for power and signal lines in high-voltage systems

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Robust protection for devices and users is required in the presence of power and signal lines across a range of high-voltage applications, including Industry 4.0 systems like factory automation and motor drives. This extends to automotive and electric vehicles (EVs), medical systems, test and measurement applications, and green energy systems such as photovoltaic systems and grid infrastructure. To achieve this protection, some form of isolation is required.

The challenge for designers is to ensure the isolation mechanism is compact, efficient, and cost effective, while also supporting bidirectional signal transmission and power transfer. Because the isolation mechanism must provide operator safety from high voltages and ensure reliable system operation, isolation devices must meet standards like International Electrotechnical Commission (IEC) 60747-5 and IEC 60747-17.

Traditional approaches to galvanic isolation using optocouplers or transformers can satisfy the IEC standards but have limitations in some applications. To more reliably meet device and user protection requirements, while also providing bidirectional signal transmission, galvanic isolation using capacitive and magnetic technologies is required.

This article briefly introduces galvanic isolation. It then reviews the IEC standards and looks at how galvanic isolation can be implemented using integrated capacitive and magnetic technologies. It presents example galvanic isolation solutions from Texas Instruments for applications including general purpose isolators that combine capacitive and magnetic technologies. Evaluation boards that speed the design process are also discussed.

The role of galvanic isolation

Galvanic isolation prevents current flow between functional sections of electronic or electrical systems, but supports the transmission of analog and digital signals and power between the sections (Figure 1). Galvanic isolation is useful for:

- Connecting functional sections that have different ground potentials
- Breaking ground loops by stopping current flow between functional sections sharing a ground
- Protecting operators from shock hazards from high-voltage sections

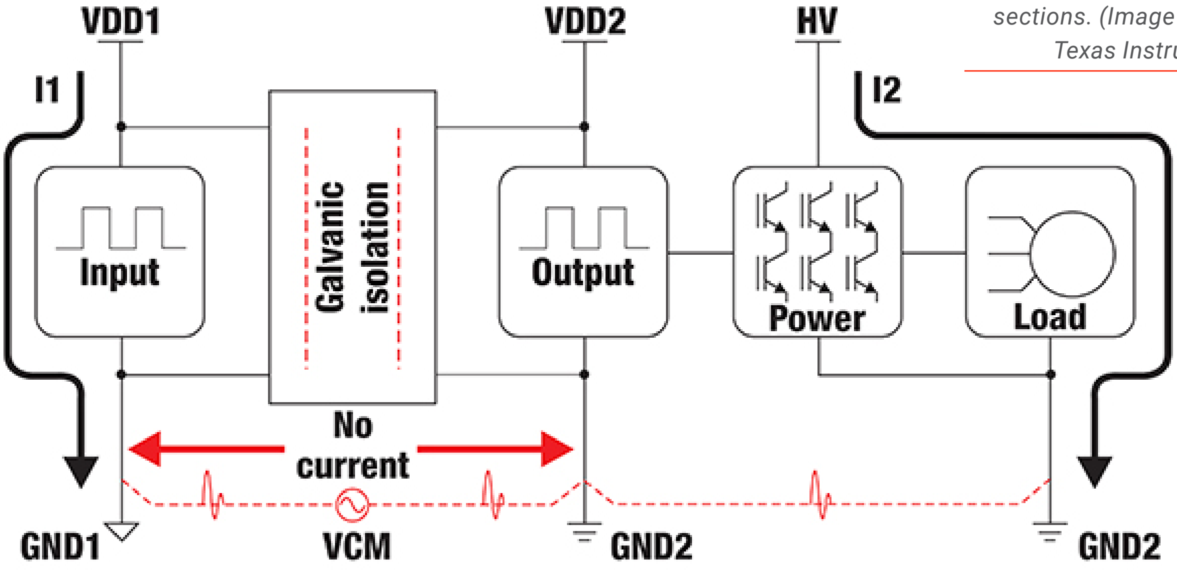


Figure 1: Galvanic isolation allows data and/or power flow, but no ground currents between isolated sections. (Image source: Texas Instruments)

Isolation types and choices

There are several isolation types to choose from and different international standards governing their use, like IEC 60747-17 for magnetic and capacitive isolation and IEC 60747-5-5 for optocouplers (Table 1).

- Functional or operational isolation ensures proper system operation but does not protect users from high voltages. It's not covered by safety regulations.
- Basic isolation is the simplest form of isolation that's included in safety regulations. It can protect users from electrical shock, but if it fails, users could still be exposed to a high voltage.
- Supplementary isolation adds a layer on top of basic isolation. It protects users from high voltages if the basic isolation fails.
- Double isolation is not a separate type of isolation. It refers to using both basic and supplementary isolation. However, most standards and safety documents refer to double isolation as a type of isolation.
- Reinforced isolation is a single isolation system that provides protection equal to double isolation. The performance and testing requirements for reinforced isolation are more stringent than for basic or supplementary isolation approaches.

While optocouplers are widely used for galvanic isolation purposes, they can only be used on signal lines, they tend to be inefficient, can send data in only one direction, and have bandwidth limitations. Optocoupler bandwidth can be improved by adding LED drive circuitry and amplifiers, but that results in higher costs and increased energy consumption. Using a transformer to provide magnetic isolation can provide an efficient solution for power and high-speed signal lines, but discrete transformers are large and costly.

To reliably and more effectively meet the demands of galvanic isolation, designers can turn to integrated capacitive and magnetic solutions that meet the IEC

Test	**IEC 60747-17 capacitive and magnetic isolators**		**IEC 60747-5-5 optocouplers**
	Basic isolation	**Reinforced isolation**	**Reinforced isolation only**
V_{IORM} - maximum repetitive peak isolation voltage	AC voltage (bipolar)	AC voltage (bipolar)	AC voltage (bipolar)
V_{IOWM} - maximum working isolation voltage	AC voltage based on time- dependent dielectric breakdown (TDDB)	AC voltage based on TDDB	Based on partial discharge test
V_{PD} - partial discharge test voltage	$V_{TEST} = 1.5 V_{IOWM}$	$V_{TEST} = 1.5 V_{IOWM}$	$V_{TEST} = 1.875 \times V_{IOWM}$
V_{IOSM} - maximum surge isolation voltage	$V_{TEST} = 1.3 V_{IMP}$	$V_{TEST} = 1.6 V \times V_{IMP}$ $10k^{V}_{PK (minimum)}$	$10 K^{V}_{PK (minimum)}$
Minimum rated lifetime	20 years x 1.2	20 years x 1.5	Not defined
Failure rate over lifetime	1,000 ppm	1 ppm	Not defined
Allowable isolation materials	Silicon dioxide (SiO_2) and thin-film polymer	SiO_2 and thin-film polymer	Not defined

Table 1: Testing and operational requirements for reinforced isolation are more demanding than for basic isolation. (Table source: Texas Instruments)

isolation standards. Capacitive isolators support analog signaling and high-speed bidirectional data transmission, with limited power transfer capability. Integrated magnetic isolation can support bidirectional transmission of high-speed data and the transfer of higher levels of power.

