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# PSD NORTH AMERICA

Power Systems Design: Empowering Global Innovation


Special Report: Powering Industrial Applications (pg31)

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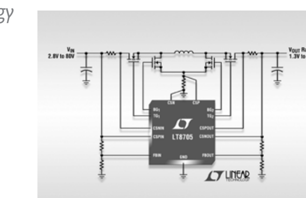
COVER STORY
Diode choice impacts power system performance (pg 14)



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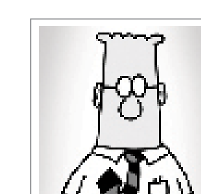

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# The trouble with technology

We have all been violently reminded over the recent decades how the automation and information revolutions are changing society and how we make things and do business. Entire multi-billion-dollar technologies, business models, and industries have vanished, and completely different ones based on the new realities have taken their place. Hardware disruption undermines the physical plant and core technologies, paced by software advances that create an alternate infrastructure where only the new technologies fit.

Each advance in core and supporting technologies has brought with it both disruption and opportunity, and not necessarily in that order. Lately some technologies have come and gone so quickly , markets never had time to develop around them. That aspect of the current general technology disruption has been spared, relatively speaking, from the industrial space, but industry is also being actively impacted by circumstances.

One of the most profound aspects of the technology and information revolution is how it affects competition. In today's world it is easier to compete, regardless how large or complex the systems involved are, because the tools are so much more powerful and the required technologies are so new and the methodologies to use them are so immature that almost any entrant into the marketplace has equal footing with the established players.

**Industrial-strength pressure**
From the perspective of power, industrial systems are in the midst of change from almost every angle. There is pressure for a designer as well as the integrator of industrial systems to make things more efficient, more reliable, more precise, more cost-effective, and be more manageable, all while guaranteeing a foolproof transition from the old to the new. Luckily, the biggest issue in upgrading a facility, process, or production line has more to do with choice then with capabilities. Yet choice is a double-edged sword, as no solution is perfect for every situation, and you must ensure that your choice is the best solution for yours.

The latest generation of intelligent devices able to function within the "Internet of Things", and the supporting infrastructures from smart phones to the web, has enabled a level of productivity and performance previously unimaginable outside of fiction. The ability of products and systems to not only report on their operating status but change their operation at a distance (and often unsupervised), empowers fast-moving innovation and development on both the device design side and system integration side.

Being an engineer in the industrial space is both extremely challenging and extremely empowering, and often the only difference between the two states is the ability to choose the right solution available for the issue at hand. The key is to understand the systems and technologies involved and how they can be leveraged with one another.

Best Regards,

**Alix Paultre**

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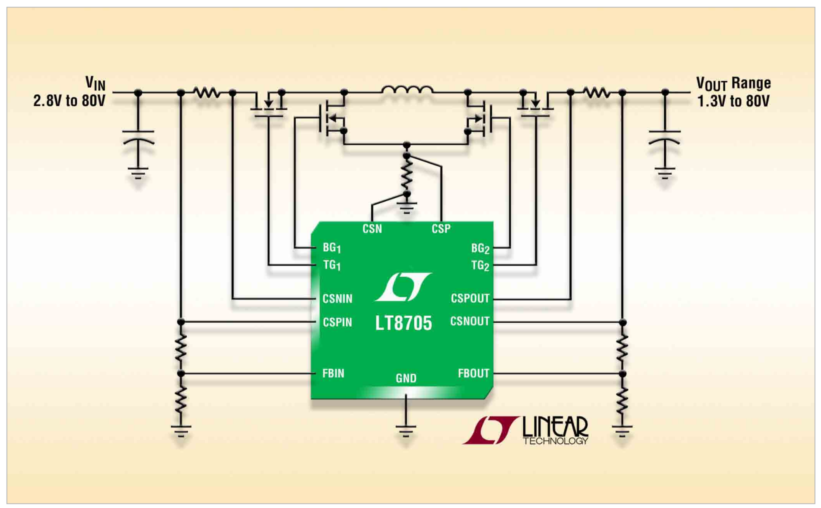
# Linear Technology controller enables conversion at up to 98% efficiency at 250W

With four feedback loops to regulate the input and output current and voltage, the LT8705 high-efficiency (up to 98%) synchronous buck-boost DC/DC controller from Linear Technology operates from input voltages above, below or equal to the regulated output voltage. The input current and voltage feedback loops can prevent overloading of solar cells. The output current loop provides a regulated output current for a battery charger or current source. The device can be used in a wide range of applications such as a voltage stabilizer in telecom and automotive requirements, as well as in solar or high impedance sources and battery systems.




*The LT8705 high-efficiency 80V Buck-Boost DC/DC Controller provides a regulated output current for a battery charger or current source.*

The controller operates over a wide 2.8V to 80V input voltage range and produces a 1.3V to 80V output, using a single inductor with 4-switch synchronous rectification. Output power up to 250W can be delivered with a single device. Higher output power can be achieved when multiple circuits are paralleled. The operating frequency is selectable between 100kHz and 400kHz, and can be synchronized to an external clock.

The LT8705 employs a proprietary current-mode control architecture for constant frequency operation in buck or boost mode and has powerful onboard quad N-channel MOSFET gate drivers. The user can select among forced continuous, discontinuous and Burst Mode® operation to maximize light load efficiency.

The operating mode of the controller is determined through the MODE pin. The MODE pin can select among discontinuous mode, forced continuous mode and Burst Mode® operation. The LT8705 also features programmable UVLO and switching currents, along with input and output current monitoring with programmable maximum levels.

Additional features include servo pins to indicate which feedback loops are active, a 3.3V/12mA LDO, adjustable soft-start, onboard die temperature monitor and ±1% reference voltage accuracy over an operating junction temperature range of -40°C to 125°C. The LT8705 is available in a 38-pin 5mm x 7mm QFN, and also a 38-lead TSSOP package with additional pin spacing for high voltage operation.

www.linear.com

# Thermal management considerations

By: Shane Callanan, Excelsys Technologies

One of the first laws of Physics that we learn during our schooling is that energy can neither be created nor destroyed, but can only be changed from one form to another. This is especially true for power supplies and their inefficiencies. These inefficiencies are converted to another form of energy, and in a power supply the only medium available is to convert this to heat. It is this heat that is the number one reason for reduced reliability of the finished design. In order to combat this, power supply designers must implement a solution to minimize this.

**Power dissipation**
First we need to look at some of the significant power dissipators in any given power convertor. Each of these produces heat, which must be dealt with. Some examples of these are:

- Power switches.
- Filter capacitors with significant ripple current
- Transformer cores and windings
- Current sense resistors.

Good thermal practice is not just for the benefit of the operating range of the design, it also has a direct impact on the reliability and MTBF of the final design. If we review the effect that heat has on the calculated MTBF of a power supply, one can clearly observe the impact of this.

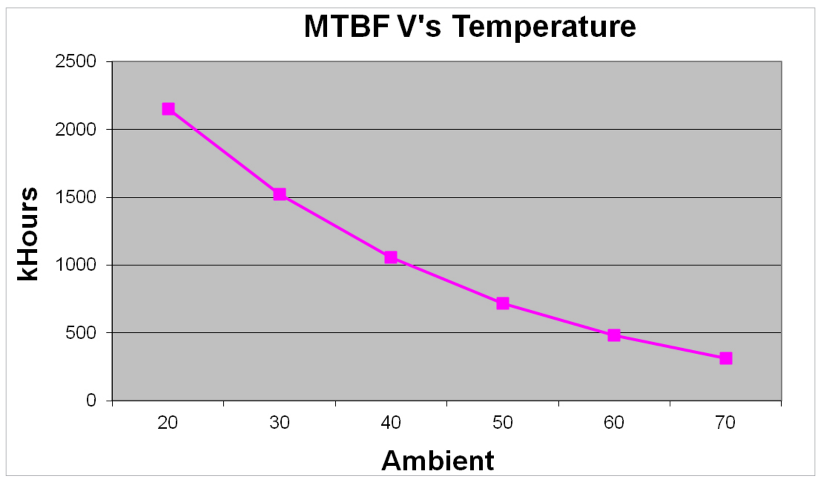



*Figure 1*

As you can see from **Figure 1** above, for every 10 degree rise in ambient temperature we see a 50% reduction in the calculated MTBF.

**Cooling Methods**
The idea of thermal management is to remove the heat from these devices, and direct it away from your supply. The most commonly used mechanisms for heat transfer in electronics design are conduction and convection.

Conduction is defined as the transfer of heat through contact with another stationary material. In the same way that water and current move, heat will flow through the material if there is a temperature differential across it. The heat flow will be from the higher temperature to the lower temperature, and the rate of heat flow will depend upon the temperature differential and the thermal conductivity of the material.

Convection is defined as the transfer of heat from the surface of an object to a moving fluid. This can either be a gas or liquid. If the fluid flow is created by gravitational forces on the fluid as its density varies, it is referred to as natural or free convection. If the fluid flow is created by external means such as fans or blowers, it is referred to as forced convection. The most commonly used fluid is air.

**Potting material**
A common method of conduction cooling is to use a potting material. This involves encapsulating the power supply (or parts of) in a material which will draw heat away from heat generating components and distribute it in a more evenly fashion across a broader system. Further methods can then be used to get this heat away from the entire system, such as heat sinking.

**The main types of potting compounds available are:**

- Epoxy resin
- Polyurethane resin
- Silicone resin
- Polyester resin

Each of these approaches has their own merits, and there is no one type of resin which fits all purposes. For example, while Silicone-based resins have excellent for use at very high continuous operating temperatures (above 180°C), they are typically more expensive. On the other hand, while polyurethane-based resins are becoming more dominant due to their cost and curing capabilities, they can be prone to attack by water, particularly at high temperatures.

One further item that you also need to consider when using any type of potting material is that the potting compound will act as a capacitor and change the behavior of the electronic circuit, especially at high frequencies. It has been found in practice that the use of certain potting compounds affects EMC by shifting the frequency distribution and amplifying certain frequencies.

**Heat Sinks**
The key to fully using a heat sink is to understand correctly what you need it to achieve and what occurs when you attached a component to a heat sink. Heat will flow from an area of high thermal resistance to one of low thermal resistance. The rate in which this heat can be transferred is also controlled by the thermal difference between the two points and the thermal resistance of the connection between the two points. This is why we typically see a thermal pad sandwiched between the component and the heat sink. Air has a very high thermal impedance, so the pad will ease the transfer of heat from the component case temperature to the heatsink.

**Using a fan**
While conduction methods can be suitable in a lot of designs, sometimes they are just not enough. Convection cooling offers the designer a much more effective method to get heat away from components. Of course this is not without its compromises. Since fans are mechanical parts, the mindset if often that these are much more likely to fail before the likes of an electrolytic capacitor or a power FET (assuming these are properly derated in the design). However, in recent years the choice of good quality fans has increased significantly, and if you choose your vendor carefully you can achieve high lifetime of fans in your system.

The choice of a fan will of course depend on the system requirements. The cooling effect of fans is purely based on the ability to push a specific volume of air across the components to be cooled. Other items such as pressure, density, noise, cost, operating etc, must also be considered when choosing your fan, but the primary function of the fan will be to move a volume of air. Generally, efficiency increases and fan size decreases as specific speed increases. This figure can be used to determine the most efficient size and type of fan for a particular application.

For lowest noise output, fans should always be operated near their peak efficiency point. A common mistake is to use a fan that is too small and running it too fast, putting strain on the mechanism. Variable-airflow applications can also cause noise problems. While the perception might be that the power supply runs quieter at lower loads, the reality might be that it will run much louder under actual loading conditions in the application.

www.excelsys.com

# Industrial power opportunities in 2013 and beyond

By: Ryan Sanderson, Associate Director, IMS Research

In 2012, demand from industrial applications reduced heavily in the second half of the year. With many uncertainties still surrounding global economic conditions, suppliers to this sector remain apprehensive about 2013 and beyond. However, this highly diversified sector is generally less volatile than others. Two key drivers are overall industrial production metrics and the need to improve power conversion efficiency to comply with legislation and to lower energy costs. Both are predicted to continue to drive growth opportunities for power electronics in industrial applications.

The demand for greater conversion efficiencies in end-applications has driven OEMs to transition to inverterised motor drives in their designs, generating new and replacement growth. This trend alone has driven over $1 billion of growth in the past two years for power semiconductor modules, despite a large decline in 2012 owing to excess inventory build-up by motor drive suppliers. This has resulted in a rapid decline in demand for new products whilst inventory levels return to typical levels. Although this is also projected to result in slower growth in 2013, an additional $2 billion of growth in the power semiconductor module market is forecast from 2012 to 2016.

The industrial sector also remained resilient for power semiconductor discrete products in 2012. Despite steep declines in the power MOSFET and IGBT markets, the global market for discrete power semiconductors in industrial applications grew by 2.6 percent, much stronger than the overall market decline of 7.4 percent. A further $1 billion of growth is forecast in this sector from 2012 to 2016.

Demands for greater efficiency in industrial applications are also driving opportunities for power supply manufacturers and the power IC suppliers who sell into power supply products. Whilst the global merchant power supply market was flat in 2012, the market for power supplies with digital control grew by 37 percent. Although industrial applications were not early adopters of digital power, they are projected to drive $300 million in digital power supply growth and $100 million in digital power IC growth from 2012 to 2017. Outside of digital power, strong growth is also forecast for products linked to increasing efficiency in industrial applications such as ICs and silicon carbide diodes for power factor correction, and power MOSFETs used for synchronous rectification at the output of industrial power supplies.

Other opportunities in this sector for 2013 and beyond include growth in demand for batteries and storage for both stationary applications and those such as material handling. Transitions from lead acid batteries to chemistries such as lithium, nickel and sodium are beginning to accelerate, providing opportunities for battery manufacturers, storage solution providers, chemical and raw material suppliers, and power semiconductor manufacturers, amongst others.

www.imsresearch.com





# Flyback Power Supply Development: Part II

By: Dr. Ray Ridley, President, Ridley Engineering

This article is the second of a series in which Dr. Ridley shows the steps involved in designing and building an offline flyback converter. The second part of the series begins testing on the bias and control circuit, and verifies the high-voltage operation of the power FET with a resistive load.

## Initial Bias and Control Chip Testing

The specifications of the flyback power supply were given in Part I of this article [1]. **Figure 1** shows the full schematic of the flyback power converter with the control, bias, and power stage blocks. All parts of the circuit are fed directly from the rectified ac input line.

The most complex part of the converter is the transformer, and its design will impact the noise, regulation, and efficiency. Before this is placed in the converter, however, it is a good idea to test the primary side control, bias, and switching with the full input line voltage. This will reveal design flaws that can be remedied before the transformer is inserted.

