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- Dynamic and static power boost

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#FIMM
Reducing the Complexity of Power Systems

As more consumer electronic devices shift toward USB-C–based battery-charging methods, new architectures and products are emerging to reduce the complexity of battery-charger systems. Infineon's article is geared toward system designers investigating the incorporation of USB-C into their embedded applications, such as smart speakers, IoT hubs, home appliances, internet gateways, and power and garden tools. The purpose of the article is to provide a comprehensive overview of the USB-C PD system, casting light on the evolving system architecture designed for battery-powered applications transitioning to USB-C. USB-PD chargers are getting smaller. Various techniques have been employed to reduce their size, yet certain power components—specifically, the boost inductor, boost diode and integrated boost switch—remain stubbornly space-consuming. In this issue, we analyze a new IC, used in boost power-factor-correction topology designs, that addresses this issue. Other topics include how to prototype a power bank charger without building dedicated hardware, gallium nitride components utilized in pre-sizing a modular high-power DC/DC converter and their adoption in markets, how silicon carbide can enable next-generation solid-state circuit breakers and the case for superjunction MDmesh. Moreover, we will discuss power modules for semi-trucks’ autonomous driving and how to simulate and estimate the value of parasitics using Keysight’s PathWave Power Electronics Professional (PEPro) software tool. PEPro is a switch-mode-power-supply next-generation electromagnetic-circuit co-simulation platform that predicts the values of the parasitic inductance on the layout. The importance of developing a renewable-energy power system is directly related to addressing global climate change concerns. The effects of climate change have economic repercussions that affect diverse industries and regions. As global temperatures continue to rise and the frequency of extreme weather events increases, crucial factors like agricultural productivity, water resources and supply chains are directly impacted. We explore a report by the Los Angeles Department of Water and Power, in partnership with the National Renewable Energy Laboratory, which outlines an ambitious plan to achieve a fully renewable-energy power system by 2045. The report comprehensively addresses various factors that must be considered to accomplish this objective. Moreover, electronic waste (e-waste) disposal is becoming more important as technology advances. Electronic components, especially PCBs, that are incorrectly dumped harm the environment. However, recyclable PCBs are a new idea. Infineon Technologies will employ recyclable PCB substrates from Jiva Materials in its demo and evaluation boards, minimizing e-waste and conserving resources. This issue will examine recyclable PCBs and how Infineon’s move may increase the adoption of this innovative technology.

Yours Sincerely,
Maurizio Di Paolo Emilio
Editor-in-Chief, Power Electronics News
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Simplified Battery-Charging System for Portable Devices Using USB-C PD

Discover the capabilities of Infineon’s EZ-PD™ PMG1-B1 MCU, with enhanced features for highly integrated, low-cost and simplified USB-C–based battery-charger designs.

By Shopitham Ram, principal applications engineer for the EZ-PD™ PMG1 high-voltage microcontroller, and Ramesh Kankanala, lead principal applications engineer for the EZ-PD™ PMG1-B1 and EZ-PD™ CCG7x automotive USB-C PD and DC/DC controllers, both at Infineon Technologies

In recent years, the USB-C connector has emerged as the preferred choice for a wide range of consumer electronics, including mobile phones, laptops, tablets and PCs. The growing ubiquity of USB-C has extended its influence into a myriad of applications, ranging from smart speakers and power tools to cameras and smart home appliances. This evolution has made USB-C the primary choice for charging and data communication across various devices. In battery-operated products
like smart speakers, the USB-C port takes on a dual-role functionality, capable of recharging the device's battery through a USB-C charger while also serving as a charging point for other devices, such as phones.

Empowered by the **USB Type-C and Power Delivery (PD) 2.0 specification**, USB-C connectors can now deliver an impressive 100 W (20 V at 5 A) through the interface. The latest advancement, USB PD Specification 3.1, has further elevated USB-C power adapters, enabling them to provide 240 W (48 V at 5 A) via the Type-C connector. This standardized USB-C framework has not only fueled the adoption of USB-C as the go-to charging connector for notebooks and mobile phones but has also contributed to sustainability efforts by reducing electronic waste and promoting the reuse of USB-C power adapters.