Isolation characteristics

Isolation voltage, working voltage, and common-mode transient immunity (CMTI) are three key characteristics of isolators. Isolation voltage specifies the maximum voltage at which the isolator can protect from dangerous voltages for a short time. The working voltage is the long-term voltage at which the isolator is designed to be used.

CMTI is the maximum slew rate (frequency) of transients on the common voltage applied between two isolated circuits that can be withstood with no adverse effect on data transmission across the isolation barrier. CMTI is specified in kilovolts per microsecond (kV/μs) or volts per nanosecond (V/ns). The capacitance between the isolated ground planes is the path where transient energy can cross the barrier and corrupt the data or waveform. A high CMTI indicates a system that is robust and where the two sides operate within specifications even when exposed to fast transient events. A low CMTI can result in distortion, missing information, jitter, and other signal integrity problems. A CMTI of 100 V/ns or higher indicates a high-performance isolator.

In addition to electrical specifications, isolators must satisfy mechanical requirements related to clearance and creepage distances. Clearance is the distance between adjacent conductors through the air, while creepage is the distance between them across the surface of the package.

Various package styles and sizes provide different levels of creepage and clearance performance. The selection of the mold compound and the use of insulator materials with the needed dielectric strength are also factors that determine the isolation rating. The dielectric strengths of commonly used materials are:

- Air ≈ 1 volt root mean square per micrometer (V_{RMS}/μm)
- Epoxies ≈ 20 V_{RMS}/μm
- Silica-filled mold compounds ≈ 100 V_{RMS}/μm
- Polyimide polymer ≈ 300 V_{RMS}/μm
- Silicon dioxide (SiO2) ≈ 500 V_{RMS}/μm

Galvanic isolation technologies

Optocouplers use an LED to transmit analog or digital signals through a dielectric insulator to a phototransistor. As mentioned, they are one-way devices. Common insulating materials used in optocouplers include air, epoxy, or mold compounds. Since these materials have relatively low dielectric strengths, a greater physical distance between the LED and phototransistor is required to achieve a given level of isolation.

Capacitive isolation uses a SiO2 insulation barrier. SiO2 has a high dielectric strength and is more stable when exposed to moisture of extreme temperatures, compared to most epoxy or mold compounds. Capacitive isolation uses various modulation techniques like on-off keying or phase-shift keying to transmit AC signals across the barrier. Capacitive isolation can be compact and can transmit high-speed signals bidirectionally but has a very limited power transmission capability, typically <100 microwatts (μW).

Magnetic isolators can transmit signals and power across the isolation barrier. Some of these isolators can transmit hundreds of milliwatts (mW) of power and can replace a secondary-side bias power supply. Magnetic isolators can use an air core or ferrite core.

Ferrite cores can handle more power. When power needs are below about 100 mW, an air core can provide a lower-cost and simpler solution. Each of the three technologies supports different combinations of signal and power transmission (Figure 2).

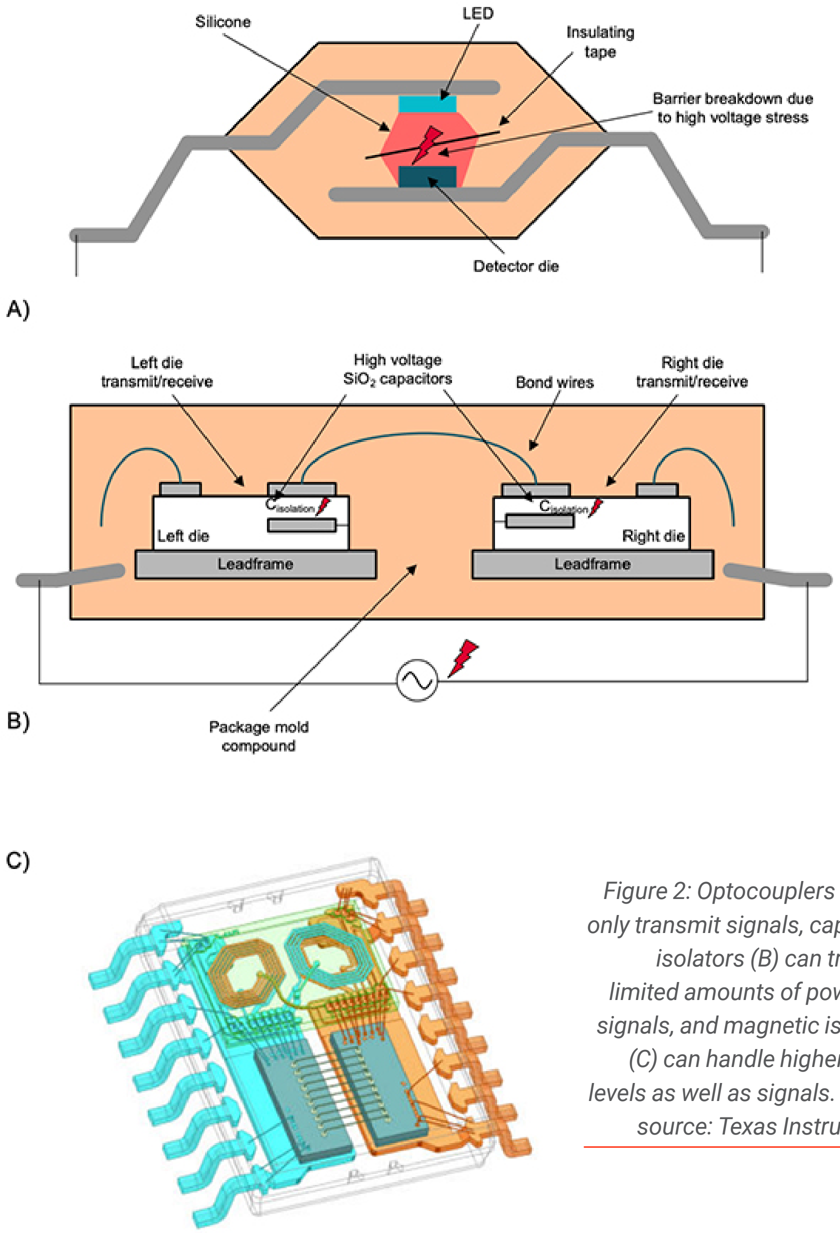


Figure 2: Optocouplers (A) can only transmit signals, capacitive isolators (B) can transmit limited amounts of power and signals, and magnetic isolators (C) can handle higher power levels as well as signals. (Image source: Texas Instruments)