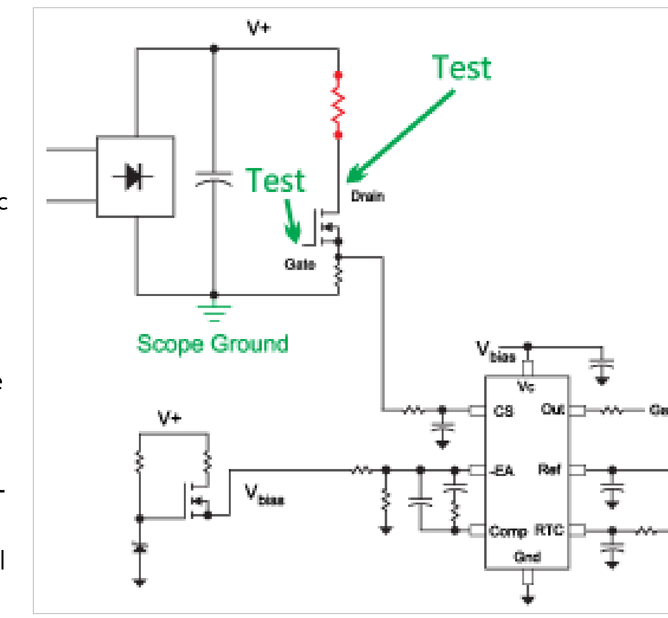



*Figure 2: Schematic of flyback converter with transformer replaced with load resistor.*

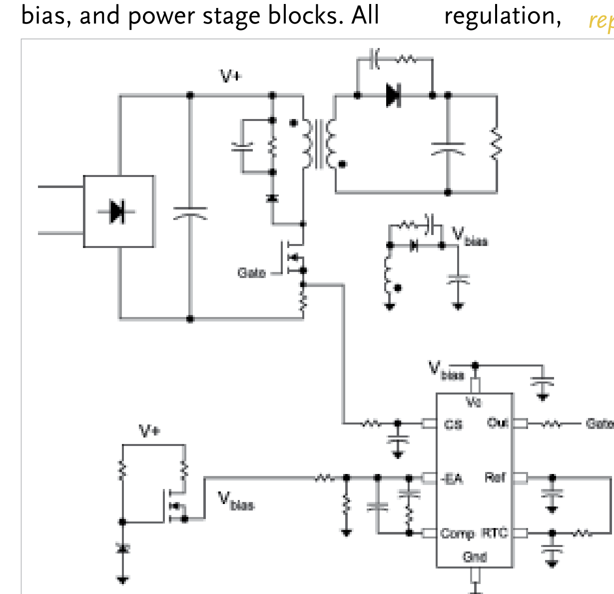



*Figure 1: Full schematic of a flyback converter.*

**Figure 2** shows the schematic of the flyback power supply system with the transformer replaced with just a load resistor. For efficient initial design and testing of low-power supplies, it is a good idea to put sockets on the board for the transformer. This allows multiple transformer design ideas to be quickly tested and compared, as we will see in the future parts of this design series. Plugging a load resistor into the primary-side sockets allows some meaningful power testing to begin.

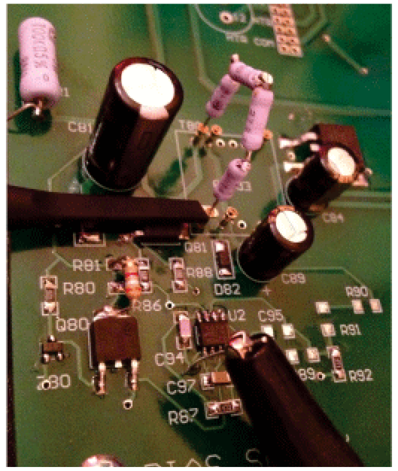


*Figure 3: Photograph of flyback converter circuit board with load resistor plugged into transformer sockets.*

Initial voltage is applied to the input to make sure the bias circuit is operating properly. For this test, the resistor in the transformer sockets is removed, and a dc bench supply is used to apply up to 60 V. As the input voltage is increased, the gate voltage on the bias FET increases until it is regulated at 15 V by the zener diode. The source of the bias FET provides voltage to the control chip, and when the start threshold of the chip is reached, the gate drive signal seen in **Figure 4** can be observed.

Once the control chip starts switching, current is drawn through the 1.8k resistor, and the chip bias will reduce. The intent of this resistor is to reduce the initial surge current through the bias FET when high voltage is suddenly applied. A through-hole resistor is used for this component since it can have high initial current and voltage, and in the event of a power supply fault, the dissipation can be significant. (When the transformer is in place, the bias network will shut off when the auxiliary voltage is above approximately 12 V, and the dissipation in the bias circuit resistor will greatly stop.)

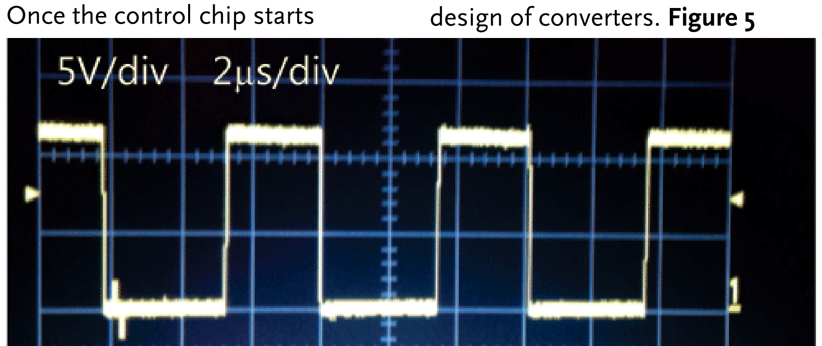



*Figure 4: Flyback converter gate drive signal.*

Once the gate drive waveforms are verified, it is a good idea to test the circuit up to the full input voltage. As described in [2], an isolated ac source is a recommended method of performing initial testing and design of converters. **Figure 5** shows a 1-kW isolation transformer and variac used to apply high voltage to the circuit. This test setup is easy to build, and provides flexibility for grounding the flyback circuit during testing.

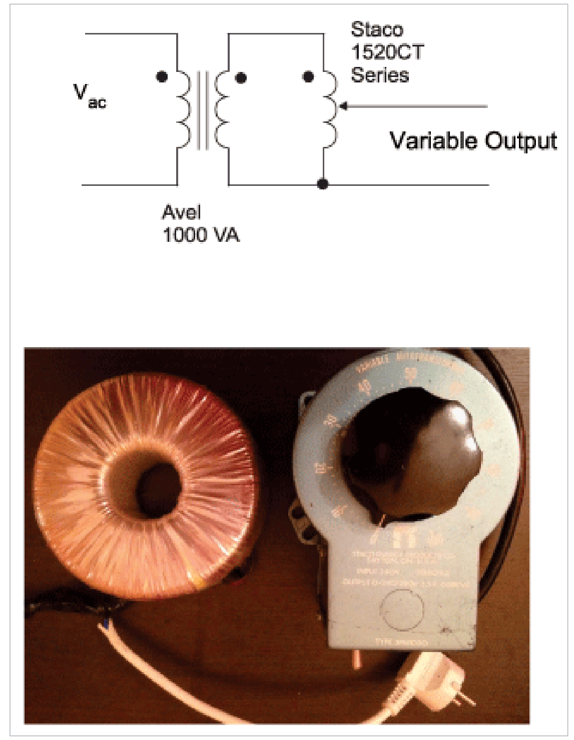



*Figure 5: Isolation transformer and variac used to apply full line voltage to converter.*

The input voltage was increased to 300 VAC to thoroughly test the bias and control circuit. Testing at high voltage was done in short bursts since the 1.8k resistor dissipation is high and cannot be sustained for long periods of time.

### FET Switching Waveforms

The load resistor was then plugged back into the sockets of the transformer to test the switching of the power FET. An initial value of 5.6k was used and this allows testing up to an input voltage of about

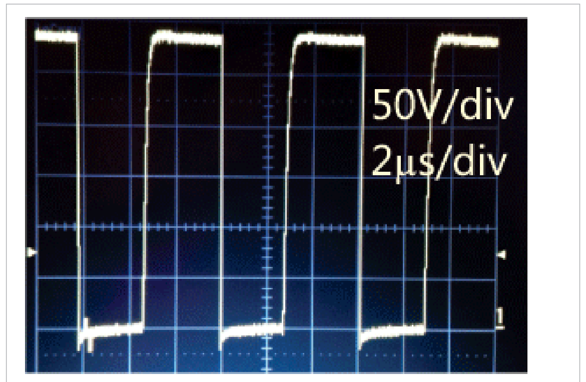



Figure 6a

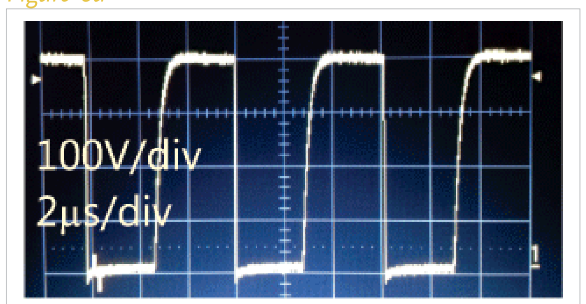



Figure 6b

Figure 6: Flyback converter drain signal with (a) 5.6k load and 190 VAC input; (b)10k load and 280 VAC input.

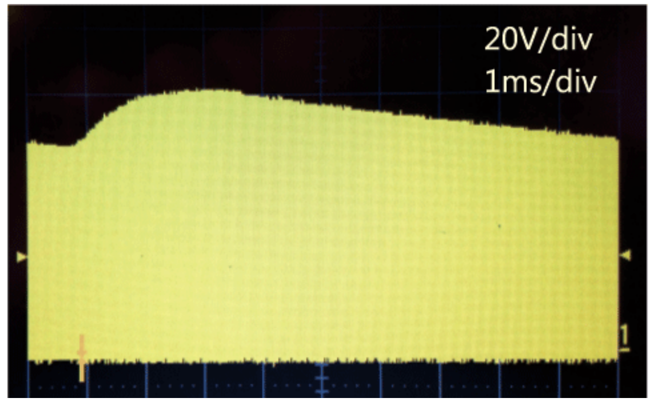



Figure 7: Flyback converter drain signal at lowest line for continuous operation. Minimum dc voltage level for continuous operation is 60 V.

120 VAC. Beyond that, the dissipation is too high, and the resistor was changed to a 10 k value with a continuous power dissipation capability of 5 W.

**Figure 6** shows the drain waveform on the FET with these two different loads. In the first plot, the circuit sees a dc input voltage of 280 V. The dissipation is about 7 W in the power resistor, but this was applied for a short duty cycle.

The second plot of Figure 6 shows the drain waveform with a 400 V dc input and a 10k load.

The large value of resistor results in a slow rise time on the FET as the output capacitance takes a significant time to charge.

**Figure 7** shows the drain waveform with the lowest line input at which the flyback converter controller will operate without experiencing dropouts. This occurs with a minimum dc input voltage of 60 V, seen at the bottom of the input capacitor ripple. A lower value of the 1.8k resistor will reduce this minimum voltage, and a higher value will increase it. It is important that the bias supply keeps running at the lowest possible input line for the converter in order to get the output into regulation at low line.

## Summary

Initial testing has been done on the circuit with the transformer replaced with a power resistor. This allowed verification of the bias circuit, control chip, and switching of the FET with a significant load and the full input voltage. This type of initial testing, without having the complications of a transformer, is very useful for finding circuit design and build problems on the primary side. It is important to do maximum input voltage testing early on in the prototype development to find any design flaws.

In the next part of this series, we will look at the design of the power transformer.

www.ridleyengineering.com

## References


1. "Flyback Power Supply Development Part I", Ridley Engineering Design Center, Article 64. www.ridleyengineering.com/index.php/design-center.html.
2. "Testing Off-Line Power Supplies", Ridley Engineering Design Center, Article 33. www.ridleyengineering.com/index.php/design-center.html
3. www.ti.com/product/uc3842, control chip datasheet.

# Diode choice impacts power system performance

## It is important to use an optimized power device for any given application

By: Omar Harmon and Dr. Holger Hüsken, Infineon Technologies

Power devices such as IGBTs and diodes are widely used in power electronics. Many applications use diodes as the PFC boost diode, free-wheeling diode, rectification on primary and secondary side, fast rectifiers for example in battery chargers. Generally, IGBTs have high switching losses due to the current tail which limits the switching frequency operation. Active power factor correction (PFC) circuits are widely used as a front end to meet these standards. Most active PFC circuit designs use boost topology in Continuous Conduction Mode (CCM) for high power applications. A boost diode is required in PFC circuits. An optimized diode is needed to meet high efficiency standards as well as high power density.

To achieve high efficiency with low EMI, it is a must to use an optimized power device for a specific application. For example, Infineon's Rapid 1 diode, with 1.35V temperature-stable forward voltage, is optimized for applications switching up to the 40kHz typically found in Home Appliance, Solar inverter and Welding machines. While Infineon's Rapid 2 diode, with short reverse recovery time, is optimized for applications switching between 40kHz to 100kHz, typical for a Boost PFC in Consumer SMPS. Application tests show lower conduction and switching losses, a soft reverse recovery and stable temperature behavior.

**Rapid 1 or Rapid 2?**

Different applications require different types of diodes. Diodes with low $V_f$ are optimized for applications operating with low switching frequency while with low $Q_{rr}$ and $t_{rr}$ are optimized for applications operating with high switching frequency. As a result of applications needing diodes specially tuned for high or low speed switching, Infineon has developed the Rapid 1 and Rapid 2 diode families. Rapid 1 is $V_f$ tuned to ensure lowest conduction losses and thus focus on application switching up to 40kHz. Meanwhile, for applications switching beyond 40kHz, the Rapid 2 has been developed to have a $t_{rr}$ <20ns, ensuring that switching losses are kept to a minimum.

P-i-N diodes are categorized via a trade-off curve of $V_f$ versus $Q_{rr}/t_{rr}$ to either have low $V_f$ with high $Q_{rr}$ and $t_{rr}$ or high $V_f$ with low $Q_{rr}$ and $t_{rr}$. Rapid 1 is a low $V_f$ diode while Rapid 2 is a low $Q_{rr}$ and $t_{rr}$ diode. Static (low $V_f$) and dynamic (low $t_{rr}$) performance of a P-i-N diode are determined by the plasma of excess charge carriers injected into the drift region of the diode. This plasma modulates the conductivity of the diode, but needs to be removed from the device before a voltage can be supported. Higher plasma concentration results in better conductivity, i.e. lower $V_f$ can be achieved, but a tradeoff exists meaning more charge is present and this takes time to remove. This high charge concentration results in a high $Q_{rr}$. Plasma level during the conduction state of a P-i-N diode is determined by the thickness of the drift layer, ambipolar carrier lifetime in the drift zone and it's variation over depth and injection efficiency of the anode or cathode. Commonly, plasma engineering is done by reducing the ambipolar lifetime, which has the drawback of a strong temperature coefficient (higher plasma at elevated temperature resulting in negative temperature coefficient of $V_f$ and strong increase of losses at high temperature) plus providing additional generation levels in the bandgap which leads to high reverse leakage current levels at higher temperatures.

**Rapid 1 for Low Switching Frequency Applications**

High power applications need high power semiconductors and devices. IGBTs are commonly used as power switches while diodes are used for rectification and free-wheeling operations. Due to its current tail, IGBT is best operated at low switching frequency. So generally, low switching frequency operation is used at very high output power systems. Low conduction loss devices are essential on low switching frequency designs. Rapid 1 with low Vf is suitable for low switching frequency and high output power applications even at increased junction temperatures.