This article targets embedded firmware engineers and system designers exploring the integration of USB-C into their embedded applications, spanning smart speakers, IoT hubs, home appliances, internet gateways, and power and garden tools. It intends to provide a comprehensive overview of the USB-C PD system, shedding light on the evolving system architecture specifically suited for battery-powered applications transitioning to USB-C. Additionally, the article offers insights into the Infineon **EZ-PD™ PMG1-B1**, an innovative, high-voltage microcontroller (MCU). It is the industry’s first high-voltage MCU that seamlessly integrates a USB-C PD controller, a buck-boost battery-charge controller and high-voltage protection circuits, leading to a reduction in overall system complexity and efficient utilization of the system bill of materials (BOM).

**TRADITIONAL BATTERY-CHARGING SYSTEM ARCHITECTURE**

Traditionally, battery-powered electronics were typically shipped with their proprietary AC/DC power adapters. These specialized chargers featured a distinctive barrel connector that frequently lacked compatibility with other adapters, rendering them unsuitable for sharing or repurposing. This practice not only hindered charger versatility but also increased the overall production costs of the product and e-waste.

These battery-charger systems typically included the following components:

- A buck-boost or a battery-charge IC to enable charging of the battery packs. These battery-charging ICs typically support various modes, such as trickle charging, pre-charging, constant-current (CC) and constant-voltage (CV), required to charge the battery packs. The battery-charging IC also supports safety timers for protection against prolonged battery charging.
- A battery management MCU to monitor and cut off charging in case the primary battery-charging IC fails.
- Sensors to monitor system temperature and battery temperature.
- Battery protection and individual cell-monitoring circuits to ensure each cell voltage doesn’t exceed safe limits.
USB-C–POWERED BATTERY-CHARGING SYSTEM ARCHITECTURE
Replacing proprietary connectors in battery-powered applications with USB-C counterparts introduces the advantage of universal charging compatibility across any USB-C adapter. Illustrated in Figure 2, the USB PD module within the battery-charger system is responsible for negotiating the USB-C PD contract with the USB-C power adapter and efficiently delivering power to the battery charger to recharge the battery pack. In scenarios where dual-role power functionality is applicable, the USB-C controller assumes the capability of not only drawing battery power but also supplying it through the USB-C connector, effectively serving as a charging hub for phones and laptops.

However, while adopting the USB-C connector eliminates the need for inbox chargers, addressing the potential tradeoffs is essential. Introducing a USB-C controller into the equation unintentionally expands both the board dimensions and the total BOM for the battery-charger system. Therefore, having an integrated solution would be ideal for reduced board size and BOM cost. Infineon's EZ-PD™ PMG1-B1 innovative component encapsulates all the highlighted blocks into a single chip. By offering a unified solution, the EZ-PD™ PMG1-B1 showcases the potential to harmonize performance, efficiency, board size and cost-effectiveness seamlessly.

EZ-PD™ PMG1-B1 HIGH-VOLTAGE MCU WITH INTEGRATED BUCK-BOOST CONTROLLERS & USB PD
EZ-PD™ PMG1-B1 is a high-voltage programmable MCU with an integrated USB-C PD block and buck-boost controller block to support battery-charging applications. It has a 32-bit Arm® Cortex®-M0 processor, 128-KB flash, 16-KB RAM and 32-KB ROM. The EZ-PD™ PMG1-B1 also supports digital blocks like PWM, timers, I²C, UART and analog blocks like 12-bit SAR ADC, integrated NFET gate drivers and more.
The USB PD block in EZ-PD™ PMG1-B1 can help negotiate up to 100 W (20 V at 5 A) power delivery contract over the USB-C connector with the USB-C power adapter. The EZ-PD™ PMG1-B1's integrated buck-boost block enables the controller to implement a two- to five-cell battery-charging system with support for various battery-charging modes, such as CC, CV, pre-charge and trickle charge.

The 12-bit SAR ADC and other high-voltage analog peripherals, such as CSA and UVOV blocks, allow the EZ-PD™ PMG1-B1 controller to monitor total battery voltage, individual battery cell voltages, total battery-charging current, battery pack temperature, battery-charger system temperature and more. This enables the integration of battery protection circuitry. The PMG1-B1's timer block allows the controller to implement battery-charging safety timers to help prevent extended battery charging due to abnormal battery conditions.