Power and signal isolation

Designers that need up to 650 mW of isolated power and four isolated signal channels capable of 100 megabits per second (Mbps) transmission rates can turn to the ISOW7841FDWER from Texas Instruments. This general purpose device has an isolation rating of 5 kilovolts root mean square (kVRMS) and a ±100 kV/µs minimum CMTI. It uses SiO2 isolation on the signal channels and thin film polymer isolation for the on-chip power transformer (Figure 3). The ISOW7841EVM eval board can help designers evaluate device performance in isolated systems and speed time to market.

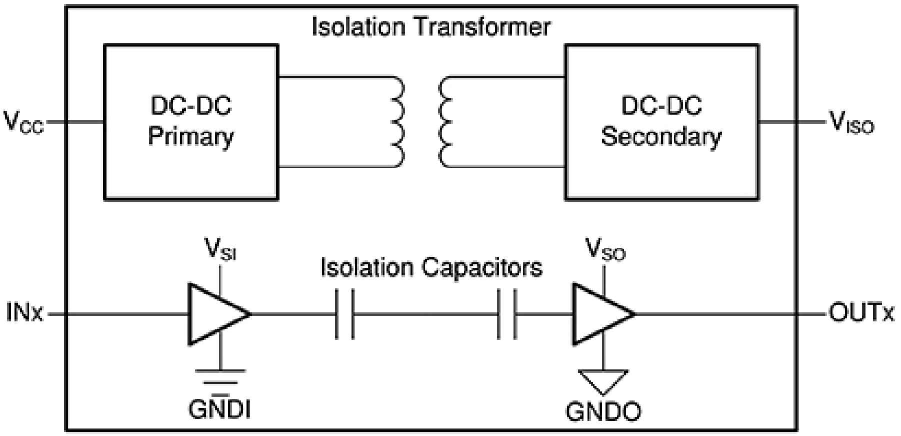


Figure 3: The ISOW7841FDWER uses polymer insulation in the power transformer (top) and SiO2 isolation capacitors in the signal chain (bottom). (Image source: Texas Instruments)

Isolated automotive DC/DC

Automotive systems that need 500 mW with 5 kV_{RMS} isolation can use the AEC-Q100 qualified UCC12051QDVERQ1 from Texas Instruments. It features a minimum CMTI of 100 V/ns, a surge capability of 10 kV_{peak}, and a working voltage of 1.2 kV_{RMS}. It uses spread spectrum modulation for the internal oscillator and an optimized internal layout to minimize radiated emissions. It includes undervoltage lockout, thermal shutdown, an enable pin, a synchronization function, and delivers an output of 5.0 or 3.3 volts direct current (VDC).

The UCC12050EVM-022 eval board enables designers to test the enable/disable function, synchronize to an external clock source, detect external clock faults, and select the output voltage. It has test points for ripple and transient response measurements. The board can simplify system integration by serving as an example of a layout that supports the rated isolation and provides good electromagnetic interference (EMI) performance (Figure 4).

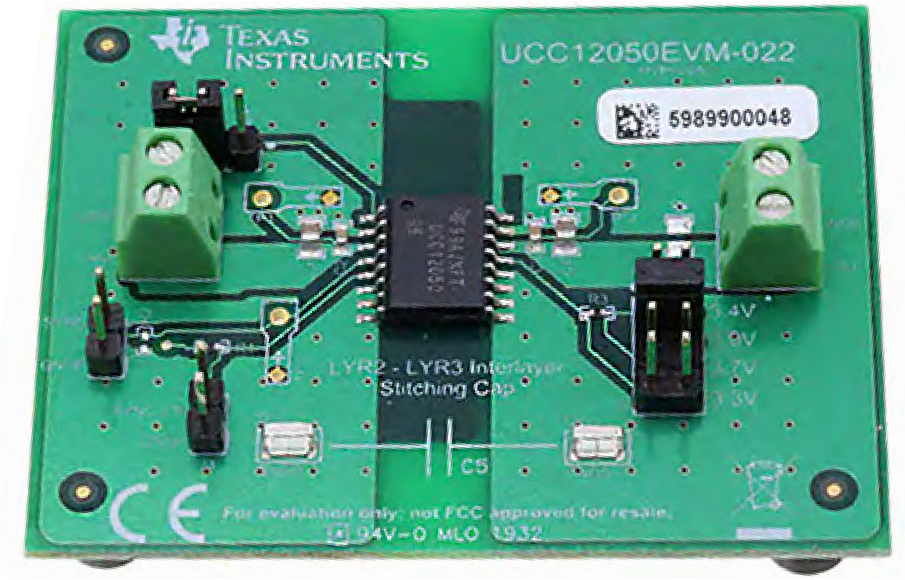


Figure 4: In addition to speeding evaluation of the UCC12051QDVERQ1 isolated DC/DC converter IC, the UCC12050EVM-022 eval board provides a suggested layout for system integration. (Image source: Texas Instruments)

CAN transceivers with capacitive isolation

For applications that need a Controller Area Network (CAN) transceiver with 1 Mbps signaling and a CMTI of 50 kV/μs, Texas Instruments offers the ISO1050DWR with an isolation rating of 5 kVRMS, and the ISO1050DUB rated for 2.5 kV_{RMS}. These transceivers meet the specifications of ISO 11898-2 for high-speed CAN operation (Figure 5). They are specified for operation from -55 to 105 degrees Celsius (°C) and include overvoltage, cross-wire, and loss of ground protection from -27 to 40 volts, overtemperature shutdown, and a -12 to +12 volt common-mode range.