Rapid 1 advancement in thin wafer technology helps to maintain a stable Vf over temperature. A 30A/650V rated Rapid 1 diode is tested against two 30A/600V low Vf competitor diodes commonly found especially in the Asian solar market. The Rapid 1 exhibits an 18mV Vf difference from 25°C to 100°C in junction temperature (Tj), which when compared to the competitor diodes, offers more stability of temperature-dependent

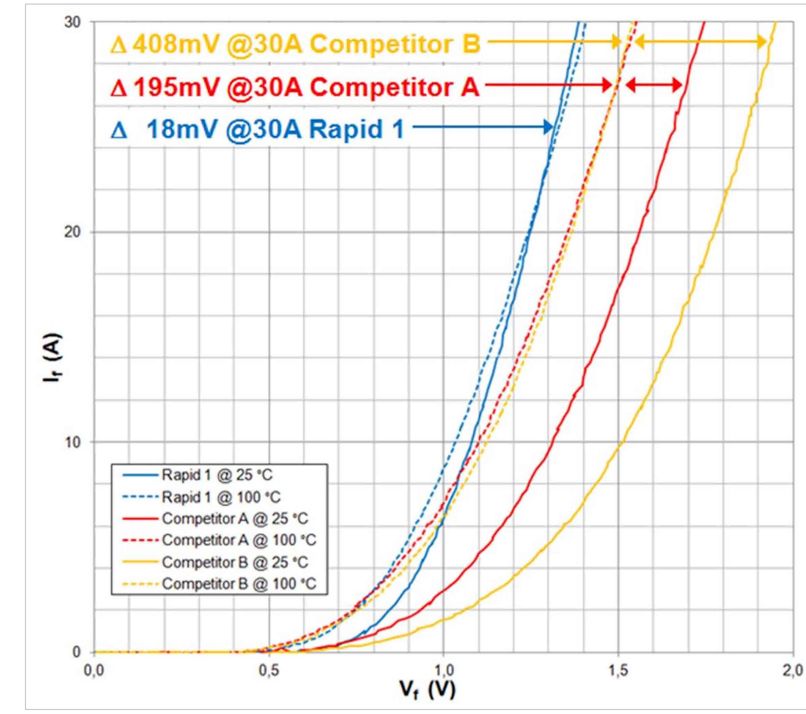



*Figure 1: Diode Forward Voltage vs. Forward Current over Temperature*

Vf compared to Competitor A (195mV) and Competitor B (408mV). Rapid 1 has also low Vf (1.406V) compared to competitor A (1.550V) and competitor B (1.542V). **(See Figure 1)**

Now we check the Vf-Qrr trade-off of these diodes to see how it affects overall performance. A double pulse test fixture is used to see how the diode will affect the power switch turn-on losses (EON). **(See Table 1)**

**Rapid 2 for PFC Applications**

The two modes of PFC operation are the Discontinuous Current Mode (DCM) and Continuous Current Mode (CCM). At DCM, the power switch turns-on while the inductor current is zero thus the boost diode has no forward current before the power switch turns-on. Hence, diodes with fast reverse recovery times are not needed. At CCM, the boost diode is conducting forward current before power switch turn-on. When the power switch turns-on, the

| | $V_f$ (V) | $I_{RRM}$ (A) | $Q_{rr}$ (nC) | $E_{on(switch)}$ (mj) |
|---|---|---|---|---|
| Rapid 1 | 1.406 | 14.99 | 861.2 | 1.019 |
| Competitor A | 1.550 | 19.22 | 712.7 | 1.016 |
| Competitor B | 1.542 | 22.74 | 772.3 | 1.019 |

*Table 1: Diode and $E_{on(switch)}$ Test Result. $I_D$=30A, $T_j$=100°C*

boost diode will be in transition from conducting to blocking state. This transition or reverse recovery time should be as fast as possible, since high current and voltage are present at this point, therefore high power losses. To have a fast reverse recovery time, boost diodes should have a low $Q_{rr}$.

Rapid 2 with low $Q_{rr}$ reduce the power switch $E_{ON}$. With soft recovery characteristics it also reduces the EMI generated during boost diode recovery. To validate this, a hard-switched CCM boost PFC circuit with an output power capability of 800W is used as a test platform. The test platform input voltage can be varied from 110 $V_{AC}$ to 220$V_{AC}$ and the output voltage ($V_{OUT}$) of the PFC is 400$V_{DC}$. Tests were done in a 25oC ambient temperature. The waveforms shown in figure 3 show an 8A/650V rated Rapid 2 boost diode reverse recovery time compared with some 8A/600V low $Q_{rr}$ version competitors. As shown the boost diode is conducting forward current ($I_F$). After 20ns, the diode starts to divert the forward current to the power switch by turning-on the power switch. After 6ns, all boost diode forward current has been diverted to the power switch. This time duration is $t_r$. After $t_r$, the boost diode undergoes reverse current conduction at rate of $di_f/dt$. Minority carriers have to be removed from the boost diode before a reverse voltage can be supported. Reverse current conduction starts after $t_r$ then

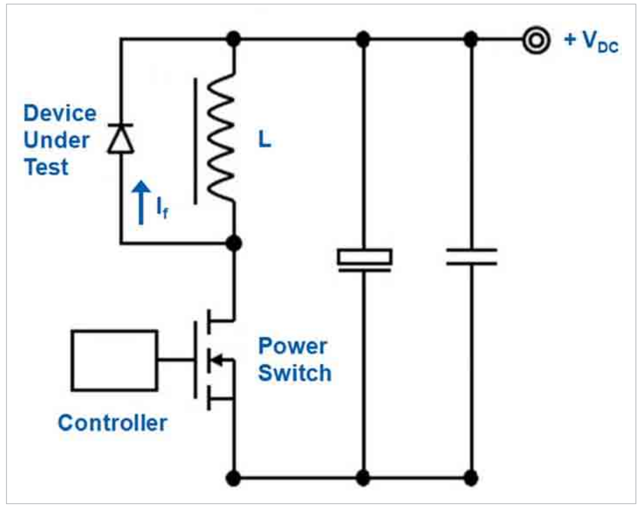



*Figure 2: Boost Diode Reverse Recovery Waveforms and Test Circuit*

peaks down to a maximum reverse current ($I_{RRM}$) then returns back to zero. (**See Figure 2**)

$I_{RRM}$ affects the $E_{ON}$ of the power switch since $I_{RRM}$ is reflected as the current peak during the power switch turn-off to turn-on transition. Hence, $I_{RRM}$ needs to be as low as possible to minimize power switch $E_{ON}$. Moreover,

| | $I_{RRM}$ (A) | $t_a$ (ns) | $t_b$ (ns) | $t_{rr}$ (ns) | $Q_{rr}$ (nC) | S | $E_{on(switch)}$ (µj) |
|---|---|---|---|---|---|---|---|
| Rapid 2 | 13.46 | 7.8 | 11.2 | 19.0 | 127.9 | 1.4 | 51,1 |
| Competitor C | 14.74 | 9.0 | 6.4 | 15.4 | 113.5 | 0.7 | 55,1 |
| Competitor D | 15.38 | 9.9 | 12.2 | 22.1 | 169.9 | 1.2 | 58,5 |
| where: | measured | measured | measured | $= t_a + t_b$ | $= t_{rr} \cdot I_{RRM} \cdot 0.5$ | $= t_b / t_a$ | measured |

*Table 2: Reverse Recovery and $E_{on(switch)}$ Test Result*

the $t_{rr}$ (i.e. $t_a + t_b$) should be as short as possible to minimize the duration of $E_{ON}$. Attention is given to the softness recovery of the boost diode where $t_b$ is longer in duration than $t_a$. The softness ratio (i.e. $S = t_b / t_a$) should always be greater than one. Less than this, the boost diode is said to be snappy in recovery. A snappy recovery may results in higher power dissipation across the boost diode during $t_b$.

Rapid 2 combines low $I_{RRM}$ and $t_a$ to have the lowest measured $E_{ON}$ of the power switches and therefore offer higher efficiency and lower $T_j$ of the power switch while maintaining a high S factor than the competitors. (**See Table 2**)

Rapid 2 has the best combination of low $Q_{rr}$ and high softness ratio (S). In a PFC efficiency comparison at 115$V_{AC}$ and 230$V_{AC}$ input voltage over the entire load range in a 25°C ambient, in a good compromise between $V_f$ and $Q_{rr}$, Rapid 2 shows a better efficiency from light to mid load while maintaining good efficiency at full load. Rapid 1 and 2 ruggedness is further increased by having a DC blocking voltage of 650V, i.e. 50V higher capability than the competitors, while having a soft recovery characteristic.

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# Measuring and sourcing DC transients and other DC test conditions

## Performing DC sourcing and measurement tasks with today's test equipment

By: Bob Zollo, Agilent Technologies

When faced with the task of setting up a test, an engineer will turn to his tried and trusted tools – the power supplies, scopes, voltmeters, and function generators that he finds on his bench. But for some DC power sourcing tasks, these tools can be troublesome. Let's take a look at five tasks and how an engineer might complete them:

1. <u>Biasing with a static DC voltage and measuring current:</u> This is the most basic application of DC power related bench instruments. Any power supply, so long as it has the right voltage and current ratings, can be set up to provide a static DC voltage. Most supplies have built-in ammeters to measure static DC current. In those instances where better measurement accuracy is needed, a DMM can be used, but they are limited to currents of 5 A or 10 A.

2. <u>Setting up turn-on/turn-off sequences:</u> Many devices today require multiple DC bias voltages to operate properly, and these devices often need a particular, controlled turn-on sequence. It is nearly impossible for you to manually turn on multiple power supplies with precise timing, which means that you must use a computer and write a program to sequence the supplies on in the right order and with the right timing. (**See Figure 1**)

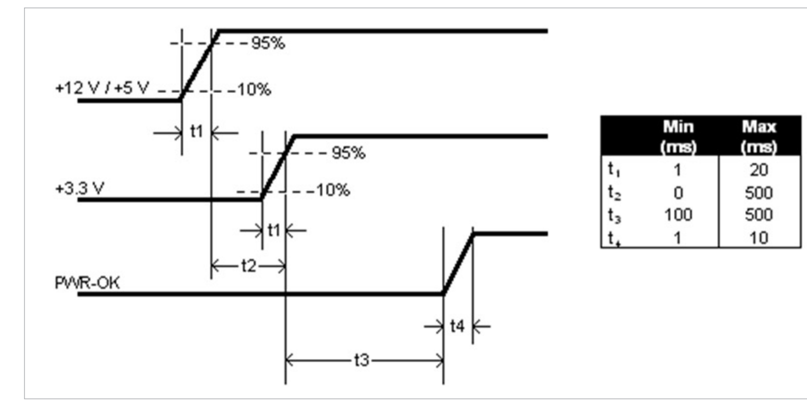


*Figure 1: A DC power supply turn-on sequence*

3. <u>Measuring and displaying current versus time to visualize power:</u> During dynamic events, such a motor pulling a peak of startup current, it is desirable to visualize the flow of current versus time. An oscilloscope is an ideal tool for measuring voltage versus time, but scopes cannot directly measure current. Current probes are commonly used, but need to be calibrated before use and drift significantly during use,

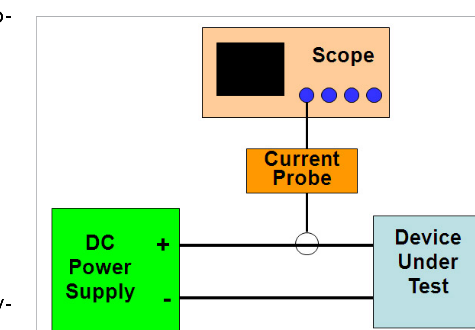


*Figure 2: A current probe is a typical method to current versus time*

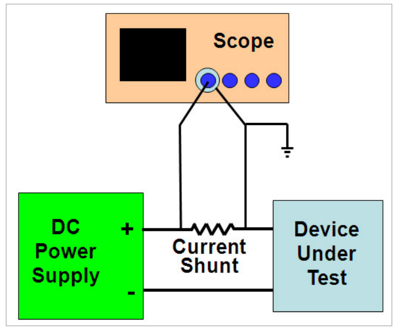


*Figure 3: Using a current shunt to measure current versus time. With most scopes, this will ground one side of the shunt*

yielding unrepeatable, imprecise measurements that may not be trustworthy (**Figure 2**).

Alternatively, a current shunt (aka current sense resistor) can be used, but to get an accurate measurement you need to precisely know its resistance value. As current flows through the shunt, the shunt will heat up and change value, so it is difficult to accurately make this measurement because the shunt value is changing. Most scope inputs are ground referenced, so when you connect the scope across the shunt, you are grounding one side of the shunt, which could cause an undesirable grounding issue. Selecting the right resistance value is another challenge. If the resistance is too high, as high current flows through the DUT, there could be an unacceptably large voltage drop across the shunt, called its burden voltage. With high peak currents typically found in motors and machinery, you will need to use a very low resistance shunt to keep the voltage low during the current peaks. Then, it will be difficult to measure the normal operating current of the device because the voltage drop across the shunt will be too small for the scope to accurately measure. (**Figure 3**)

4. Generating DC bias supply transients and disturbances: When characterizing a design or troubleshooting fault conditions, you will want to subject the design to a variety of conditions to see how the device responds. High transient currents found during motor startup or machine turn-on can wreak havoc on nearby sensitive systems, so it is important to be able to recreate these transient conditions and look for problems they may cause. To generate these conditions, you would turn to an arbitrary generator to create a modulation waveform and then use that waveform to drive a powerful DC power supply to generate the transient – provided the DC source has an analog programming input that can be driven by the Arb. And is the DC source fast enough to track the Arb and create the waveform? To create these transients, you will probably end up building a mini-test ATE system to program the Arb, drive the power supply and measure the resultant behavior of the DUT. (**Figure 4**)

An Alternate Solution for DC Sourcing and Measurement Tasks

A different approach is the DC Power Analyzer, which combines the capabilities of four power supplies, voltmeter/ammeter, scope, arbitrary waveform generator, and datalogger in a package that fits nicely on the bench. Thus, the DC Power Analyzer offers an alternative to a collection of standard bench instruments.

A DC Power Analyzer eliminates the need for multiple pieces of equipment and complex test setups. All of the measurements and functions are available right from the front panel, so it also eliminates the need to develop and debug test programs. As a result, it provides engineers the ability to setup tests and make measurements. And since all functions are integrated into a single instrument, it is fully specified so the engineer can have confidence in the performance of his test equipment.

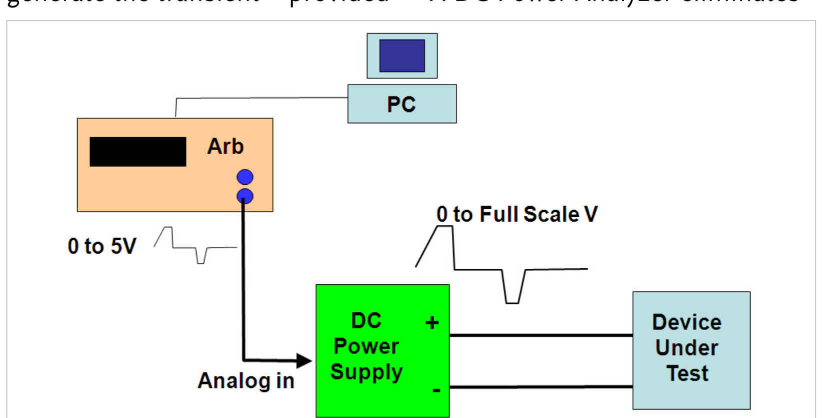


*Figure 4: Creating a DC supply transient with an arbitrary waveform generator and a DC power supply. The DC supply acts like a power amplifier of the small signal from the Arb. A PC may be required to calculate the points of the Arb and download them into the Arb.*

Let's look at those four tasks again and how a DC Power Analyzer could handle them:

1. Biasing with a static DC voltage and measuring current: The DC Power Analyzer's most basic function is to provide DC voltage and current, like any other power source. But if your needs are only for simple, static DC bias, the trusty power supply on your bench right now is quite capable; the DC Power Analyzer would be overkill.

2. Setting up turn-on/turn-off sequences: The DC Power Analyzer can sequence the turn on of its 4 DC power supplies. Turn on/off delays between outputs can be set directly from the front panel with delay times.

3. Measuring and displaying current versus time to visualize power: The DC Power Analyzer has a built-in scope function that can directly measure the current versus time flowing out of its power supply into your device. There is no need for a current probe or a current shunt, so all of the measurement challenges associated with the transducer are eliminated.

4. Generating DC bias supply transients and disturbances: In the DC Power Analyzer, the built-in arbitrary waveform generator's only job is to modulate the DC power supplies. Canned waveforms, like sine, staircase, and pulse, are available. User defined waveforms are also supported so it is easy to create DC supply transients to simulate real world power disturbances right from the front panel of the DC Power Analyzer. Furthermore, the DC Power Analyzer can make voltage transitions in as fast as 160 microseconds. This means that narrow pulses and other fast events can be faithfully produced.

**A demanding task**

As DC bias tasks become more sophisticated, involving sequencing and dynamic sourcing and measurement, traditional instruments start to fall short. These tasks will require complex interaction of several instruments and transducers, causing setup and configuration challenges. Often, a PC is used and software must be written to orchestrate tasks that are too complicated for a person to manually execute. All of this adds up to a lot of setup time to make the required measurements.