The EZ-PD™ PMG1-B1 offers a high level of integration and lower BOM cost for USB-C–based battery-charging designs. Figure 3 shows a detailed block diagram of a five-cell battery-charging system designed using the EZ-PD™ PMG1-B1 high-voltage MCU.

The EZ-PD™ PMG1-B1 MCU has a high-voltage regulator that allows the device to directly power from the $V_{BUS}$ supply (4 V to 24 V, with 40-V tolerance) on the USB-C connector. The device also has a standby/low-power regulator to power the device from the battery pack when the USB-C $V_{BUS}$ supply is not available.
Integrating these high-voltage regulators eliminates the need for an external regulator and reduces the system's cost. The lower power consumption of the standby regulators and the deep-sleep support of the EZ-PD™ PMG1-B1 MCU prevent the MCU from draining the battery pack and offer longer shelf life. In addition, the EZ-PD™ PMG1-B1's USB PD block has an internal dead battery $R_d$ that allows the device to make a power delivery contract with any USB-C adapter and charge a depleted battery.

**CRITICALITY OF BUCK-BOOST/BATTERY-CHARGER IC IN A USB-C BATTERY-CHARGING SYSTEM**

In battery-charging applications, the power conversion needs to be highly efficient for a given input and the type of battery connected. USB PD Specification 3.0–compliant USB-C adapters may provide $V_{BUS}$ voltage from 5 V to 21 V on the USB-C connector. The USB-C input $V_{BUS}$ voltage can be higher or lower than the required output voltage to charge the battery. Similarly, the characteristics of the battery charger may also vary from manufacturer to manufacturer. The battery-charger IC needs to provide a stable output voltage for the entire $V_{BUS}$ input range and is expected to charge the battery seamlessly, efficiently and, more importantly, safely for all input ranges.

Figure 4 shows an example of peak-current-mode–controlled four-switch buck-boost converter (without polarity reversal) topology. This topology can be used to step up and step down the input $V_{BUS}$ voltages. Based on the input $V_{BUS}$ voltage and required output voltage, the buck-boost converter may operate in buck-, boost- or buck-boost modes and charge the battery pack seamlessly.
The battery-charger control loop uses two transconductance amplifiers \( (g_{m_{CV}}, g_{m_{CC}}) \) to implement CC and CV modes. An external compensator network (Type 2 compensator) sets the frequency response of the CC and CV feedback loops and regulates the output voltage \( (V_{BAT}) \) or output battery current \( (I_{BAT}) \) during CV or CC mode, respectively. The battery pack voltage \( (V_{BAT}) \) is dictated by the reference voltage \( V_{REF_{CV}} \) and the configurable internal resistor divider of RU and RB. The measured amplified average battery-charging current \( cc_{ctrl} \) and reference current \( V_{REF_{CC}} \) dictates the battery pack charging current.

**BATTERY-CHARGING ALGORITHMS**

A spectrum of charging techniques comes into play to ensure prolonged battery life and optimal battery capacity utilization. These methods, including trickle charging, CC, CV and top-off charging, are meticulously selected based on the battery’s state of charge (SOC) and its prevailing temperature.

In CC mode, the charging current is constant, while in CV mode, the output voltage directed toward the battery pack is constant.

**MULTISTAGE CC-MODE CHARGING ALGORITHM**

In CC mode, a fixed current is used to charge the battery continuously. A high-charging current charges the battery faster. However, it significantly affects the lifespan of the battery. While a low charging current may provide high-capacity utilization, it takes longer to charge the battery and is inconvenient for the users. Hence, an optimum charging strategy based on the battery capacity
must be chosen to increase the charge capacity and decrease the charging periods without increasing the battery temperature or compromising the battery life.

Implementing a multistage CC battery-charging algorithm provides better utilization of the battery capacity. Once the battery voltage reaches the specified cutoff voltage, the charging current can be reduced by 40%, 20% and 6% (this percentage of current steps can be customized) of the rated current, respectively, when the terminal voltage reaches the specified cutoff voltage.