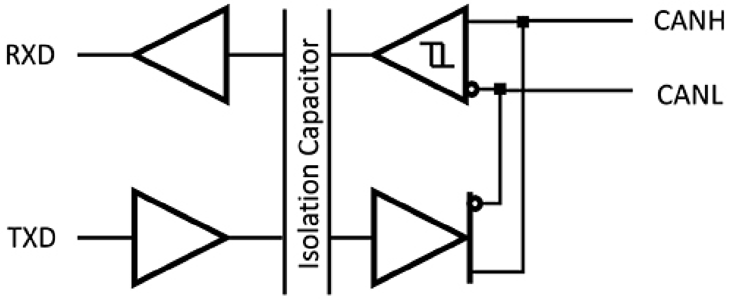


Figure 5: The isolated ISO1050DWR and ISO1050DUB transceivers meet ISO 11898-2 for high-speed CAN operation. (Image source: Texas Instruments)

The ISO1050EVM eval module with input and output connections and test points for key performance measurements can speed the integration of these devices into automotive systems.

Isolated RS-485/RS-422 transceivers

Systems that need a 500 kilobits per second (kbps) RS-485/RS-422 transceiver with 5 kV_{RMS} isolation can select from Texas Instruments' half-duplex ISO1410BDWR or the full-duplex ISO1412BDWR (Figure 6). The SiO2 isolation barrier supports robust data transfer in the presence of large ground potential differences. These transceivers are rated for operation from -40 to 125 °C. The bus pins are designed to withstand high levels of electrostatic discharge (ESD) and electrical fast transient (EFT) events, eliminating the need for additional protection components.

Designers can use the ISO1410DWEVM and the ISO1412DWEVM eval boards to evaluate various system parameters. Test signals and sequences can be applied, and performance characteristics like propagation delay, power consumption, and different bus and driver conditions can be evaluated.

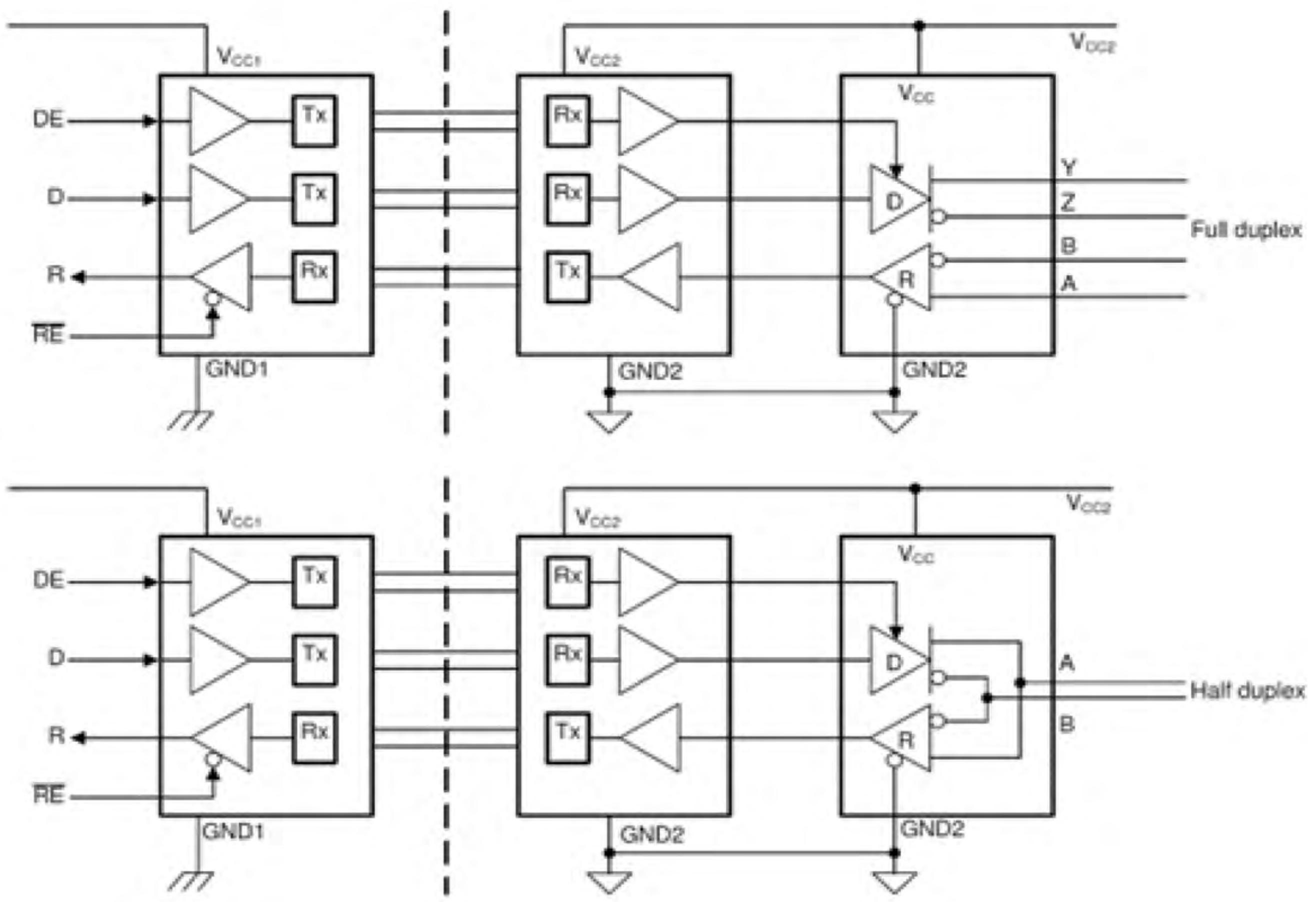
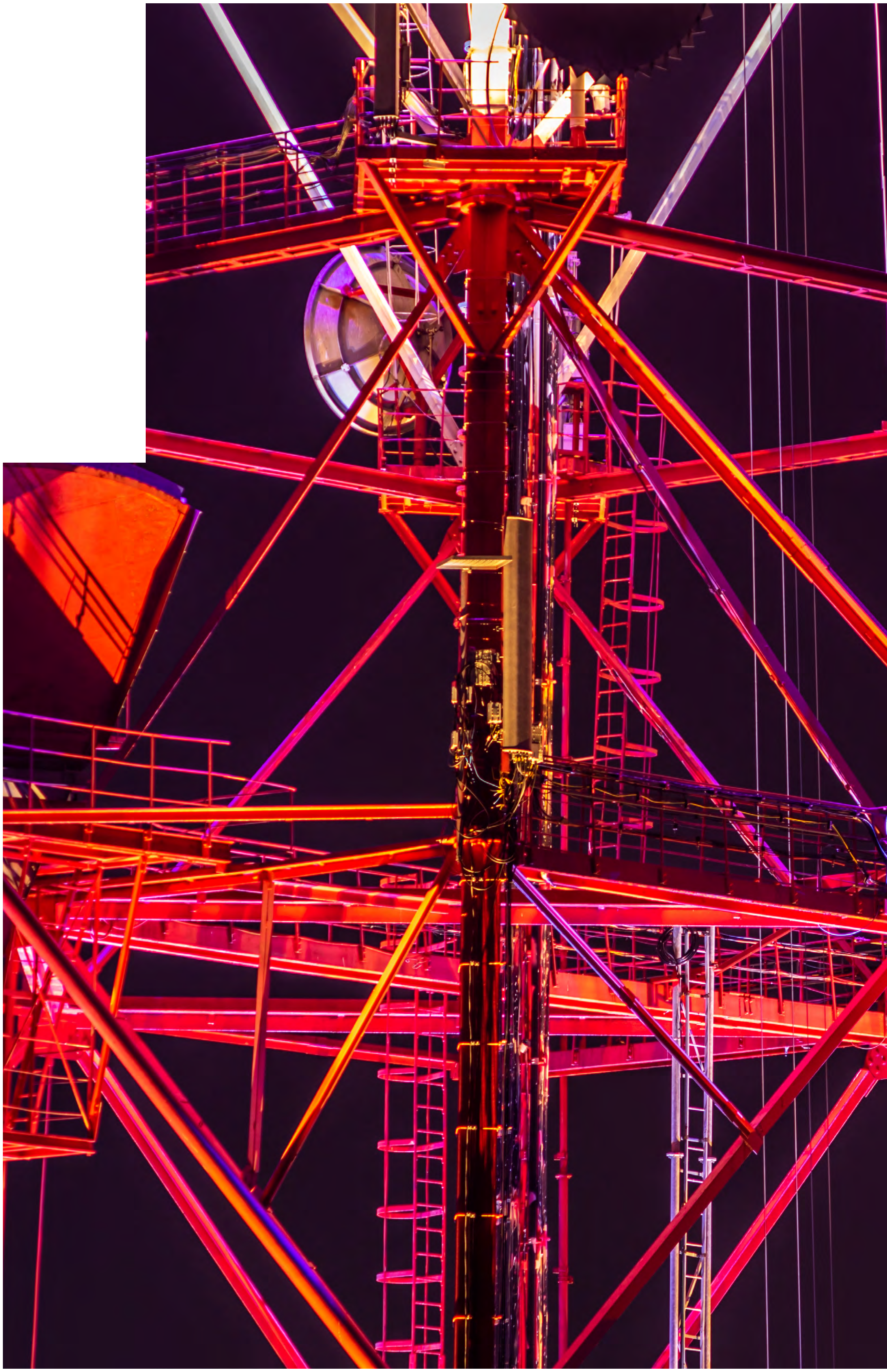