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# Compensation Methods In Voltage Regulators

## An evolution from analog to digital

By: Bruce Rose, Technical Marketing Manager, CUI

An analogy to assist in understanding compensation in voltage regulators lies in the suspension system of an automobile. Operators of cars desire different styles of ride depending upon the use of the car. Riders in limousines would like to enjoy a smooth ride and not notice any external disturbances. At the other extreme, racecar drivers would like their cars to respond quickly to the external forces of starting, stopping and turning. A properly tuned suspension system will give the car its desired ride qualities, similar to adjusting the feedback compensation circuit of a voltage regulator.

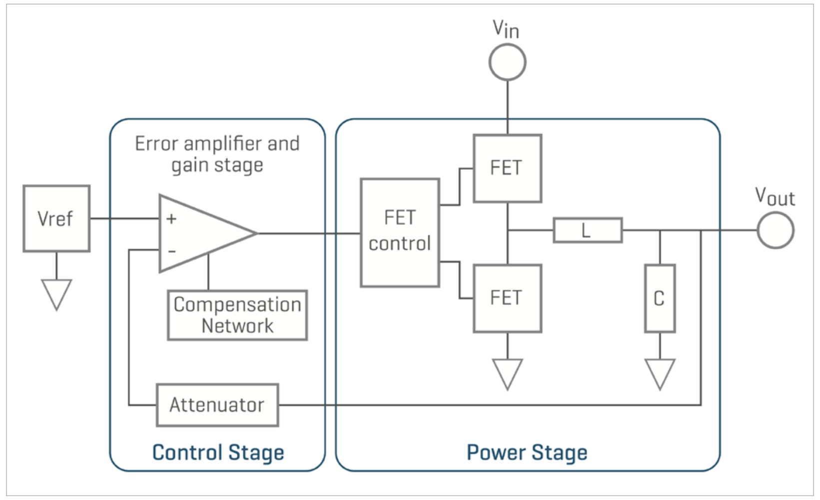


*Figure 1: Analog Switching Voltage Regulator*

**Switching regulators**

In order to achieve good power conversion efficiency, design engineers often employ switching regulators (figure 1). Typical switching regulators consist of two primary functional blocks; a power stage and a control stage. The power stage conducts the current flow in the voltage regulator. It contains switching FETs (field effect transistors), a circuit to control the switching of the FETs and an output filter that includes inductance and capacitance. The control stage provides the signals to the power stage, such that the switching regulator produces the desired output voltage waveform. The control stage consists of an attenuator, an error amplifier, a gain circuit and a compensation circuit. The switching regulator can either be built with discrete components soldered directly to the host circuit board or obtained from manufacturers that offer voltage regulator point of load (POL) modules with the components placed on a daughter circuit board which is then connected to the host circuit board.

In most analog switching regulators, internal nodes are brought external to the circuit so that the user can select the circuit compensation components. This external compensation feature allows the user to optimize the performance of the switching regulator for their application. Optimizing the voltage regulator transient response involves measuring or modeling the circuit and then calculating the values of the compensation components. The circuit is then modeled or measured with the compensation components installed. This process is often repeated many times until the desired result is achieved. Optimizing the compensation

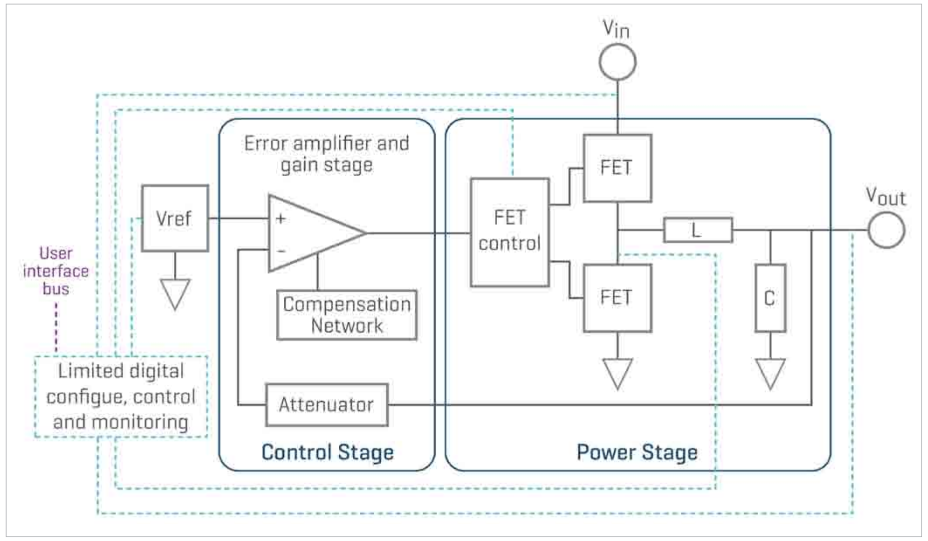


*Figure 2: Analog Switching Voltage Regulator with 'Digital Wrapper'*

of a digital switching regulator is accomplished in a similar manner; however changes are made using firmware rather than physical components.

Proper implementation of the compensation network within an analog-switching regulator requires engineers with special tools, skills and experience. If an analog switching regulator is measured during the compensation design phase, then the circuit board needs to be re-soldered many times. If the circuit is modeled and not measured, there is still the need to eventually solder together a physical circuit to measure the performance. The process of re-soldering the compensation components introduces a substantial level of risk to the design process. It is common that the wrong value of a compensation component is installed, another part of the circuit is accidently modified, or the circuit board is damaged during the design process. It is also possible that the circuits drawing power from the voltage regulator can become damaged due to improper compensation of the voltage regulator. When any of these events occur, time delays and expenses are incurred to recognize the problem, identify a solution to the problem, and implement the repair. The above mentioned risks, procedures and required resources exist whether a discrete design of an analog switching regulator is implemented or a POL module based upon an analog switching regulator is used.

As a result of the increasing number of digital systems being implemented in today's designs, voltage regulator vendors are now offering analog switching regulators with 'digital wrappers' (figure 2) . The voltage regulator portions of these circuits are very similar to the traditional analog switching regulators. The digital wrapper enables the system to employ software to implement CCM (configure, control and monitor) functions of the voltage regulator, in a limited manner. The ability to use CCM functions in a voltage regulator via software control is of benefit to the design team during the development phase and to the user of the final product.

Analog switching regulators with digital wrappers are being offered to design engineers for discrete designs and as POL modules. Some module vendors have chosen to include most of the compensation components internal to the module. The module user is then provided a single internal compensation node and is required to select only one resistor and one capacitor to adjust the performance of the module.

The advantage of this process is that tuning the performance of the module is simpler than when the user must select all of the compensation components. A trade-off of this compensation technique is that the user is not able to select the complete set of compensation network components. The ability to select all of the compensation components would enable greater optimization of the performance of the voltage regulator. The ability to select only a single resistor and capacitor is similar to selecting the shock absorbers for a car, but not being allowed to tune any other component in the suspension system.

**Compensating digital voltage regulators**

The technical evolution of voltage regulators started with analog switching topologies for increased efficiency, transitioning to the addition of digital wrappers for limited CCM functions. Today digital switching voltage regulators are available to design engineers, providing superior performance to earlier topologies. Similar to analog switching regulators, digital regulators require a control circuit and a power stage. The power stage for a digital switching regulator is similar to that for an analog switching regulator. The control circuit in a digital regulator is implemented with digital and mixed-signal circuits. An advantage of this topology is that extensive CCM functions can be implemented. The extensive set of CCM functions in a digital voltage regulator provides greater benefit than the limited CCM functions present in an analog switcher with a digital wrapper. Another advantage of digital switching regulators is that optimizing the performance of the circuit can be accomplished more easily and automatically.

The compensation function in a digital voltage regulator can be implemented as proportional, integral, differential (PID) taps, which are coefficients used in the digital control circuit to define the response of the voltage regulator. An advantage of using firmware PID taps is that the designer can configure and control the performance of the voltage regulator with software. An infinite number of changes can be made to the response characteristics of the circuit without risk of damaging components or the circuit board. In addition, the behavior of the system can be monitored and the performance of the voltage regulator circuit can be re-tuned throughout the life of the product. This ability to easily modify the performance of the voltage regulator is similar to push-button suspension tuning which is available in some cars.

**Auto compensation**

Some advanced digital regulator controllers offer the ability to automatically compensate the regulator for optimum performance by monitoring the characteristics of the output voltage waveform. One advantage of automatic compensation is that the circuit designer does not need any special tools, knowledge or experience to optimize the performance of the voltage regulator.

In a regulator with analog compensation components, the compensation must be set such that the output voltage characteristics are acceptable over changes due to initial component tolerances, aging, temperature, input voltage and many other factors. This means that the circuit is never operating at the optimum performance point.

Digital voltage regulators with automatic compensation enable the voltage regulator to operate at peak performance regardless of changes in the system. Automatic compensation of digital voltage regulators can bethought of as having an expert mechanic always in the car to optimize the ride without any burden on the driver or passengers.

Proper compensation of voltage regulators enables users to realize optimum performance from their circuits. Tuning the performance of a circuit using traditional analog switching regulators involves a substantial level of risk. Vendors of some analog voltage regulator-based POL modules offer products that simplify the task of compensation by limiting the choices available to the user. Conversely, digital voltage regulators enable firmware based CCM functions, which permit the voltage regulator to operate at optimum performance.

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# Rail-to-Rail power monitoring up to 80V & beyond

## Accurate monitoring is crucial to efficiency and reliability

By: Christopher Gobok, Product Marketing Engineer, Linear Technology

Today's electronic designs continue to grow in complexity, making power consumption and overall efficiency even more important. Accurate voltage and current monitoring is crucial to conserving power and guaranteeing reliability. Board-level power monitoring is no longer just found in racks and servers – solar chargers, military weaponry, industrial machinery, and advanced automotive electronics are just a few non-traditional applications where power monitoring is quickly finding usefulness. Smarter, efficient systems and a more interconnected world continues to fuel the need for end users to have control and knowledge of electrical parameters in an effort to stay the green course and conserve valuable resources.

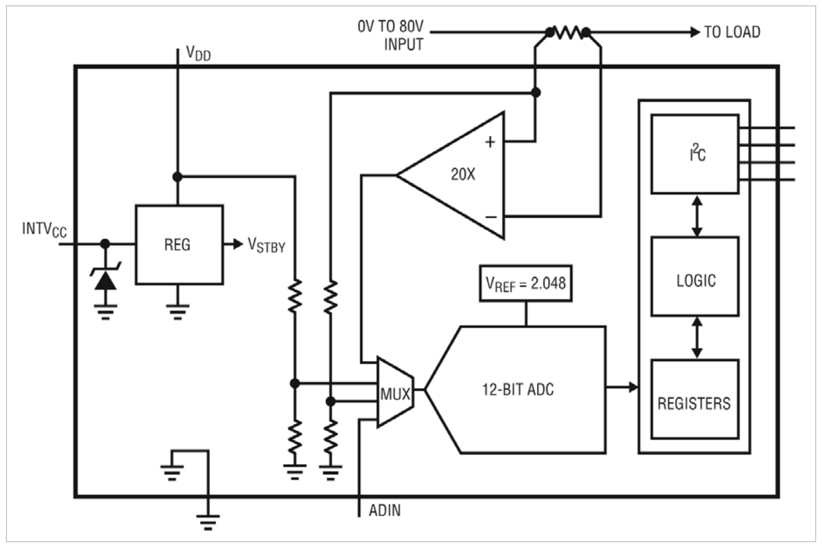


*Figure 1: Simplified LTC2945 Block Diagram*

A discrete power monitoring solution can be built using a microprocessor and a handful of other components. System overhead including polling data, multiplying parameters or analyzing data requires a power monitoring IC for a solution that alleviates a host of these burdensome tasks. Knowledge of voltage, current or power levels provides instant insight into a system's health, and a parametric alert may be all that is needed to provide early detection of a fault so preventative action can be taken before catastrophic events occur. Alternatively, systems can be optimized by understanding usage patterns, such as how much current is being drawn over time.

**The Power Monitor Role Model**

Power monitors have been built in many different ways, which isn't surprising considering that a variety of components are necessary to monitor power input to a system. To measure current, a sense resistor and amplifier are needed, and it is most convenient if the amplifier common-mode range extends to the positive supply rail and translates its output to ground. Precision resistive dividers are needed to measure voltage and, if there is more than one voltage to monitor, a mux must also be added to the list. A multichannel analog-to-digital converter (ADC) comes next, with a precise reference and some means of interfacing to a microprocessor, while perhaps sharing I/O lines with neighboring ICs. If detection of minimum and maximum values or alerts is required, code needs to be written and constantly executed. Because of the overall complexity and difficulty of finding suitable components, power supply monitoring easily lends itself to an integrated solution.

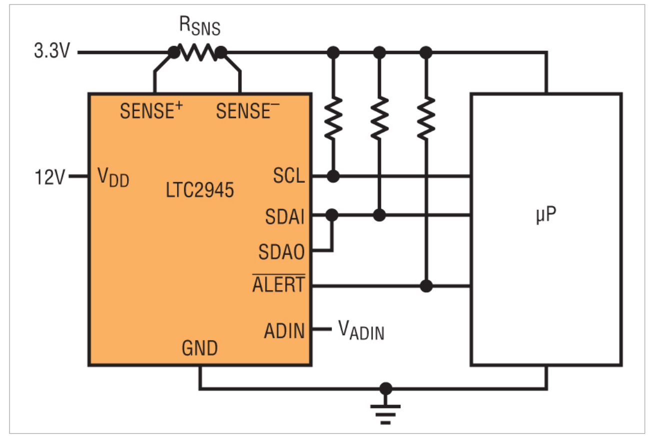


*Figure 2: LTC2945 Input Supply Monito with 12V $V_{DD}$ Input*

One solution from Linear Technology integrates the necessary functional blocks in a small 3mm x 3mm QFN or MS12 package. The LTC2945 makes power monitoring very practical where a discrete solution is out of the question due to space, complexity or cost. The LTC2945 operates on as little as 2.7V, but can monitor the voltage and current of any 0V to 80V rail, as well as its own supply voltage and one additional voltage input. An onboard shunt regulator provides support for supplies greater than 80V. For flexibility, the sense resistor is external, enabling the LTC2945 to accurately monitor currents ranging from milliamps to amps or more. The ADC has 12-bit resolution and a maximum total unadjusted error (TUE) of 0.75% for voltage and 0.75% for current. The additional ADC input (ADIN pin) TUE is also just 0.75%. The LTC2945 also integrates a digital multiplier, which calculates a 24-bit power result and stores this value, along with measurements, status and user configuration in I²C accessible registers.

The LTC2945 finds its way into many complex, space-constrained applications including RAID systems, telecommunications, transportation, solar monitoring systems, and industrial computer/control systems. Fortunately, only a few simple connections need be made to this device. **Figure 2** shows the LTC2945 monitoring the input voltage and current of a 3.3V microprocessor, while being powered by 12V. The only required external components are a sense resistor and three pull-up resistors.

**Powering the Power Monitor**

A solution like the LTC2945 can derive its power from a wide range of supplies which drastically simplifies the design process for any application. **Figure 3a** shows the device being used to monitor a supply that ranges from 4V to 80V. No secondary bias supply is needed since the $V_{DD}$ supply pin can be connected directly to the monitored supply. If the LTC2945 is used to monitor a supply that goes as low as 0V, it can derive power from a wide range secondary supply connected to $V_{DD}$ as shown in **Figure 3b**. Similarly, if a low voltage supply as low as 2.7V is present, the LTC2945 can be configured as shown in **Figure 3c** to minimize power consumption.