EZ-PD™ PMG1-B1 also supports a smart-charging algorithm in which the MCU calculates the input power available from the USB-C adapters, then periodically measures the battery output voltage and dynamically updates the battery-charging current. This enables maximum utilization of the available input USB-C power. Figure 5 shows an EZ-PD™ PMG1-B1–based multistage battery-charging profile of a five-cell lithium-ion battery with support for the smart-charging algorithm. Notice the battery current is periodically updated as the measured battery voltage increases.

### MIXED CC- & CV-MODE CHARGING ALGORITHM

In this method, the charging starts with CC mode, and when the battery terminal voltage reaches the maximum safe threshold value, the charging mode transfers to the CV charging method. The charging process is completed when the charging...
current goes below the cutoff threshold. CC mode helps accelerate the charging time, and CV mode influences the capacity utilization of the battery.

Mixed CC-CV charging mode provides longer battery life and greater safety. CC mode prevents overcurrent charging, and CV mode prevents overvoltage. If the battery voltage goes below a specified threshold, the charging can be resumed automatically (Figure 6).

INDIVIDUAL CELL MONITORING & BATTERY PROTECTION

Lithium-ion battery cell voltage cannot exceed 4.20 V for the safety and longevity of the battery pack. In addition to monitoring the total battery pack voltage while charging, it is also critical to monitor individual cells’ voltages and ensure the cell voltage doesn’t exceed 4.20 V. EZ-PD™ PMG1-B1’s 12-bit SAR ADC along with GPIOs enable individual cell monitoring of the battery pack. The EZ-PD™ PMG1-B1’s battery-charging algorithm can cut off charging to the battery pack if any individual cell voltages exceed 4.20 V and protect the battery pack.

The multi-purpose high-side CSA block supports CC mode for implementing the battery-charging algorithm. In addition, the CSA block monitors the battery-charging current and offers hardware-based protection against overcurrent issues on the battery pack. The CSA block can cut off the battery charging without firmware intervention in the event of detecting an overcurrent. The overcurrent threshold can be configured through EZ-PD™ PMG1-B1 firmware.

Similarly, the EZ-PD™ PMG1-B1’s UVOV block can detect any undervoltage (UV) and overvoltage (OV) conditions on the battery voltage ($V_{BAT}$) and can cut off the battery charging without firmware intervention. The threshold levels for OV and UV detection can be set independently.

POWER THROTTLING BASED ON TEMPERATURE

At lower temperatures, the internal resistances of the battery increase and the battery capacity decreases. At colder temperatures, charging the battery using reduced current is recommended to prevent the batteries from getting damaged. Similarly, charging a hot battery at full current can result in the battery catching fire. So measuring the battery temperature and modulating or terminating the battery-charging process is critical for safety as well as for the increased life of the battery.
The graph in Figure 7 shows how the battery-charging current can be modulated or terminated based on the measured battery temperature. In addition to implementing the typical CC and CV loop, the battery-charging algorithm can also incorporate the throttling of the charging currents based on measured battery temperatures.

**ROLE OF EZ-PD™ PMG1-B1’s PROGRAMMABILITY IN USB-C BATTERY-CHARGING APPLICATIONS**

The EZ-PD™ PMG1-B1 offers the software programmability of a traditional MCU. This allows the developer to use firmware and configure various battery-charging parameters as well as power delivery parameters. Below are some of the firmware-configurable features:

▶ Total number of battery cells (two to five cells)
▶ Trickle-charging and pre-charging thresholds
▶ Enable/disable individual cell monitoring
▶ Configuring individual battery cell thresholds
▶ Configuring total battery voltage and charging current
▶ Configuring thresholds for temperature monitoring
▶ Battery OV, UV, overcurrent and overtemperature protection
▶ Selecting charging algorithms (CC versus CC + CV mode)
▶ Negotiated power delivery contract voltage and current

In addition to the above features, the developers can also implement some custom features like temperature-based power throttling and communication of battery status with an external SOC over interfaces like I²C, UART, etc.