Figure 6: The full-duplex ISO1412BDWR (top) and the half-duplex ISO1410BDWR (bottom) support 500 kbps data rates and feature 5 kV_{RMS} isolation (vertical dashed line). (Image source: Texas Instruments)

Conclusion

Designers of high-voltage Industry 4.0, automotive, medical, green energy, and other systems need galvanic isolation to protect both devices and users, while meeting size, cost, and reliability requirements, along with associated safety standards. As shown, capacitive and magnetic galvanic isolation in power and signal lines can produce compact and high-performance solutions. These isolation technologies have high CMTIs and meet the requirements of IEC 60747-17 for reinforced isolation.



Ensuring compact, flexible, and accurate circuit protection that meets IEC and UL safety standards

By Jeff Shepard
Contributed By DigiKey's
North American Editors

Device and end-user protection against potentially damaging voltage, current, and temperature conditions are needed in applications like USB Type-C® alternating current (AC) adapters, networking equipment, and consumer and industrial electronics. Using conventional fuses or positive temperature coefficient thermistors (PTCs) can provide compact solutions and some protection. However, a growing number of applications require higher levels of protection and greater flexibility, including faster response times and programmable and resettable overvoltage protection (OVP), overcurrent protection (OCP), undervoltage lockout (UVLO), overtemperature protection (OTP), soft start, and/or reverse-current blocking (RCB). In the case of USB Type-C AC adapters, it's also necessary to support fast role swapping (FRS) that complies with the timing requirement defined in the USB Power Delivery specification.

It's possible to design protective circuits to implement all these functions, but the design process takes time. Also, obtaining UL or IEC 62368-1 safety recognition can further extend time to market. In addition, a solution using discrete components can increase overall solution footprint.

To quickly implement compact and accurate protection functions that meet UL and IEC safety standards, designers can turn to eFuse regulators. These integrated protection ICs have programmable protection thresholds to support design flexibility, and protection can be latching or have automatic recovery when the fault is removed. They have low "on" resistance to maximize efficiency and include soft start to minimize inrush currents. Some models include certified FRS capability for use in USB Type-C AC adapters.

This article provides an introduction to eFuses, including voltage and current ratings and representative applications. It then looks at how protection functions including, OCP, soft start, OVP, UVLO, and OTP are implemented. It closes by presenting a series of eFuse ICs from Littelfuse optimized for specific applications, along with system integration considerations to speed time to market.

eFuse selection criteria

eFuse requirements for a given application are strongly related to the operating voltage and current of the system. For low voltage and low current systems up to about 5 volts direct current (V_{DC}) input and 2 amperes (A) of current, features such as OCP, OTP, UVLO, and inrush current suppression (dV/dt) for hot-swap and hot-plug events are commonly required. For applications that consume between 2 and 6 A, with input voltages up to 24 V_{DC}, OVP, current limiting/OCP, and "power good" signals are often needed. Current timers and monitors for system monitoring and OCP and RCB, are common in applications using 6 A and higher and voltages of 24 V_{DC} and higher (Figure 1).