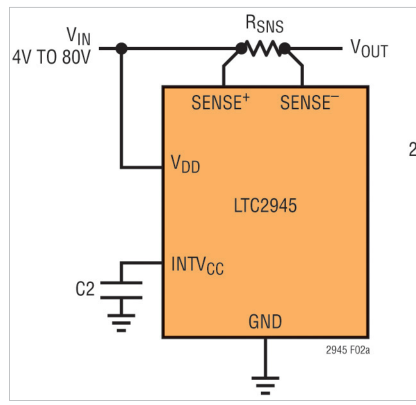


*Figure 3a: LTC2945 Derives Power from the Supply Being Monitored*

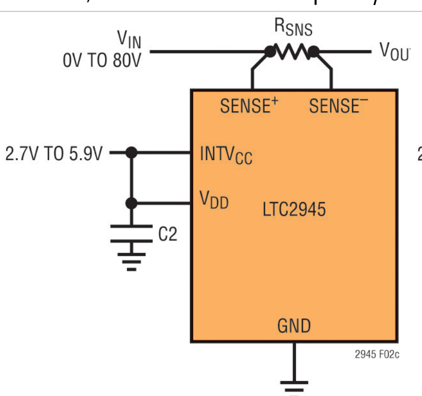


*Figure 3b: LTC2945 Derives Power from a Wide Range Secondary Supply*

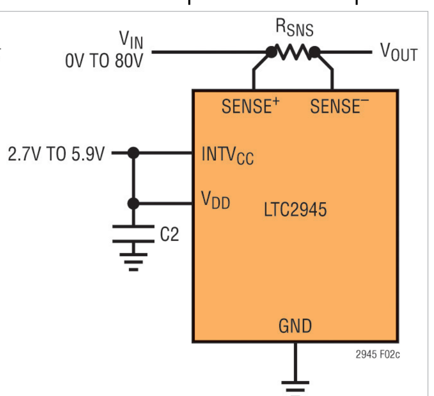


*Figure 3c: LTC2945 Derives Power from a Low Voltage Secondary Supply*

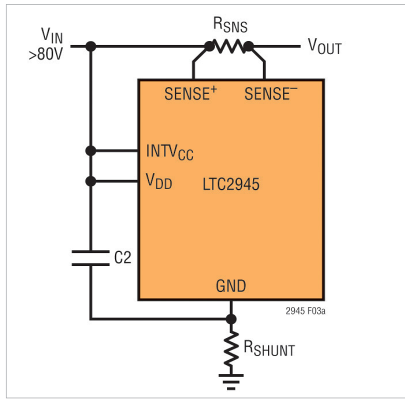


*Figure 4a: LTC2945 Derives Power through High-Side Shunt Regulator*

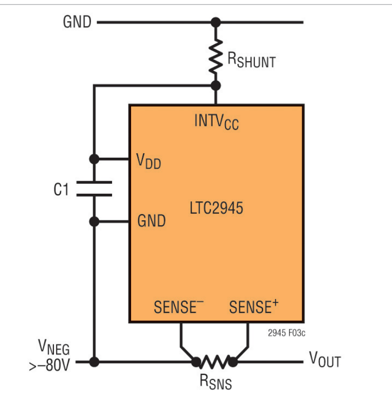


*Figure 4b: LTC2945 Derives Power through Low-Side Shunt Regulator in Low-Side Current Sense Topology*

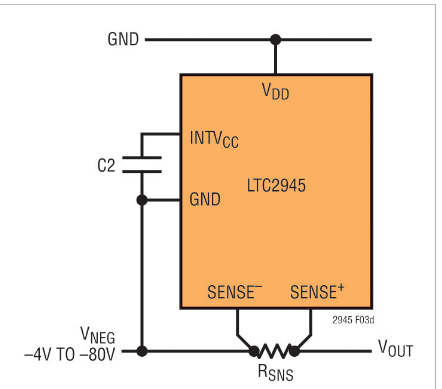


*Figure 4c: LTC2945 Derives Power from the Supply Being Monitored in Low-Side Current Sense Topology*

For supplies greater than ±80V, the onboard linear regulator at the $INTV_{CC}$ pin can be used in both high and low side configurations to provide power to the LTC2945 through an external shunt resistor. **Figure 4a** shows a high side power monitor with an input monitoring range beyond 80V in a high-side shunt regulator configuration. The LTC2945 ground is separated from the circuit ground through $R_{SHUNT}$ and clamped at 6.3V below the input supply. Due to the different ground levels, the LTC2945's I²C signals would need to be level shifted for communication with other ground referenced components; a current mirror would also be needed to measure the external voltage on the spare ADC input. **Figure 4b** shows the LTC2945 deriving power from a greater than -80V supply. Here, the low-side shunt regulator configuration allows operation by clamping the voltage at $INTV_{CC}$ to 6.3V above the input supply, which in this case is a negative rail. As shown in **figure 4c**, a shunt resistor is not required if the input supply is below -80V and transients are limited to below -100V, where $V_{DD}$ measures the supply voltage at circuit ground with respect to the LTC2945 ground.

**Digital Convenience**

Consistent with the flexible powering options, the LTC2945 includes a host of digital features that simplifies design. The most apparent digital feature is the integration of a digital multiplier which provides users with a 24-bit power value, alleviating the host of polling voltage and current data and performing an extra computation. The LTC2945 calculates power by multiplying 12-bit measured current with 12-bit measured voltage. In continuous mode, the differential sense voltage is measured to obtain the load current data. However, the voltage data can be selected between the supply voltage, positive sense voltage, or spare ADC input voltage. The 24-bit power value is then calculated at a rate of 7.5Hz in continuous mode and not refreshed at all in snapshot mode.

The LTC2945 has minimum and maximum registers for current and voltage, as well as power, which eliminate the need for continuous software polling and free the I²C bus and host to perform other tasks. In addition to detecting and storing min/max values, the LTC2945 has min/max limit registers that can be used to issue an alert in the event any of the limits are exceeded, again, eliminating the need for the microprocessor to constantly poll the LTC2945 and analyze data. For a power monitor, an alert response can be equally as valuable as minimum and maximum registers. **Figure 5** shows how the LTC2945 generates an alert signal via software and hardware. Measured data is compared against user defined thresholds; overvoltage, undervoltage, overcurrent, undercurrent, overpower, and underpower thresholds can all be defined and simultaneously monitored. Then, a status register informs the user which parametric thresholds have been exceeded, while actual fault values are logged in another register and can be interrogated at a later time. A separate alert register allows users to select which parameters will respond in accordance with the SMBus alert response protocol, where the Alert Response Address is broadcasted and the /ALERT pin is pulled low to notify the host of an alert event.

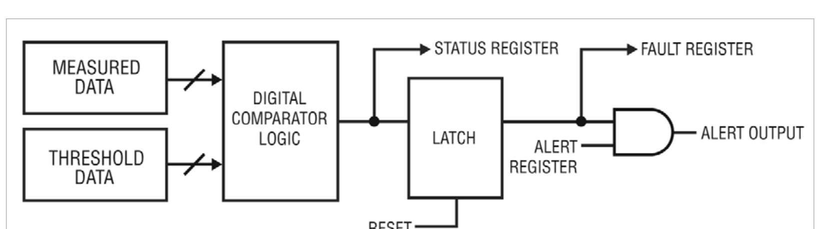


*Figure 5: LTC2945 Fault Alert Generation*

The LTC2945 uses a standard I²C interface with very unique enhancements to communicate with the outside world. Nine I²C device addresses are available so multiple LTC2945s can be easily designed into the same system. All LTC2945 devices respond to a common address, which allows the bus master to write to several LTC2945s simultaneously, regardless of their individual address. A stuck-bus reset timer resets the internal I²C state machine to allow normal communication to resume in the event that I²C signals are held low for over 33ms (stuck bus condition). A split I²C data line conveniently eliminates the need to use I²C splitters or combiners for bidirectional transmission and receiving of data across an isolation boundary. Furthermore, the LTC2945-1 has an inverted data output for use with inverting opto-isolator configurations.

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# The no-load power crunch: 30 mW and beyond

## Many regions are introducing limits for no-load power consumption and operating efficiency

By: Adnaan Lokhandwala, Product Manager, Texas Instruments

No-load/vampire and standby power consumption are hot buttons in the power electronics industry today. No-load power is the electrical power consumed by an adapter/charger when the end equipment it powers is disconnected. Standby power is the power consumed by the system when not performing its primary function, but maintaining system functions like remote control, user display, clock, and so on. The need to reduce active-mode power consumption is somewhat obvious. What has not been so obvious is the need to minimize power drain in standby and no-load when products are essentially doing nothing.

Several studies have been performed worldwide to quantify standby and no-load consumption by domestic equipment and AC power adapters, with emphasis on its environmental impact. The International Energy Agency (IEA) estimates that five to 15 percent (depending on country) of household electricity consumption is wasted in these modes and accounts for one percent of the global $CO_2$ emissions. This resulted in tighter regulations and new industry-specific initiatives encouraging manufacturers to develop more efficient AC/DC designs.

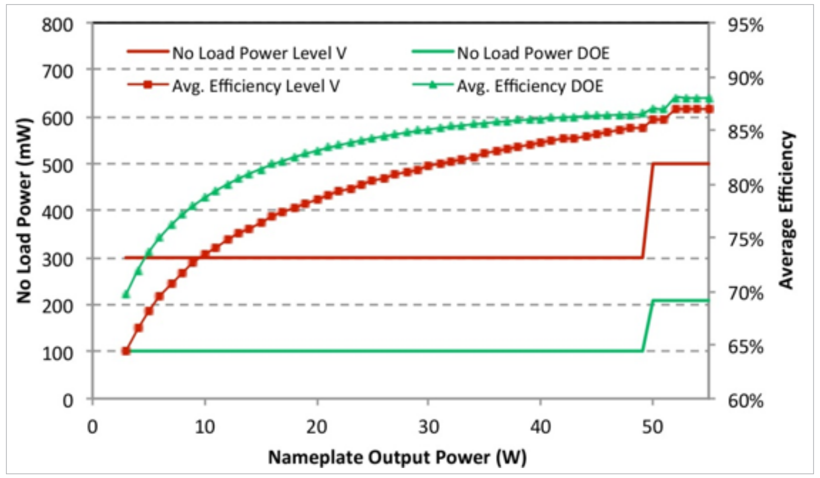


*Figure 1: DOE proposed regulations vs. Level V performance for a 5V output EPS.*

**Regulations driving green performance**

Many global regions are introducing mandatory and voluntary limits for no-load power consumption and operating efficiency of EPSs. In the US the main drivers are California Energy Commission (CEC), which is mandatory, and the voluntary Energy Star program from the US Environmental Protection Agency (EPA). Energy Star defined the International Efficiency Marking Protocol (Level I-V) in 2006, which set the minimum efficiency and no-load power consumption levels for EPSs. Similarly, the European Commission has issued the Energy Using Products (EuP) Directive Lot 6 applicable for standby and off-mode losses of EuPs. In 2011, they lowered this level to 300 mW for adapters ≤ 51W or 500 mW for adapters > 51W. The IEA 1-Watt initiative to reduce standby power use by any appliance to not more than 1W in 2010, and 0.5W in 2013 has driven regulations in many countries and regions.





In March 2012, the U.S. Department of Energy (DOE) issued a Notice of Proposed Rulemaking (NOPR) that lays out the first mandatory regulations for external battery chargers and further tighten regulations on EPSs. In the Level VI standard, the proposed regulations significantly tighten and expand the range of the current minimum efficiency requirements. The proposal contains seven new product classifications (B-E, X, H & N), and multiple output and >250W EPSs. The performance requirements per this new regulation for a 5V output direct operation EPS (Class C) are compared with the current Level V standards (**see Figure 1**).

The European Commission's Integrated Product Policy Program (ECIPP) and the world's top mobile phone makers introduced a voluntary energy rating system for mobile phone chargers, making it easier for consumers to determine which ones use the least energy at no load. The rating system ranges from five stars (<30 mW no-load power) for the most efficient chargers down to zero stars for chargers consuming the most energy.

There is a strong momentum building in the EPS market to push this 30 mW no-load performance point beyond the mobile charger market to higher power applications like tablets, ultra books, notebook, TVs, and other electronics.

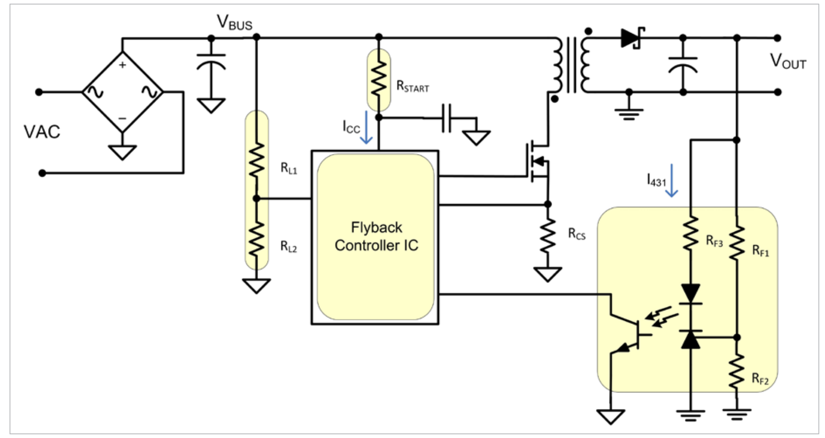


*Figure 2: Conventional AC/DC flyback architecture.*

Minuscule power consumption within the power supply leaves much more power available for use by electronic systems designed to comply with standby power limits. For example, a power supply that consumes only 10 mW at no-load allows a higher margin for other leaky circuit components (such as input filters, capacitors, and bias components), while still providing the power required to support system standby activities like remote activation, LCD display panel, and the like.

**Understanding no-load power losses**

The flyback topology remains the preferred choice for non-PFC EPS adapters due to its simplicity and low cost. Four key elements that contribute most to the system no-load power losses are startup bias resistor, input line sense network, IC bias power (no-load current, switching frequency, etc), and feedback bias power (**See Figure 2**). An electromagnetic interference (EMI) filter, snubber and MOSFET switching losses make up the remaining no-load power consumption.

Resistive start-up circuits are used in power supplies to start the controller IC when the AC input is first applied. There is a tradeoff between start-up time and no-load power. To decrease start-up time, $R_{START}$ must be lowered, which increases no-load power. Most designs also require AC line brownout protection to disable the power supply and prevent over-heating (if thermistor thermal protection is not included). This function usually is implemented with high-voltage (HV) line-sensing resistors that add to the no-load power consumption.

$$P_{START\_UP} \approx \frac{V_{BUS}^2}{R_{START}} \quad \text{(Eq. 1)}$$

$$P_{LINE\_SENSE} = \frac{V_{BUS}^2}{R_{L1} + R_{L2}} \quad \text{(Eq. 2)}$$

Typical AC/DC power supplies have a feedback network to send the error signal from the isolated secondary to the primary-side controller via a TL431 shunt regulator and optocoupler. There are two fundamental issues with this approach: a) the TL431 needs a minimum cathode bias current ($I_{431\_MIN}$) under all conditions; and b) the standard optocoupler configuration consumes the most current at no-load conditions ($I_{431\_SAT}$). The overall losses from this feedback network are shown is Equation 3. Note that this loss becomes a significant portion of the no-load power budget when the converter output voltage increases. The IC current consumption during no-load $I_{CCNO\_LOAD}$ (quiescent current + the averaged MOSFET gate-drive current) is accounted for in Equation 4. For example, a recent state-of-the-art 5V/2A USB wall charger was tested for no-load power consumption and measured 121 mW at 230V AC.

$$P_{FEEDBACK} = \frac{V_{OUT}^2}{R_{F1} + R_{F2}} + V_{OUT} \times I_{431\_sat} \quad \text{(Eq. 3)}$$

$$P_{IC} = V_{CC} \times I_{CCNO\_LOAD} \quad \text{(Eq. 4)}$$

Nearly every wall-powered device today sits poised in standby mode pulling “some” line current, until it receives an alert to get up and running. For wall adapters/chargers powering consumer electronics, the no-load power issue is more challenging as there is no indication on when the load will be connected. The adapter is expected to consume the least possible or even no power while maintaining enough active intelligence to be able to respond instantaneously when the load is back. With billions of power supplies in use today that typically are left plugged in and unused for an average of 20 hours a day, the issue of no-load power is cumulatively huge with a correspondingly huge payback potential, if carefully addressed with industry regulations and smart power supply design choices.