**CONCLUSION**

As more consumer electronic devices shift toward USB-C–based battery-charging methods, new architectures and products are emerging to reduce the complexity of battery-charger systems. Infineon’s EZ-PD™ PMG1-B1 is built on a novel architecture offering high integration levels. The EZ-PD™ PMG1-B1 device integrates an MCU, a USB PD block and a battery charger into a single-chip solution, effectively reducing the system’s BOM cost and complexity. Additionally, the programmability of EZ-PD™ PMG1-B1 empowers users to customize the battery-charging algorithm, while the integrated hardware protection features make it an ideal solution for battery-powered applications.

Click here to delve deeper into Infineon’s transformative USB-C high-voltage MCU technology. Get ready to embrace the future of efficient and sustainable battery charging.
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- ELI-Falkas, CTO at Wolfspeed
- Annette Clayton, CEO at Schneider Electric
- Dr. Susan Hubbard, Oak Ridge National Laboratory

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GaN Components Utilized in Pre-Sizing a Modular High-Power DC/DC Converter

By Saumitra Jagdale, contributing writer for Power Electronics News

Recent trends in engineering aircraft are shifting toward a more electric aircraft (MEA) paradigm—increasing the use of electric energy over pneumatic and hydraulic energies to power on-board systems. Implementation of MEA has some undeniable advantages, such as energy efficiency and low-cost maintenance, which are imminent to see from its increasing implementation in recent aircraft like the Airbus A380 or the Boeing 787. To incorporate the same, significant revisions to the electric power supply architecture are inevitable to ensure the best performance.

The electric power architecture is based on multiple on-board grids, both interconnected and galvanically isolated. Also, there are two network voltage levels: a 28-VDC standard low-voltage DC (LVDC) bus to power the control devices and a 270-VDC/540-VDC high-voltage DC (HVDC) bus for power actuators. Power conversion is key to the implementation of a more electric approach, outlining the quantifiable benefits of switching from a single converter based on directly adapted components to a multi-converter structure adopting the most appropriate components to achieve a given specification.

Major challenges when it comes to MEA are developing smaller and lighter electric power systems; hence, the architecture is to be centered around power density and power-to-weight ratio. According to the literature, wide-bandgap technologies can be credited to achieving up to a 2-kW/kg...
ower-to-weight ratio with the use of a combination of gallium nitride and silicon carbide components. The use of GaN components also proposes lower power losses, in turn contributing to conversion efficiency and reducing the size of the thermal management system. They can also withstand higher junction temperatures.

Designing a dual active bridge (DAB) in this case suits the contextual needs, as it further meets the requirements of galvanic isolation, high power density, high power ratings and high efficiency. Considering the use of GaN components, a modular architecture based on the series and/or parallel connection of lower-power elementary bricks is necessary (Figure 1).

**SIMULATING THE MODULAR ELECTRIC POWER ARCHITECTURE**

Rather than carrying out tedious and expensive implementations and tests to bring about technological advancements, a simulation-based design of the power electronics involved in the interconnection between LVDC and HVDC networks in MEA implementation is more convenient. The electrical power-conversion function is performed by a combination of elementary bricks. These are based on DAB technology and are controlled using a single-phase-shift control strategy. Figure 2 outlines the 11 macro-parameters of the DAB converter in the model.

The models generated also account for several losses associated with the semiconductors (the GaN components), the magnetic components and so on. Considering transistor conduction losses, reverse conduction losses during dead time, iron losses, copper losses and more are also crucial in determining the power-to-weight ratio of models, as it is the main performance factor in focus. The paper in the references walks through several equations to calculate power losses due to conduction losses, iron losses and more. These equations play a cumulative role in calculating the power-to-weight ratio.

Likewise, several design decisions were made to significantly minimize losses:

- The use of planar transformers, as they meet the requirements of modern power electronics to limit skin effect and proximity effects
- Parallel windings to reduce copper losses and current density at a low voltage
The simulated model design also made computations for mass estimation models. The generated models must pass several criteria for performance to be used in experiments—optimization is a subsequent requirement.

## INCULCATING OPTIMIZATION INTO THE MODELS

To proceed with the optimization process, adding physical constraints must be given precedence, especially considering the transformer. This process constitutes introducing coefficients and constants, which ground the equations in reality and also aid them to suit the power electronics requirements.