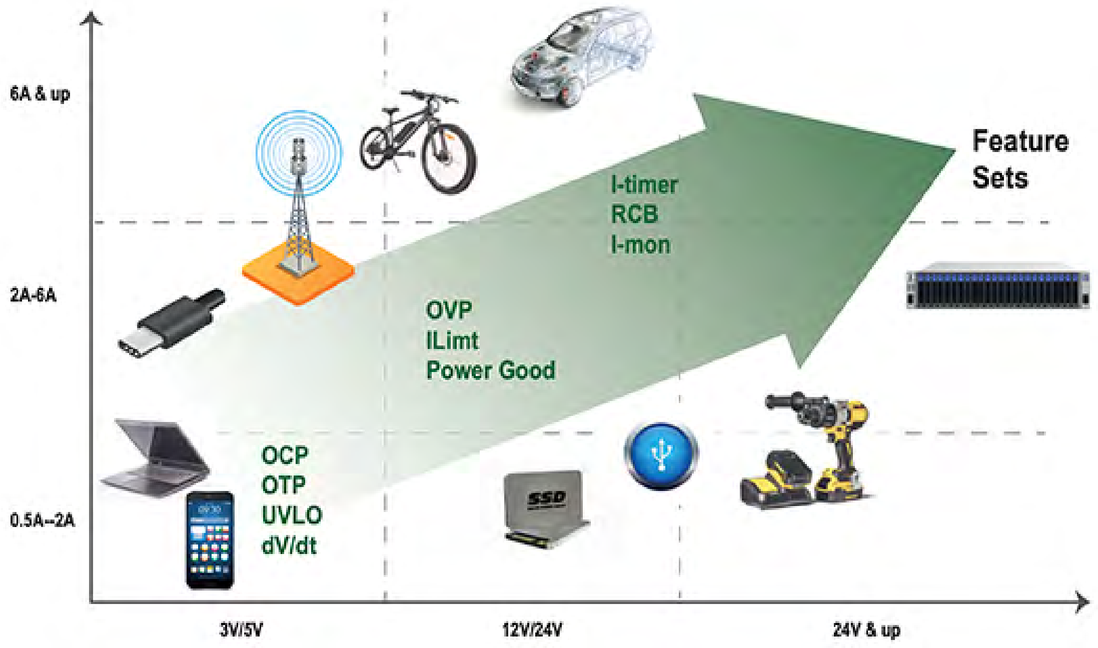


Figure 1: eFuse feature sets are strongly correlated with the input voltage (horizontal axis) and input current (vertical axis) of the application. (Image source: Littelfuse)

Current protection and soft start

Excessive currents can cause electronic components to exceed their rated operating temperatures, impairing performance and reducing lifetimes. A current protection circuit monitors the current (I), and if it exceeds the 'I-limit' set level which is above the rated 'Iout' operating current, the input current is first regulated at a fixed level for several microseconds (μs) and then automatically reduced to a safe level. Depending on the eFuse being used, the I-limit value can be fixed or programmable. When an overcurrent occurs, the eFuse reduces the input current for a fixed time, usually several milliseconds (ms), and then turns it back on to see if the fault has been cleared. If the fault is still there, it will again automatically regulate and reduce the current, wait several ms, and restart. The sequence of reducing the current and restarting until the fault is removed is sometimes referred to as 'hiccup mode' protection. In the case of a short-circuit condition, the input current rises very rapidly, and the eFuse immediately reduces the input current to a safe level (**Figure 2**).

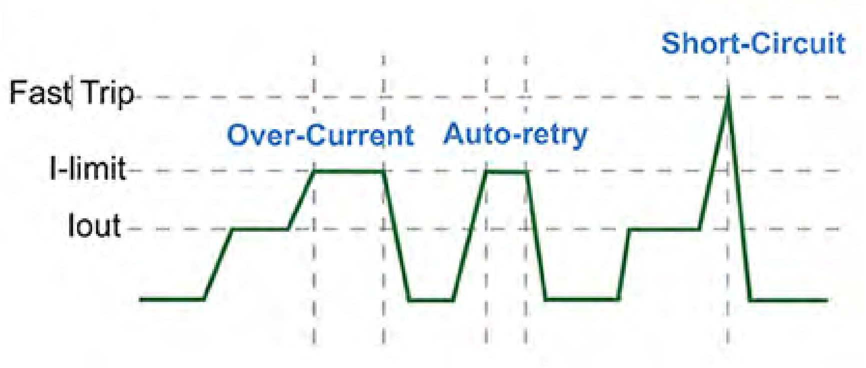


Figure 2: eFuses include current limiting with auto-retry to protect against excessive load currents and short-circuit protection. (Image source: Littelfuse)

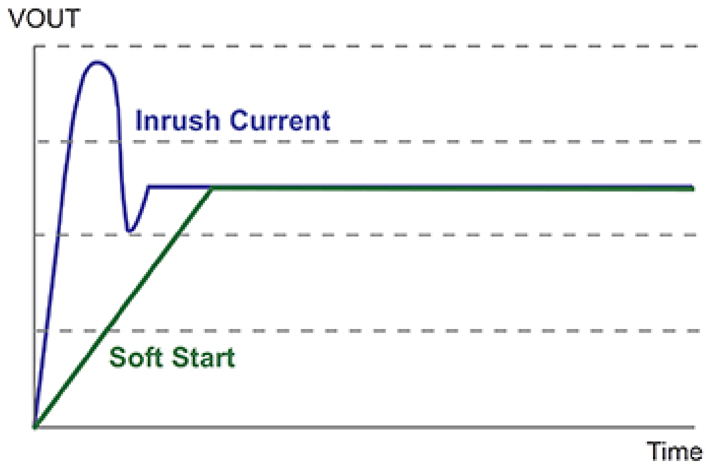


Figure 3: Soft start in an eFuse prevents potentially harmful inrush currents and can be fixed or programmable. (Image source: Littelfuse)

Soft start limits the inrush current flow when a device is turned on. Without soft start, the only limitations on the current are the relatively low impedances of the printed circuit board (pc board) traces and the components. High inrush currents can damage the power supply circuit or the components. Soft start slowly turns on the eFuse, providing slew rate control and limiting the inrush current (**Figure 3**). The soft start rate can be fixed or programmable.