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# Special Report: Powering Industrial Applications

PSD NORTH AMERICA
Power Systems Design: Empowering Global Innovation

INSIDE:

# Power measurements as an aid to energy efficiency

## Governments and regulatory authorities are establishing new standards

By: Hafeez Najumudeen, Yokogawa Europe & Africa

Manufacturers are increasingly focusing their efforts on energy conservation. This trend is reflected in the growing emphasis on both renewable energy and energy efficiency measures to reduce the amount of energy consumed. Governments and regulatory authorities are establishing new standards for the energy consumption of various types of equipment, which has to comply with complex and stringent specifications, and in many cases have to carry energy efficiency labels to show that they meet these requirements.

**Standby power consumption**

Typical of this trend is the demand for a lower threshold in standby power consumption. This is an important area for a number of reasons. For example, it is estimated that between 5% and 15% of residential electricity used in the OECD countries can be attributed to the power consumption of appliances in standby mode: equivalent to about 240 million tonnes of carbon dioxide emissions every year. Moreover, by 2020 it is expected that approximately 4.6 billion products will be featuring a standby option, contributing around 50 TWh of electricity consumption per year. This amount is equal to the total electricity consumption of a country like Greece or Portugal.

The International Energy Agency (IEA) has launched a 1 W standby initiative, and it is expected to decrease this threshold to 0.5 W by 2013. The scale of the challenge presented by these limits is illustrated by the fact that 18.5% of all household appliances in “off” mode and 31% in standby mode failed to comply with the 1 W initiative. The proposed reduction to 0.5 W will result in 41.5% in “off” mode and 66.4% in standby failing to comply.

If an item of equipment has power consumption between 0.5 W and 1.0 W, it is estimated that electricity consumption in standby/off mode by 2020 will be about 15 TWh. This represents a saving of around 35 TWh of electricity: equivalent to the total electricity consumption of Denmark.

**User requirements**

In order to meet these regulatory requirements, equipment suppliers will need to measure the actual power consumption of their products, often at very low power levels.

There is also a need to carry out measurements other than the standard electrical parameters of voltage, current and power, because of the increased regulatory emphasis on power quality which demands measurements in areas such as harmonics and frequency-based parameters. Equally important, particularly in the production environment, are ease and flexibility of use, to ensure that employees with all skill levels are able to operate the instruments. Production testing also requires a communications interface so that the measuring instrument can interact with PCs and other instruments to create an automatic test system for improving productivity and enhancing quality assurance.

**Digital power meters**

One example of how these challenges are addressed can be found in Yokogawa’s latest generation of digital power meters (Fig.1), which offer a basic accuracy of 0.1% of reading, guaranteed accuracy over the entire measurement range (from 1% to 130%), a wide measurement range from standby power levels of a few milliamperes up to 40 A, and the flexibility to enable users to target different technical and commercial applications.

In addition to standard power measurements, these instruments incorporate a wide range of harmonic measurement capabilities, including the ability to carry out simultaneous measurement of normal power parameters such as RMS, mean or DC power along with measurement of harmonics up to the 50th order. As a result, overall measurement times are reduced, allowing users to allocate their effort and time to other tasks. Other features of the new instruments include a bandwidth of DC and 0.5 Hz to 100 kHz (up to 20 kHz for 40 A on the WT310HC), plus an auto-range function for measurement and integration. Software is also available for testing equipment compliance to industry energy-saving standards such as IEC62301 Ed2.0 and IEC62018 for standby mode equipment or for dealing with waveforms having a crest factor of 5 or more.

**Quality assurance and production line testing of electrical devices:** The instruments’ compact half-rack mounting size plus the choice of interfaces makes it easy to integrate into a customised production test system. In addition to the USB, RS232 or GPIB and Ethernet capability, a D/A output function is also available for data recording. Test times are minimised via the ability to make simultaneous power and harmonic measurements, and the communication interfaces make it possible to capture measured data remotely. It is also easy to create a test program using sample program and LabVIEW drivers.

**Power consumption and efficiency measurements on industrial motors:** This application benefits from the ability to make accurate measurements on fundamental power parameters over a broad bandwidth (DC to 100 kHz) and to make long-term energy measurements using the integration capability. The user can also save the measurement data and monitor the results along with other parameters using the D/A interface and an external waveform recorder.

**Measurements on distorted waveform including both DC and AC components and simultaneous measurement:** The digital power meters can measure DC components and distorted waveforms including rectified and half/full waves without changing the measurement mode. A line filter (cut-off 500 Hz) can eliminate unnecessary components. The broadband capability allows the instrument to measure the RMS value of distorted waveform like rectified half wave without any change in measurement mode.

**Evaluation of equipment against international standards:** International standards such as SPEC Energy Star and IEC62301 specify limits on parameters such as crest factor and total harmonic distortion. The high resolution of 5 mW and low current range of 5 mA are ideal for these applications. PC-compatible free software is also available to make measurements to the IEC62301 standard. The ability to carry out simultaneous normal and harmonic measurements results in a low-cost test solution.

**Evaluation of uninterruptible power supplies (UPS):** It is possible to evaluate a UPS against the IEC62301 standard using the integration feature for energy measurement and the integrated auto-range function. For a UPS that complies with the performance test of IEC standards, the power meter can calculate and measure the efficiency and the strain rate and the frequency and output level between the input and output at the same time.

**A global concern**

Energy efficiency has become a global concern over the past decade, and evolving national and international standards will help to ensure that power efficiency is incorporated into all the key stages of the design and manufacture of electrical appliances. Ensuring compliance with these standards requires accurate measurement.

www.yokogawa.com

# Using Uninterruptible Power Supplies in harsh environments

## Increasing issues of wide temperature ranges on UPS use

By: Michael A. Stout, V.P. Engineering, Falcon Electric

When used in a controlled temperature environment ranging from 0°C to 40°C (32°F to 104°F) any domestically available on-line UPS should meet the requirement, as most have been tested and approved for operation over this temperature range by a safety agency such as Underwriters Laboratories (UL). However, there is an ever-increasing requirement to use on-line UPS technology in much wider temperature environments. Many harsh power environments are located in remote outdoor locations, where power sensitive equipment and the on-line UPS must be installed inside buildings without any climate control systems, or in protective NEMA rated enclosures.

**Site requirements audit -**

An audit should determine the operational temperature and humidity ranges, any conditions that dictate installing the UPS inside a protective NEMA enclosure (**figure 1**), and the level of NEMA protection required. Power quality at the site with respect to the need for additional high voltage transient or lightning protection, galvanic isolation must also be considered in addition to assessing the amount of battery backup time. Always review code compliance.

**The wide-temperature online UPS**

Industrial-grade, wide temperature online UPS products are now on the market having operational temperature ratings of -30°C to +65 C (-22°F to 149°F). A standard off-the-shelf on-line UPS having a UL or ETL Listing for operation over a 0°C to 40°C temperature range typically has been submitted by the manufacturer to the safety agency for an engineering evaluation. A UPS incorporates many high power components like transformers and chokes that can over-heat and not only cause the UPS to fail, but present a risk of an internal UPS fire. The safety agency also reviews the types of circuit board and plastic materials used in construction of the UPS with regards to their temperature ratings and limits.

Most on-line UPS manufacturers design their products for operation in the standard 0°C to 40°C operating environment

*Figure 1*

and submit them to the safety agency for evaluation over the same operational temperature range. Installing this UPS in a building without temperature control in the summer in Phoenix would be using the UPS outside of the safety agency's product listing status. This could result in the UPS having a reduced reliability and life span, or in an outright failure. At the higher temperatures of Phoenix, plastics used in the UPS construction and the battery can become deformed or cracked. The standard UPS batteries used are typically not rated for temperatures above 40° to 50°C. Further, per the battery manufacturer's rated 50°C temperatures, the battery service can be reduced from five years to a few months.

**Cold temperatures**

Temperatures below 0°C present their own set of unique problems. Due to the electro/chemical design of most Valve Regulated Lead-Acid (VRLA) batteries, temperatures below -20°C, depending on the battery design, can impair the batteries ability to deliver sufficient current to power the UPS. The amount of battery runtime can be reduced to less than 50% of its normal time when operated at 0°C. Below -40°C the electrolyte found inside electrolytic capacitors used in the circuitry of the UPS can greatly lower the capacitor's capacitance or even freeze causing capacitor's to rupture. This can cause the internal electrolytic capacitors to slowly dry out over the following months, resulting in a UPS failure. Below -40°C, if not rated for this low temperature some integrated circuits and optical isolator devices can function improperly causing the UPS to go to an alarm condition until warmed up. Again, a full UPS failure can result. At this low temperature, batteries can also freeze along with the plastics used in their case material becoming brittle and subject to cracking. As the battery electrolyte freezes, it expands the plastic case and can cause the batteries to leak acidic electrolyte inside the UPS when the ambient temperature raises enough to allow the batteries to thaw out. This often renders the UPS unusable, requiring it to be replaced. n standard on-line UPS having an operational temperature rating of 0°C to 40°C should not be installed in protected outdoor locations having temperature extremes outside its rated limits, yet it is often attempted.

www.FalconUPS.com

# Smart and efficient cities

## Sensors, networking, and smart design will improve energy efficiency and service delivery using technologies available today

By: Chris Sullivan, Technical Marketing, Newark element14

A city by its very nature tends towards chaos. As the population of the world continues to grow, so does the population living in urban areas. The need to maintain all of the essential services that keep us living a comfortable lifestyle implies that more and more resources will have to be allocated to the utilities that none of us usually notice until they go wrong.

The only way around this is to simplify these processes by making, for example, our water, gas, electricity, and transportation as easy and simple as possible to distribute and monitor. Consumer goods are leaps and bounds ahead in this respect. Gadgets that we didn't know we wanted or needed can appeal directly to our hearts by their simplicity, and have already woven themselves into the fabric of our daily lives. A smart city should take this approach and apply it to all aspects of our infrastructure.

Without massive government spending, or starting from scratch, patchwork modifications to our existing utilities and transit systems will form the core of our future cities. Again, our desire for simplicity spills over into the need for efficiency, and it is here that sensing and automation technology can effectively improve the day-to-day services that we're used to.

### Transportation

A growing number of cities around the world are also returning to more traditional forms of mass transit. Our love affair with the car is on borrowed time, and electrified trolley buses and trams will be a common sight in smart cities of the future as it becomes more and more expensive to operate a passenger vehicle. Some European cities, in fact, never phased out trams as obsolete and they continue to provide an essential and clean form of mass transit.

Low-cost low-power technologies such as RFID have already been widely adopted for keeping track of products in shops and our baggage at airports. As cities become increasingly large and the pressure for efficiency in every service grows, even the garbage that we make and would like to forget about requires the expertise of electronic engineers. Using low power systems to keep control of shared residential garbage and recycling facilities would make the process of collecting and disposing of waste much more efficient, and some cities such as Barcelona have already implemented semi-automated block refuse collection.

### Water

The water that flows through the pipes of our smart city will more than likely be flowing through much the same distribution network as today. The problems of water scarcity and water loss will become massively important as the world population grows bigger, and measures will need to be taken to limit our consumption. In the US, 6 billion gallons per day are lost and controlling the leakage of water and limiting water consumption could save $15 billion per year globally according to the World Bank.

Utility companies seeking to limit water loss have already started to adopt smart systems from companies such as the Israeli start-up TaKaDu to limit water loss. By combining software with telemetry and smart metering, utility companies have made some inroads into limiting water loss.

This example of using innovative electronics to cut down on waste showcases how our cities are becoming smart in our lifetimes. It is by using technology available today that electronic engineers can make even the simplest of utilities smart. However, questions remain as to what extent it's possible to prop up an aging infrastructure, and whether these measures significantly future-proof our utilities.

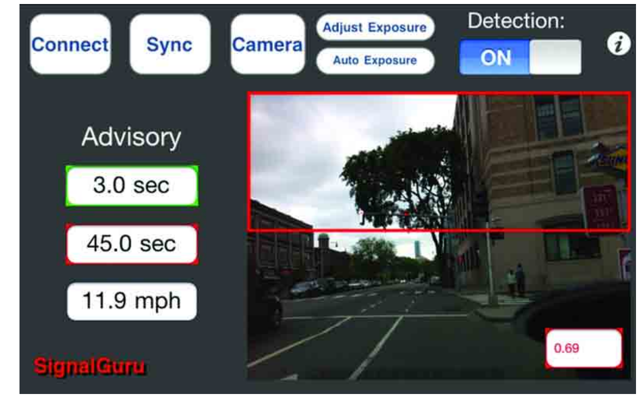


*Figure 1: The SignalGuru application from MIT and Princeton, saves drivers an average of 20% fuel costs compared to those that had to stop at traffic lights.*

### Communication

It is in communication that it is easiest in some ways to imagine a smart city. Trials currently underway into 4G networks will one day become a day-to-day reality for the majority of cities. It doesn't take an enormous leap of the imagination to think of ourselves walking through a city of the future watching HD video streamed in real-time to our tablet or smart phone.

Looking to countries like South Korea, who are far ahead of the curve in terms of a super fast internet, we can expect that countries across the world will follow suit over the next decade. However, the fast lane of communication will also need to run in parallel with much lower power channels.

Wireless control of the appliances in our homes is already a reality with some applications allowing us to communicate with a home server remotely to turn the central heating on, or record a TV show. The move to digital television has made available significant white space in the RF spectrum, providing a much-needed set of frequencies that will allow our ever-growing use of telecommunications to expand further.

Despite this, as demand for bandwidth continues to increase, so too will the sophistication of the communication methods. The development of SDMA (space division multiple access) and smart antennae will be critical if our future smart cities are to support the kind of network traffic that may be generated with high-definition audio and video in communications.

### Traffic management

As we drive around the streets of our smart city, wireless communications between our vehicles will become more and more important. Keeping our cars moving through what are now gridlocked streets will reduce emissions, improve trade links, and shorten our journey times to work.

A combination of dynamic traffic monitoring, GPS, and low-power vehicle-to-vehicle communications will serve to keep the wheels turning. Many countries have already implemented aspects of this type of traffic control, especially *managed* motorways, which are intended to slow down traffic to the speed necessary to avoid jams, though a more cohesive approach will be needed as our cities grow.

As a current example, smart social-networking application running on dash-mounted smart phones crowd sources the timing of red traffic lights and shares that information with other drivers to optimise fuel usage and resulting emissions (**figure 1**). The SignalGuru application, a project of the Massachusetts Institute of Technology and Princeton University, allows drivers to save an average of 20% fuel costs compared to those that had to stop at traffic lights (**reference 1**).

The application has worked well in Cambridge, Massachusetts where traffic lights are on a fixed timing. The system worked less well in Singapore where traffic light timings vary, but one can envision M2M (machine-to-machine) connected devices being able to track and communicate traffic light timings as well information from other vehicles through a real time database to make our roads safer and more efficient.

### Street lighting

Lighting our way as we make our

journeys around the cities of tomorrow, it will not be the familiar orange glow of the sodium street light that guides us, but energy efficient LEDs casting a cold white light. As the cost of LED illumination decreases, we can expect to see accelerated uptake of LED street lighting throughout our cities.

Replacing existing lighting technology with energy efficient LEDs would halve the carbon footprint that street lighting carries. Many of the cities we live in already use LED technology in traffic lights and signals, though uptake of street lighting has been slower with some residents complaining about the perceived brightness of cold color temperature LEDs. The balance will need to be struck in the cities of the future between sleepy residential zones and major routes where a white light will give increased attention span.