The optimization of the simulated model designs was conducted using a particle-swarm–optimization algorithm. The required optimization is with respect to the power-to-weight ratio. While executing the optimization algorithm, the parameters were adjusted to generate three optimal solutions and one sub-optimal solution. Among the optimal solutions, Case A used an E43 ferrite core, Case B used an E58 ferrite core and Case C used an E64 core.

Case B resulted in a promising 4.5-kW/kg power-to-weight ratio—performing twice as high as the state-of-the-art. Hence, GaN transistors can forge a path toward significant advancements in power electronics, irrespective of their association with aircraft implementations and tests. Meanwhile, Case C had a bigger core, resulting in higher low-voltage currents along with unnecessary winding capacitors, which in turn limits the switching frequency. Case A, with a smaller core, had a significantly lower low-voltage current, leading to lower copper losses but increasing the GaN driving energy and core losses.

The sub-optimal solution had a lower power density along with an additional 0.5 points of efficiency compared with Case B.

### Table 2: A table of the design parameters for the DAB converter (Source: ScienceDirect)

<table>
<thead>
<tr>
<th>Category</th>
<th>Symbol</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAB operating parameters</td>
<td>$f$</td>
<td>Switching frequency</td>
</tr>
<tr>
<td></td>
<td>$L$</td>
<td>DAB inductance value</td>
</tr>
<tr>
<td>Geometric parameters of the transformer</td>
<td>FCR</td>
<td>Ferrite Core Reference</td>
</tr>
<tr>
<td></td>
<td>$e_c$</td>
<td>Conductor thickness</td>
</tr>
<tr>
<td></td>
<td>$d_{pp}$</td>
<td>Insulator thickness between conductor of the same winding</td>
</tr>
<tr>
<td></td>
<td>$d_{ps}$</td>
<td>Insulator thickness between conductor of different winding</td>
</tr>
<tr>
<td></td>
<td>$e_0$</td>
<td>Air gap thickness</td>
</tr>
<tr>
<td></td>
<td>WIC</td>
<td>Winding Interleaving Configuration</td>
</tr>
<tr>
<td>Parameters related to the bridges</td>
<td>HVGaN</td>
<td>HV bridge GaN reference</td>
</tr>
<tr>
<td></td>
<td>LVGaN</td>
<td>LV bridge GaN reference</td>
</tr>
<tr>
<td></td>
<td>$N_1$</td>
<td>Number of transistors in parallel in the HV bridge</td>
</tr>
<tr>
<td></td>
<td>$N_2$</td>
<td>Number of transistors in parallel in the LV bridge</td>
</tr>
</tbody>
</table>
Note that there were two winding configurations suiting the scrutiny that contributed to achieving a high resonant frequency and therefore a high switching frequency.

**EXPERIMENTATION VALIDATION AND RESULT OF THE PROPOSED MODELS**

Validating the implementation hypotheses is the subsequent crucial step. For this, it must be checked that at least four GaN transistors may be driven using the same gate driver and routed with insignificant parasitic inductances and low resistive connections. Thermal management based on a single heatsink per bridge should also be validated.

The first experimental trial included:

- High-voltage and low-voltage bridges based on GaN systems and EPC components
- A DAB of 1.9 kW with a frequency of 304 kHz

It resulted in a difference of approximately 15% between the measurement and model at a frequency of 300 kHz. Such a difference is attributed to the fact that the modeling was done in 2D, while a transformer is in 3D. However, the objective to reduce the mass remains largely accomplished. The simulation-based approach, being generic and quick, can be used in examining the optimum defined regarding the evolution of the technological characteristics of the various components used in the power converter. The results of the performance index achieved here are the consequence of using the new GaN components, especially given their parallelization.

**References**


The AspenCore Guide to Gallium Nitride

This 150+ page book on Gallium Nitride (GaN) power devices provides a comprehensive look at the technology, applications, market, and future of this emerging wide-bandgap material for power electronics.
The AspenCore Guide to Silicon Carbide

Silicon Carbide (SiC), a wide-bandgap semiconductor, is driving a profound transformation of power electronics and clean energy systems. This 145-page guide offers a detailed analysis of the market trends and an in-depth discussion of key aspects of SiC power technology.
How to Prototype a Power Bank Charger Without Building Dedicated Hardware

By Diarmuid Carey, staff applications engineer for central applications at Analog Devices Inc.