UVLO and OVP

Too much or too little voltage can also result in system malfunctions and possible damage. UVLO in an eFuse prevents the device from operating if the input voltage is lower than a preset threshold. In addition, if the input voltage rises too slowly, or if the power source has a significant internal resistance (like a battery), the voltage can drop as the load current rises, causing

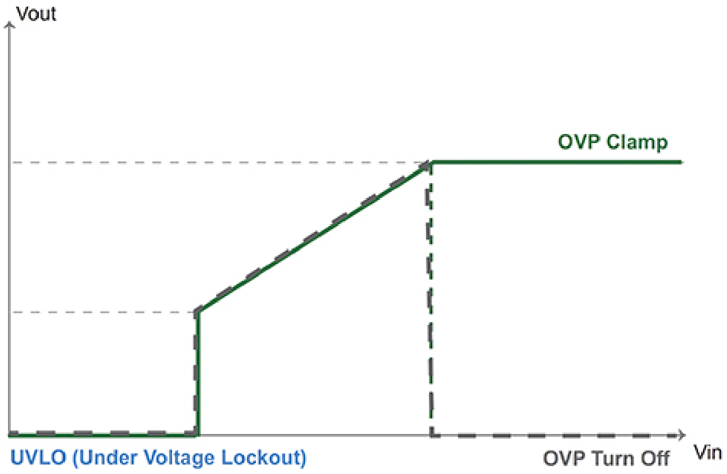


Figure 4: When the input voltage reaches the OVP clamp value, it is prevented from rising any further, and the eFuse turns off the output to protect the system. (Image source: Littelfuse)

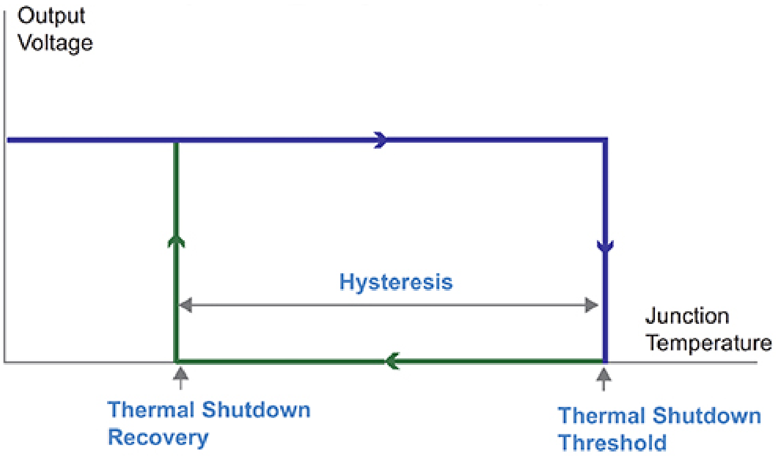


Figure 5: OTP includes hysteresis that restarts the eFuse once the temperature has dropped by a predetermined amount. (Image source: Littelfuse)

the voltage to repeatedly cross the UVLO threshold. When that happens, the UVLO function can go into oscillation. Using a UVLO circuit with a hysteresis (lag) of about 150 to 300 millivolts (mV) can eliminate oscillations and ensure smooth operation of the UVLO function.

OVP protects the device from being stressed or damaged by excessively high voltages. When an overvoltage condition is detected, the eFuse immediately clamps the voltage to protect the system, then turns off. It also discharges the output capacitors to ground through an internal resistor. When the voltage falls to a specified value, the eFuse automatically turns on (**Figure 4**). The OVP threshold can be fixed or programmable.

Thermal protection

Excessive temperatures can also result in damage or improper functioning, so eFuses include an internal temperature sensor. OTP is typically implemented as a two-stage process. First is the thermal regulation temperature, usually around 125°C, at which point the eFuse limits current flow to try and stop the temperature rise. If the temperature continues to increase, and the device junction temperature exceeds the thermal shutdown threshold (TSHDN)—usually around 140°C—the eFuse turns off. OTP also includes hysteresis, and the eFuse will restart when the internal temperature falls 20°C below the TSHDN (**Figure 5**).

Compact 5-volt eFuses for battery-powered devices

Designers of Bluetooth headsets, wearables, tablet PCs, and other adapter-powered devices can turn to the 5-volt, 5 A-rated LS0505EVD22 in a DFN2X2_8L package, and the 5-volt, 4 A-rated LS0504EVT233 in a SOT23_3L package for compact solutions that provide OVP, OCP, and soft start

(**Figure 6**). The 50 milliohm (mΩ) on resistance of the internal switch minimizes power dissipation. The OVP reacts immediately in the event of excessive voltage and discharges the output capacitor. The current limit threshold is set with an external resistor, and the OCP operates in hiccup mode for overcurrent or short-circuit conditions. The automatic soft start function provides a smooth voltage ramp up, limiting the inrush current to a safe level.

18 volt / 5 A eFuses

The LS1205E series eFuses have an operating voltage range of 2.7 to 18 VDC, a current rating of 5 A, and are suitable for use in hard disk drives, solid-state disk drives, and adapter-powered devices like notebook computers and networking devices. These eFuses feature a switch with a 25 mΩ on resistance and are in a 10-lead DFN3×3 package. They include programmable soft start time, programmable current limit threshold up to 5 A, short-circuit protection, UVLO, and fold-back OTP. Two models are available:

The LS1205EV includes three selectable input voltage ranges. The output clamp voltage and UVLO thresholds are based on the selected input voltage range.

The LS1205EF includes an open drain fault indicator function that signals the occurrence of UVLO, OVP, short-circuit, and thermal shutdown faults.

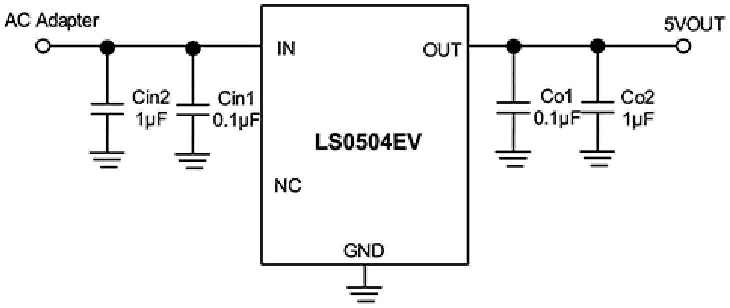


Figure 6: The LS0504EVT233 eFuse is in a compact SOT23 package for use in space-constrained applications. (Image source: Littelfuse)

28-volt eFuse with RCB and FRS

Designers of notebooks and tablet computers, docking stations, and network devices that need Thunderbolt or USB Type-C PD functionality with RCB and FRS, can turn to the LS2406ERQ23 28 volt, 6 A eFuse regulator that includes OCP, OVP, short-circuit, soft start and OTP (**Figure 7**). The power switch has an on resistance of 24 mΩ to minimize power dissipation during normal operation, the OCP, OVP and soft start functions are programmable, and the OTP includes automatic recovery when the device cools. This eFuse features an always-on RCB function regardless of the enable signal (EN) logic state. FRS and the integrated input and output discharge functions meet the USB PD specifications.