**Energy harvesting**

It is in the home that our smart cities will first take root. With oil and gas prices continuing to climb, alternative energy on a personal scale will become a key feature of housing in our future cities. Home solar power is already popular, though in the smart city photovoltaic cells will be concentrated on commercial buildings and ground mounts rather than houses.

While the UK has the greatest proportion of residential solar panels in Europe at 95% of total generation capacity, it is only 12% in

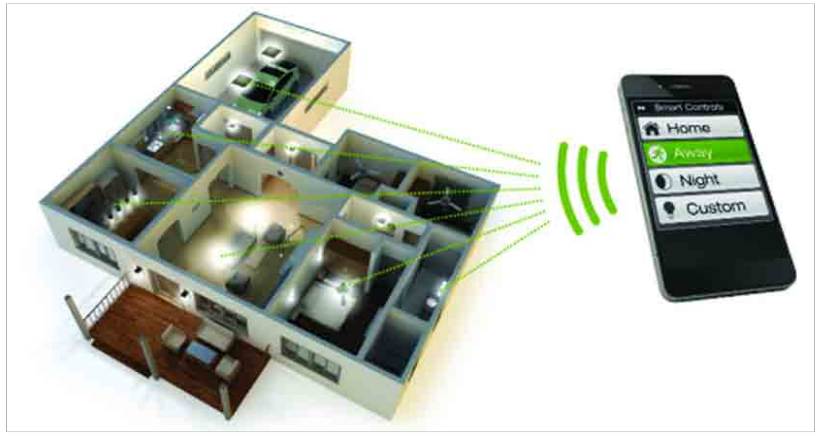


*Figure 2: The internet-enabled Greenchip Smart Lighting network provides convenient control of energy efficient lighting for the smart home.*

Germany, where the total output is much higher—7 GW compared to the UK's 45 MW—according to the European Photovoltaic Industry Association. In the smart home, making the most of every electricity drain through energy efficiency and energy harvesting will produce the savings required to reduce our overall carbon footprint. Here again it is the low-cost low-power products and methods that will make our homes smart.

**Smart homes**

It is when we return to our homes at the end of the day where the smart city will probably have the most impact. Energy recapture, smart metering, and personal health monitoring will ensure that our houses are safer, more comfortable, and energy efficient than ever.

Energy savings will also derive from the centralization of home computing. What we experience now as the Cloud will become more pervasive, though home servers and centralized computers will be important components in reducing the number of computers in the home. With this centralization will also come the potential to capture waste heat. In larger, commercial buildings, the waste heat from the server room could provide an important heat source for the building as a whole.

The introduction of smart meters will give consumers the option to monitor and control their power consumption online—a much-talked-about flagship of smart cities. This is just the beginning. What if every light bulb had an IP address? The possibilities are endless: You could monitor, manage and control every light bulb from any Internet-enabled device, turning lights on and off individually, dimming or creating scenes from your smartphone, tablet, PC, or TV to save energy as well as electricity costs (**figure 2**).

Your *smart lighting* network could have dozens or even hundreds of appliances connected through a wireless network designed for





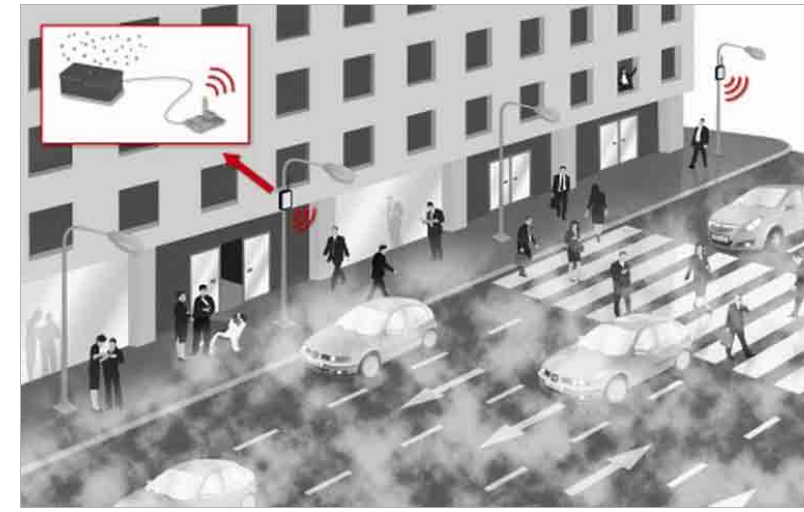

*Figure 3: Sensors able to monitor gas, radiation, particulate matter, and vibration could integrate into wireless networks to build a wide range of services for quake and gas monitoring.*

maximum energy savings, communicating information about their environment and power consumption levels, and alerting you to any problems. An example of such capability has been provided by NXP and partners in their internet-enabled Greenchip Smart Lighting network, which starts to shape a new dimension in energy efficient lighting for the smart home (**reference 2**).

**Public health and urban management**

In the end, it may be that the size of the smart city is limited by technology that monitors our health and wellbeing. The vast sprawling metropolis of the developing world has expanded so quickly owing to the availability of cars and mass transit, but the effect has been compounded by the need to be close to healthcare facilities.

With improvements in communications links allowing for remote diagnosis and surgery, it will no longer be as critical to live close to an urban center to experience an adequate standard of care. This may lead, in turn, to a slowing of the advance that has characterized the vast cities of China, India, and indeed the US several decades before them.

Beyond matters of individual health, today's city councils face many public-health challenges requiring effective monitoring. Atmospheric pollution—whether in the form of gases such as $CO^2$ and $NO^2$ or particulates—is a threat to the health of urban dwellers by causing respiratory diseases.

Sensor boards able to monitor gas, radiation, particulate matter, and vibrational data could be integrated into wireless networks to build a wide range of services for quake and gas monitoring (**figure 3**). These technologies could facilitate even more localised applications such as structural health monitoring on buildings.

Sensors and networks have so far addressed these within different standards and different vertical applications. A uniform modular approach run on open source software would allow city councils to enable better infrastructure cost effectively (**reference 3**).

A current example of a city-wide network is found in Portugal, which is pioneering a sensory system for a smart city and estimates 100 million sensors across an area of just 17 $km^2$ (**figure 4**). The biggest challenge to a smart city becoming reality is the ability to analyse seamlessly and process huge amounts of the data generated in real time, according to TU Darmstadt project Cocoon team.

The answer to this is to channel all the data coming from these sensors and services into an overarching control system via its own operating system. Urban OS, developed by Living PlanetIT and its technology partners, is an operating system that could manage communication between sensors and devices such as traffic lights, air conditioning or water pumps that influence the quality of city life.

For example, in the event of a fire, the Urban OS might manage traffic lights so fire engines can reach the blaze swiftly or help evacuate people much more quickly and efficiently within nearby or affected

*Figure 4: Portugal is pioneering a sensory system for a smart city and estimates 100 million sensors across an area of just 17 km².*

buildings (**reference 4**). A secure system that can uninterruptedly run the infrastructure of our cities would bring the sensory network of smart urban areas to life.

**Evolving to smart and efficient cities**

Living in such a rapidly advancing age, it is easy to forget that the cities we live in were driven by an earlier time, when the gears and levers of industry were oiled by large work forces that lived close to their jobs. The world will never quite shrink to the point that Arthur C Clarke envisaged in 1964 but, as our vast urban areas become smarter in myriad ways, it is likely that the city will become an easily accessible hub facilitating our daily lives. After all, cities are a way of centralizing and making things easier.

Elements of the smart city are with us today, dispersed throughout the world. The clean tram systems of Strasbourg, the autonomous transportation at Heathrow Airport in London, the solar collectors of Masdar city, and the augmented reality many of us use on our smart phones will all one day be key features of our smart cities.

Above all, the technology we need to make our cities smart is here with us today. It is the engineers, the innovators of the world, who will be the ones to turn applications once reserved for flashy gadgetry into essential services that keep our utilities, transport, and communications running. It will be the quiet unnoticed background that enables us to live the complicated lives we choose to.

www.element14.com

**References:**

1. Source: Massachusetts Institute of Technology and Princeton University, USA
2. Source: NXP
3. Source: Libelium
4. Source: Living Planet IT, Project Cocoon TU Darmstadt





# eGaN FETs improve performance in industrial POL converters

## Converter choice impacts cost-effectiveness and efficiency

By: David Reusch, Ph.D., Director, Applications & Stephen L. Colino, V.P., Sales & Marketing
Efficient Power Conversion Corporation

Designers of point of load (POL) converters used in 24 VDC systems traditionally have had to decide between the high cost of an isolated converter and the low frequency and efficiency of a buck converter. When compared with the 12 V POL converter common in computing systems, the higher voltage of the 24 V POL converter increases FET voltage to at least 40 volts to accommodate switch-node ringing and increases commutation and $C_{OSS}$ losses.

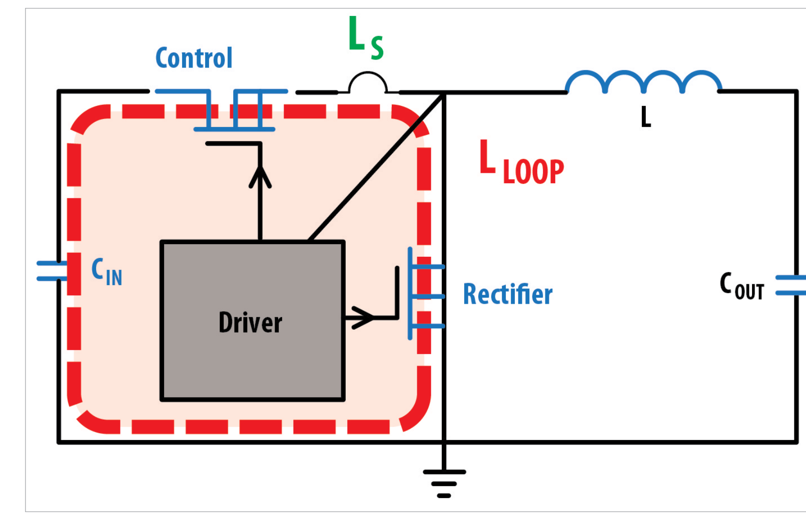


*Figure 1*

eGaN FETs, such as those from EPC, offer ultra-low $Q_{GD}$ for low commutation losses and low $Q_{OSS}$ for lower losses when charging and discharging the output capacitance. In addition, the innovative Land Grid Array (LGA), wafer level packaging of EPC's eGaN FETs allow ultralow inductance in both the high frequency power loop and gate drive loop, and most importantly, the path common to these loops, known as the common source inductance (CSI) to help minimize current commutation losses. Low charge and CSI of eGaN FETs allow designers to push power density higher by pushing frequency higher without the efficiency penalty of traditional MOSFETs.

**Experimental Setup**

The circuit that will be discussed is a buck converter with 24 $V_{IN}$, 1.2 $V_{OUT}$ with an output filter inductance of 300 nH, switching at 1 MHz, and an output current of up to 20 A. The eGaN FET boards were run with 5 V gate drives using the LM5113 eGaN FET driver from Texas Instruments. As MOSFETs run more efficiently with a higher gate voltage, 8 V, ISL2111 is used to reduce $R_{DS(ON)}$ and limit gate drive losses. Layouts for MOSFET and eGaN FET boards were made as similar as possible to minimize board parasitic differences.

There are two key areas where inductance is critical to performance, the CSI ($L_S$) and the inductance of the high frequency power loop $L_{LOOP}$. CSI external to the package was minimized in all designs by separating the gate drive loop from the power loop right at the source foot on the PCB for each package. Additionally, a second eGaN FET board was designed to take advantage of the eGaN FET's small size and interleaved drain and source terminations which allows a very low inductance PCB layout.

Common figures of merit (FOMs) used to compare FETs are $R_{DS(ON)}$ x ($Q_{GD}$ + $Q_{GS2}$) and $R_{DS(ON)}$ ) x

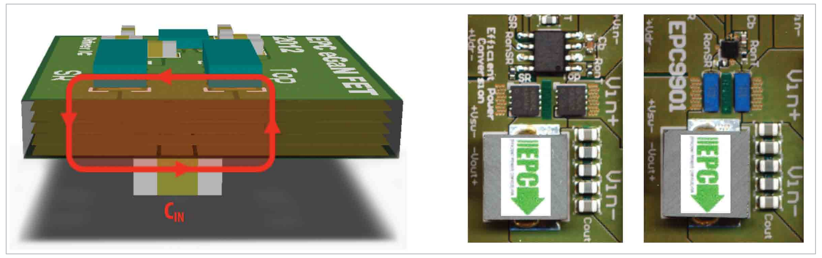

*Figure 2a* *Figure 2b* *Figure 2c*

*Figure 2: Conventional vertical power loop PCB layout (a) Side view (b) MOSFET top view (c) eGaN FET top view*

($Q_{OSS}$ + $Q_{RR}$) where $Q_{GS2}$ is the portion of $Q_{GS}$ where current is commutated [1]. FOMs are good for comparing technologies, but within a technology, scaling the die size trades switching losses against conduction losses. For low duty cycle buck applications, the low capacitance of a small device far outweighs its high $R_{DS(ON)}$ for the control switch, but the opposite is true for the rectifier switch. For each socket and a given set of operating conditions, efficiency rises, peaks at an optimum die size, then falls as die size increases. The Infineon BSZ097N04LSG was used for the MOSFET control switch and BSZ040N04LSG was used for the rectifier switch. For the eGaN FET boards, the EPC2015 was used for both control and rectifier switches. It should be noted that with the EPC2015 as the eGaN FET control switch, switching losses grossly outweigh on-state losses, and there is much room for efficiency gains from future die optimization.

The first layout is a vertical layout where the FETs were on one side of the board and input capacitors on the other. A side view of the vertical layout is shown in **figure 2a**, and the comparison of the MOSFET and eGaN FET layout is shown in **figures 2b** and **2c**. The significant layout advantage of the eGaN FET board was a smaller high frequency loop that was made possible by the smaller size of the eGaN FET and the lower package parasitics of the LGA package. The high frequency loop inductance for the eGaN FET board is estimated at 1.0 nH while the MOSFET board was estimated at 2.0 nH. It should be noted that the bulk of the high frequency loop inductance in the MOSFET design is the package inductance. In most cases, MOSFET manufacturers do not specify package inductance.

With much of the parasitic inductance being in the board, and the interleaved source and drain of the LGA package, eGaN FETs are able to take advantage of further layout optimization. A second eGaN FET layout has input capacitors placed next to the control FET with the return from the rectifier FET being brought back on the second layer for flux cancellation, reducing the high frequency DC loop inductance. Between the two eGaN FETs and below the rectifier FET are interleaved vias of switch-node and power return that match the lands of the rectifier switch. The rectifier source vias between the two FETs reduce the length of the high frequency power loop, lowering inductance. The rectifier source vias below the rectifier FET reduce resistance, thus conduction losses during freewheeling. Interleaving the power return and switch-node vias provides opposite current flow in them reducing AC conduction losses by reducing eddy and proximity effects [3]. High frequency power loop inductance is estimated to be 400 pH. This optimal layout is shown in **figure 3**.