Ideally, any power supply design should start with some basic proof-of-concept tests, which often involve testing an existing demo board. The demo simply takes this preexisting step (of testing single rails on the demo hardware) and expands on it to produce a working system using demo hardware. Furthermore, as this demo was needed within a relatively short timeframe, the typical development process of design, layout, build, assemble and test (plus any design iteration) was not possible, so the system was prototyped in its entirety using nothing but readily available hardware.

APPLICATION
To answer the question posed in the headline, it was necessary to choose a high-level application as a starting point to prove this was possible. This led to the power bank charging application being selected as a proof of concept. As power management is a prerequisite for every electronic project, any other application could have been selected.
A power bank charger is a common-enough application, which most consumers have encountered and used. For example, many travelers carry one to ensure their phone remains charged over a long journey. A power bank is essentially a battery pack (capacity varies depending on the price and range required), with one or more USB-A ports as well as a USB-C input port to charge it. It is possible, of course, to layer additional complexity on top of this basic functionality—for example, the addition of a wireless charging pad or an input to allow solar charging of the bank for outdoor enthusiasts.

For this application, the option to charge the battery via solar or to charge via a DC input from a standard 12-V AC-to-DC wall wart was included. The outputs included some basic USB-A charging ports (two in total), producing 5 V for use with mobile phones and a range of USB-powered electronics.

**HARDWARE SELECTION**

*Power source selection: LTC4416*

In this example, the design will support two input power sources (a solar panel and an AC-to-DC wall wart, which is just a simple AC-to-DC power supply). For this reason, a device called a power path prioritizer is required not only to intelligently switch between the available sources, depending on which was available, but to manage the situation where they both were available by assigning priority to one source over the other. A simple version of this implementation can be achieved by using some simple diodes—commonly connecting the two cathodes of the diodes and connecting the anodes to their respective sources.

Unfortunately, this configuration is lossy due to the diode drop inherent in a typical diode (approximately 0.6 V), but it also doesn’t allow for any clever selection criteria to be implemented—for example, priority selection. It simply allows the higher potential input to pass through.

Here, **LTC4416** comes into play: It not only replaces the lossy diodes with PFETs, which are far more efficient, but allows for priority to be assigned. In this application, priority will always be assigned to the wall wart. This allows the design to take advantage of the available power (and higher current)

<table>
<thead>
<tr>
<th>E1</th>
<th>E2</th>
<th>Operation Mode</th>
<th>$I_{SDPFT1}$</th>
<th>$I_{SDPFT2}$</th>
</tr>
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<tbody>
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<td>0</td>
<td>Load sharing</td>
<td>Enabled</td>
<td>Enabled</td>
</tr>
<tr>
<td>1</td>
<td>Sense</td>
<td>V1 is less than V2</td>
<td>Enabled</td>
<td></td>
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<tr>
<td>Sense</td>
<td>0</td>
<td>V1 is greater than V2</td>
<td></td>
<td>Enabled</td>
</tr>
<tr>
<td>0</td>
<td>X</td>
<td>Channel 1 disabled</td>
<td>Disabled</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>1</td>
<td>Channel 2 disabled</td>
<td></td>
<td>Disabled</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Both channels disabled</td>
<td>Disabled</td>
<td>Disabled</td>
</tr>
</tbody>
</table>

*Table 1: Modes of operation from the LTC4416 datasheet*
when it is available. This device is exceptionally flexible, with many operational modes possible depending on the design requirements. Table 1 (sourced from the LTC4416 datasheet) displays the modes of operation.

**Switching buck battery charger: LTC4162-L**

For the battery charger, the **LTC4162-L** was selected due to its wide input voltage range (up to 35 V) and 3.2-A charging capability, as well as the integrated FET design, which results in a small solution size. This is a commonly used, full-featured charger IC, which has great application flexibility, as it comes in many battery chemistry variants, such as LiFePO₄, Li-ion and lead acid, as well as an I²C interface to allow the user to extract telemetry information.

It was selected for this application not only because of its aforementioned flexibility on the input and battery voltage but also because of its integrated nature, which helps to keep the solution size to a minimum. Another useful feature is maximum power-point tracking (MPPT): If solar is one of the possible input sources for your design, MPPT is a must to ensure the design extracts as much available power as possible. The LTC4162 also has a built-in power path control that is useful in this application when the input source is removed, allowing the provision of the battery voltage to the output terminals for use downstream.