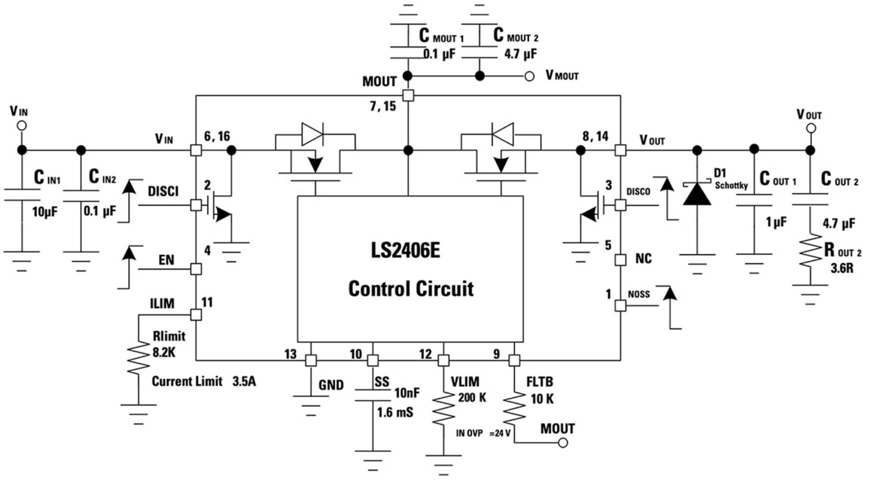
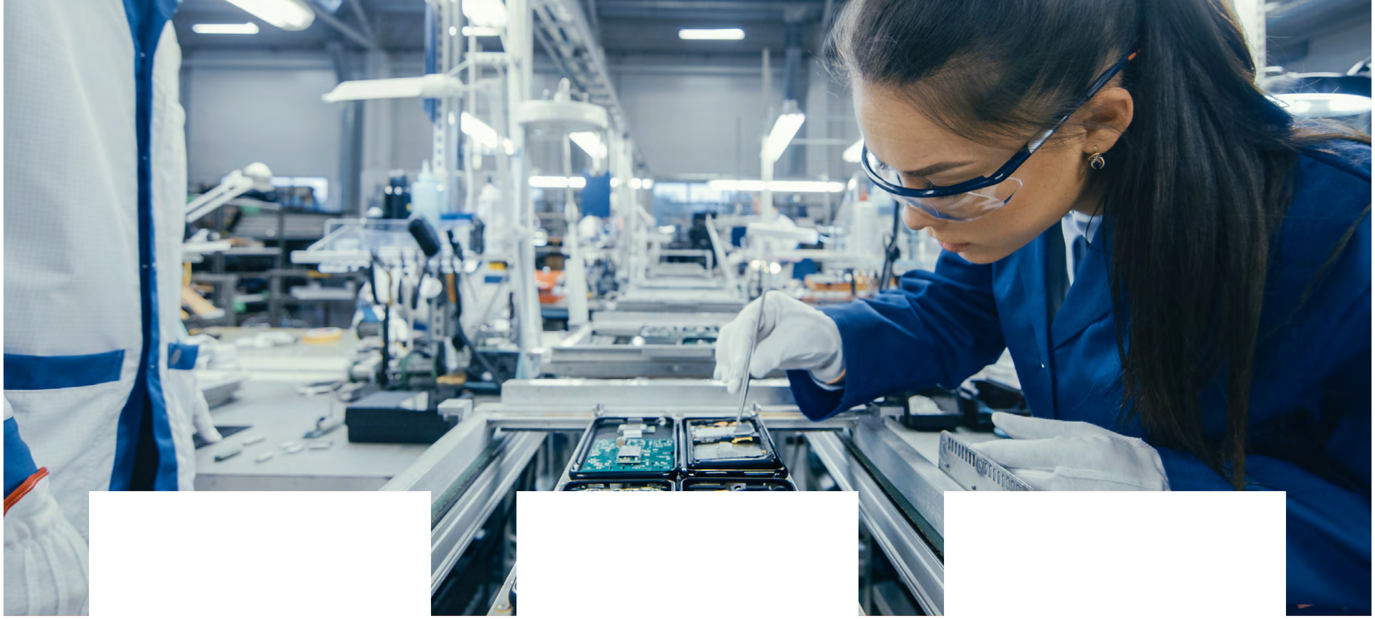


Figure 7: Typical application of the LS2406ERQ23 eFuse supporting reverse-current blocking and FRS for USB Type-C PD applications. (Image source: Littelfuse)



The LS2406ERQ23 comes in a low-profile, 16-lead QFN 2.5 millimeter (mm) x 3.2 mm package and is UL Recognized to UL/CSA 62368-1.

Board layout guidelines

For the LS1205E series, as well as the LS0505EVD22 and LS0504EVT233, here are some general board layout considerations to help ensure a successful implementation:

- A 0.1 microfarad (μF) or larger ceramic decoupling capacitor should be placed between the IN terminal and ground (GND), and between the OUT terminal and GND. When the input power path inductance is negligible, such as in hot-plug applications, this capacitor may not be necessary.
- Decoupling capacitors should be placed as close as possible to the IN, OUT, and GND terminals, and the loop area formed by the connections must be minimized.
- High-amperage power traces should be sized to carry at least twice the maximum expected current and should be as short as possible.
- The GND terminal of the eFuse must be connected directly to the pc board ground plane. The ground plane of the pc board should be an island or copper plane.

For the LS1205E series only: Locate all support components like RILIM, capacitor SS (CSS), and resistors for EN, as close as possible to the corresponding connection pin, and use the shortest possible trace length to connect the other side of the component to GND. The traces should be placed to prevent coupling to any switching signals on the pc board, and the length of the traces for the RILIM and CSS components should be as short as possible to minimize the effect of parasitics on the current limit setting and soft start timing.

For the LS2406ERQ23, refer to the datasheet for layout considerations related to USB Type-C cable short-circuit protection and FRS components.

Conclusion

For protection of both users and devices, and to meet applicable standards, designers can turn to integrated protection eFuse regulators that provide a variety of functions including OVP, OCP, ULVO, OTP, and reverse-current blocking. With programmable protection thresholds and reset capability, eFuses support design flexibility, while also featuring low “on” resistance switches to maximize efficiency and include soft start to minimize inrush currents. Some models include certified FRS and RCB for use in USB Type-C AC adapters.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aeris
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muRata
onsemi
ANALOG DEVICES
TE
life.augmented
KEMET
Infineon
OMRON
AMD
samtec
SILICON LABS
TDK
Adesto
CITIZEN
CEL
E Ink
DigiKey
we get technical