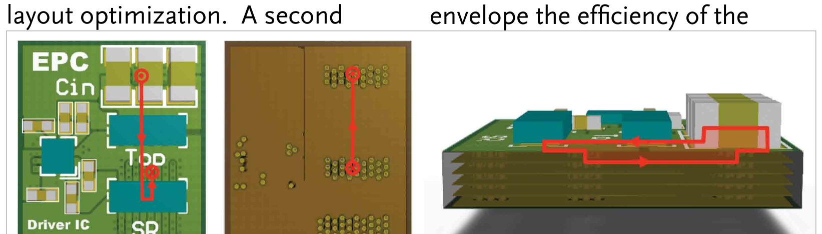


*Figure 3a* *Figure 3b* *Figure 3c*

*Figure 3: Optimal high frequency power loop with eGaN FETs (a) Top view (b) Top view of inner layer 1 (c) Side cross-sectional view*

**Results**

Efficiency results are shown in **figure 4** for the vertical layouts of the MOSFET and eGaN FET circuits along with the optimized eGaN FET circuit. The efficiencies of both eGaN FET boards completely envelope the efficiency of the MOSFET board. 20 A efficiency was increased by 2% while **4 A** efficiency was increased by over 9.5%

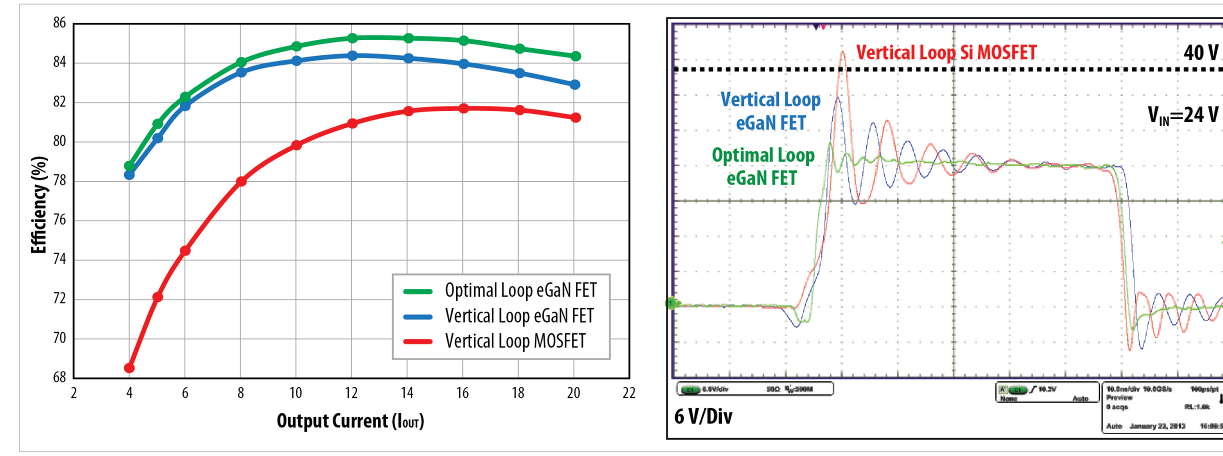


*Figure 4a* *Figure 4b*

*Figure 4: Comparison of eGaN FET vertical layout, optimal layout and MOSFET vertical layout for efficiency (a) and switch-node waveforms ($I_{OUT}$=20 A) (b) ($V_{IN}$=24 V, $V_{OUT}$=1.2 V, $F_{SW}$=1 MHz, $L_{BUCK}$ =300 nH, eGaN FETs: Control Switch: EPC2015, Synchronous Rectifier: EPC2015, MOSFETs: Control Switch: BSZ097N04LSG, Synchronous Rectifier: BSZ040N04LSG)*

High frequency power loop inductance had a dramatic effect on switch-node overshoot and ringing. The optimal layout eGaN FET board peaked just above 24 V and rang out in 10 ns, while the MOSFET board peaked over 40 V, and took half the on-state pulse time to ring out as shown in figure **4b**.

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# Space Systems need IBA too

By: David G. Morrison, Editor, How2Power.com

The intermediate bus architecture (IBA) has been a popular approach for powering commercial as well as military and aerospace applications for several years. Typically, a single isolated dc-dc converter generates an intermediate voltage bus such as 12 V, which then feeds a number of nonisolated, point-of-load converters (POLs). These POLs step down the intermediate voltage to generate the various board-level supply voltages needed in the system. This form of distributed power saves cost by limiting isolation to just one dc-dc conversion stage, rather than using isolated converters in both stages as was done previously.

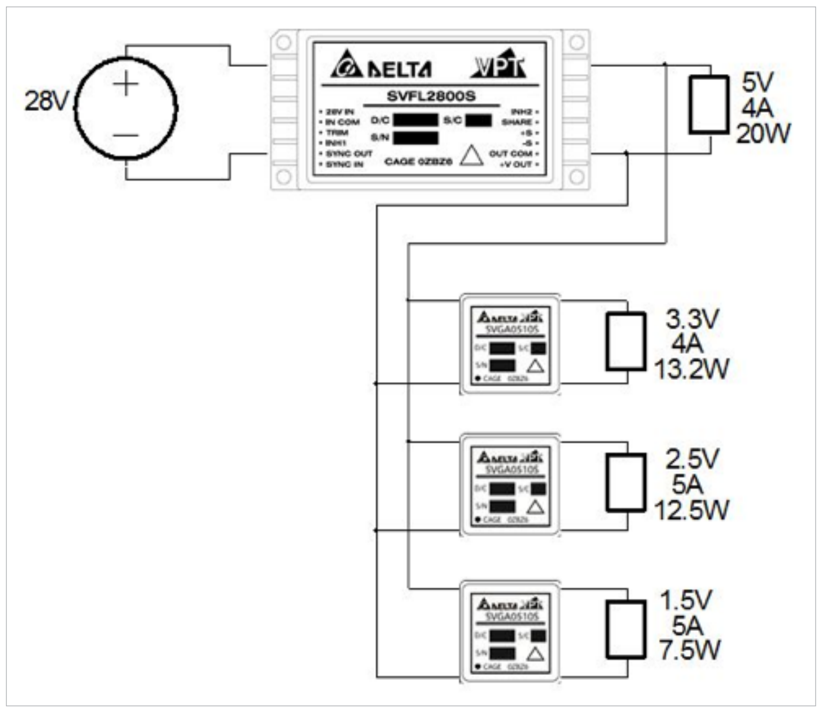


*Figure: In recent years, the arrival of more power hungry loads and the availability of space-qualified point-of-load converters have led to adoption of the intermediate bus architecture in space-based applications (Courtesy of VPT.)*

But as Leonard Leslie, manager of Space Product Engineering at VPT Inc., discusses in a recent article in How2Power Today, until a few years ago, the IBA approach was not widely applied in space-based applications. In part, this was because the digital chips (CPUs, DSPs, FPGAs, etc.) being used in space were several generations behind those used in commercial applications and their power requirements were correspondingly lower. So, instead of using POLs to generate board-level supply voltages, designers could generate those voltages using linear regulators. Given the power demands, the losses incurred in using linear regulators was tolerable. This approach also reflected the fact that linear regulators were readily available in space-grade versions, while POLs were not.

Designers might have continued to rely on linear regulators except that, as Leslie explains, the data processing chips offered for space began to catch up with the performance of their commercial counterparts. As that happened their current and power requirements rose, making the losses incurred by linear regulators unacceptable and creating a need for the more-efficient POLs. In the last few years, a select group of power module and space-electronics manufacturers have responded by providing space-grade POLs, many of which were on display at the recent NSREC 2012 conference. As a result, the intermediate bus architecture is now being applied in space applications (**see the figure**.)

As Leslie discusses in his article, the IBA offers a number of benefits for space systems, making it easier for designers to optimize the power system for efficiency, size and weight—three critical elements in any space application. He also discusses other advantages such as reduced bill-of-materials component count, greater system flexibility, and lower system cost. In addition, Leslie discusses the load requirements (regulation and ripple voltage) and input requirements (EMI, impedance interactions with the isolated converter) that influence use of the POLs. These considerations are similar to those encountered in designing power systems for non-space applications.

However, as Leslie discusses in detail, the unique environmental requirements of space (mainly the need to withstand the effects of radiation) influence the application of the IBA in unique ways. Leslie discusses the two main radiation-related criteria for space-grade power converters. One is total ionizing dose (TID) and displacement damage (DD), while the other is single event effects (SEE). Leslie explains how the various forms of radiation result in degraded performance for semiconductor devices and why the TID and DD, and SEE specifications are necessary when evaluating components for space.

There are certain radiation-induced failure modes that are specific to power conversion components and circuitry as Leslie explains in his article. He also outlines steps that can be taken to lessen a power converter's susceptibility to these failure modes through the designer's choice of device ratings, use of external capacitance, and even the selection of an intermediate bus voltage. Naturally, there will be tradeoffs. Finally, the author notes the value of MIL-PRF-38534 Class K screening for power converters to assure greater reliability.

From Leslie's discussion, it is clear that necessity has driven the application of the IBA into space systems for similar reasons it has become popular in the commercial world. But the rigors of developing and qualifying space-based power converters and systems and the requirements for extreme reliability suggest that certain aspects of the final power system design—particularly BOM costs—will look very different from those seen in commercial applications.

To read Leslie's article, see "Rad Hard Processors And Power Converters Propel Intermediate Bus Architecture Into Space Applications," in the January 2013 issue of How2Power Today, available online at www.how2power.com/newsletters.

**About the Author**

When not writing this column, David G. Morrison is busy building an exotic power electronics portal called How2Power.com. Do not visit this website if you're looking for the same old, same old. Do come here if you enjoy discovering free technical resources that may help you develop power systems, components, or tools. Also, do not visit How2Power.com if you fancy annoying pop-up ads or having to register to view all the good material. How2Power.com was designed with the engineer's convenience in mind, so it does not offer such features. For a quick musical tour of the website and its monthly newsletter, watch the videos at www.how2power.com and www.how2power.com/newsletters/.

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# Should we regulate progress?

By: Alix Paultre, Editorial Director, PSD

One of the biggest issues a design engineer must face not involved with the application itself is the regulatory environment of the market involved. In the case of most immature technology spaces, and especially in the area of "green" products, this environment is often unclear, hypocritical, and contradictory. Standards and requirements need to be clarified and codified, but where should that clarification come from? Who should be allowed to codify it?

**Why regulate?**
Regulation is viewed by some as a waste of time and effort, and that the marketplace has inherent controls and balances to prevent abuse, and companies and individuals are responsible for applying their own standards on the products they use and consume. Others believe that every facet of every aspect of everything should be controlled, regulated, organized, and inspected to protect companies and individuals from fraud, misrepresentation, poor quality, and often themselves. The reality is that neither extreme is intelligent or desirable, and that the market and society needs to agree on the areas that need to be regulated for the good of the marketplace and the society.

In the "green" space, these issues are currently being hotly debated, with aspects ranging from technology choices to infrastructure compatibility to the matter of who should be doing the regulation, manufacturers, the government, or consumers. The EPA and the Department of Energy spar over who gets to regulate energy efficiency in products, special-interest groups spar with (and within) trade associations, and manufacturers spar with one another. Should we approach the market from a national level? State-level regulation? Impose international requirements? As Einstein said, reality is determined by the point of view of the observer.

**Can you regulate the future?**
Can you truly control where, what, and how people choose to create the future? Does banning a product accelerate the abandonment of an obsolete technology, or incentives foment the adoption of the next generation of technology? Or does it work best in the context of a competitive market?

Nations are now banning the incandescent bulb (one of the last vestiges of century-old vacuum-tube technology still present today) to advance the adoption of the next thing, but who can determine that? Some argue that CFLs shouldn't even be allowed on the shelves, some push for LED as the be-all solution, and some would like us to wait and see how inorganic and organic EL tech develops in the near future. LCD didn't need any incentives to knock the CRT out of our society so quickly that most people can't even remember the brouhaha over the national HDTV standard.

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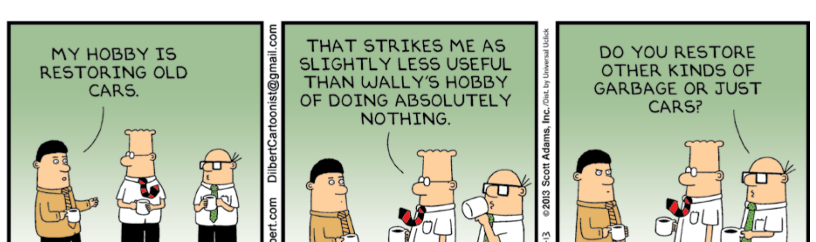

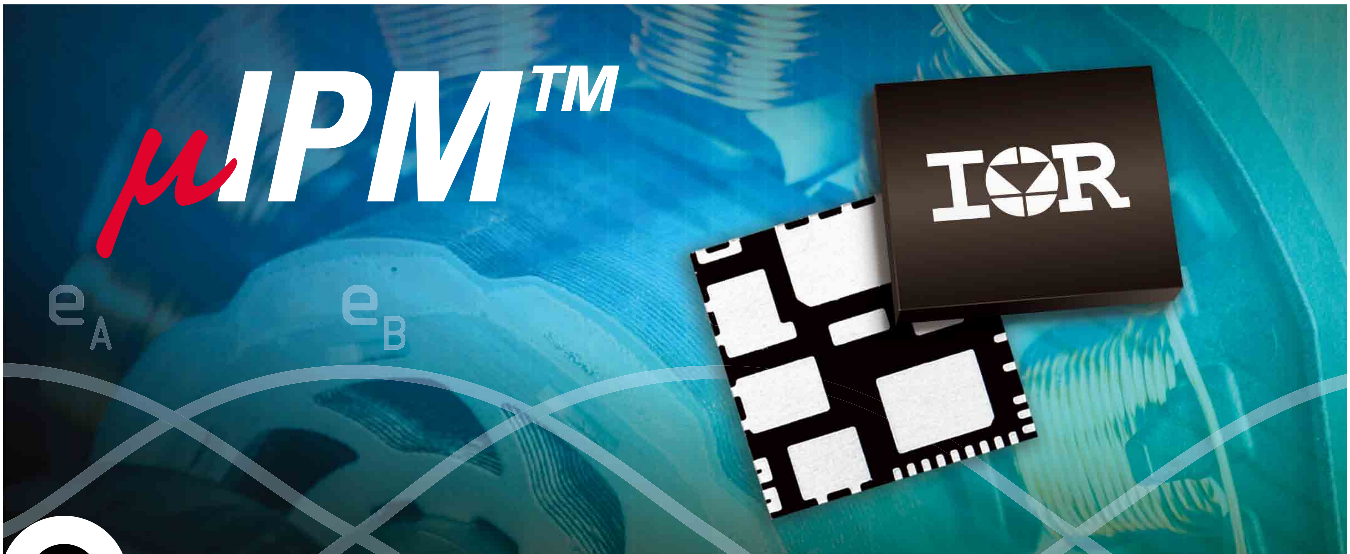


# Innovative Power Module Reduces System Size

## μIPM™ Power Modules Deliver up to 60% Smaller Footprint

**Specifications:**

| Part Number | Size (mm) | Voltage | IO (DC@ 25°C) | Motor Current** | | Motor Power VO=150/75VRMS | Topology |
|---|---|---|---|---|---|---|---|
| | | | | w/o HS | w/HS | | |
| IRSM836-024MA | 12x12 | 250V | 2A | 470mA | 550mA | 60W/72W | 3P Open Source |
| IRSM836-044MA | 12x12 | 250V | 4A | 750mA | 850mA | 95W/110W | 3P Open Source |
| IRSM836-025MA | 12x12 | 500V | 2A | 360mA | 440mA | 93W/114W | 3P Open Source |
| IRSM836-035MB | 12x12 | 500V | 3A | 420mA | 510mA | 108W/135W | 3P Common Source |
| IRSM836-035MA | 12x12 | 500V | 3A | 420mA | 510mA | 100W/130W | 3P Open Source |
| IRSM836-045MA | 12x12 | 500V | 4A | 550mA | 750mA | 145W/195W | 3P Open Source |

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- 12x12x0.9mm PQFN package offers up to 60% smaller footprint
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- Slashes assembly time and cost
- Simplifies procurement and inventory management
- Reference design kits available for quick evaluation on any 3-phase motor

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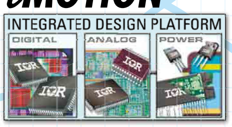


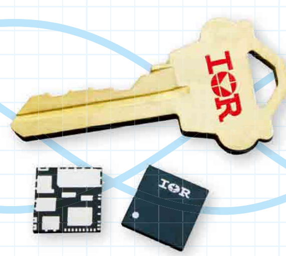


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