**USB charging solution: CN0509**

The board selected to provide the USB charging voltage for the connected device is from ADI’s *Circuits from the Lab* collection of reference designs and solutions. Typically, a single device is shown...
on an evaluation board to allow evaluation of that specific device. Circuits from the Lab boards, however, are more solution-focused implementations that make use of several ADI products from different product portfolios to solve a particular system requirement.

The **CN0509** was designed to be a wide-input-voltage–range, dual USB power charger. It was developed for use in emergencies like natural disasters or extended power outages. An example power source that many would have available to them is a car battery. This board can be powered by a car battery to provide two 5-V ports, which are isolated from the primary voltage for safety. There is a range of alternative power sources that you may have available, from stacks of loose batteries to motors, to act as a simple generator. The CN0509 has a wide input voltage range, so it will be able to run from any supply in the range of 5 V to 100 V. For all of the above reasons, this makes it an ideal candidate to pair with the existing boards to provide the USB charging outputs required for the power bank charger.

Reverse-polarity protection is included to protect the circuit from an incorrectly connected supply, and an isolated flyback converter is utilized to isolate the charger outputs from the input source—this is particularly useful if a −48-V communication backup supply is used as a power source. This can result in a phone being charged to −48 V and creating a hazardous situation. Isolated conversion prevents this from occurring. Another note here is that the CN0509 board is quite small; much of this is attributed to the highly efficient ICs selected and the no-opto flyback **LT8302**. A key differentiation is that the flyback converter LT8302 does not need an isolated optical feedback path.

There are two USB ports on this board: One is a standard USB port (without D+/D– connected), and the other port has a DCP controller to monitor the USB data line voltages so that it can...
enable fast charging and provide 5 V at 2 A max. Achieving this higher level of charge current is dependent on the input voltage utilized. Based on the performance graph shown in Figure 4, 12 V is optimal.

POWER SOURCES

The primary power source selected was a 60-W AC-to-DC 12-V adapter. This served as one input to the LTC4416 demo board, and a relatively small solar panel was purchased to provide an alternative input source. Because this project was to be used at an indoor event and there was never going to be sufficient lighting available to provide a reasonable level of available power to run from solar, this feature was included simply to demonstrate the capability and functionality of the power path prioritizer.

This design was developed to be a power bank, and as such, it would require a battery pack to act as the storage element. Shipping restrictions in relation to batteries are prohibitive. The demo was developed specifically so that a generic battery pack could be bought and inserted to run the demo on its arrival. Based on this limitation, a rechargeable 2× series cell Li-ion battery pack generating a nominal 7.4 V with a 2,600-mAh capacity was selected to run the demo for the event. It is worth noting that a larger-capacity battery could easily be installed here if required.

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![Figure 4: A CN0509 max charge current vs. $V_{in}$](image)

![Figure 5: The power bank charger application tree](image)
DEMO BUILD
From a build perspective, the hardware was standard, so no electrical modifications were required beyond some adjustments of the LTC4416 thresholds to ensure the correct priority for the input power sources. To make it more visually appealing for the event, the boards were mounted on a simple black Perspex sheet using some standard metal standoffs.

The charge current that was being provided for the evening was monitored by a simple USB meter. This device visually represented how much current was available to charge the attendee’s phones.

HOW IT PERFORMED
The demo performed its core function effectively: It comfortably charged the battery pack from two alternative sources, the handover between sources was managed well by the power path...
prioritizer and the CN0509 nicely provided a charge to the connected USB devices. This power bank has another useful feature that many power bank chargers do not have: the ability to simultaneously charge the battery pack and charge the connected USB device. For example, my power bank, which many would consider reasonably high-end, will not charge the phone and the bank itself at the same time, which is a frustrating limitation.

The charge current to the USB port is limited by the capability of the LTC4162, with its internal FET design providing a max of 3.2 A—the bulk of the current is sent to the battery during charging. The remaining current can be used through the USB charger ports.

Any time the input power source is removed, the power path FET on the LTC4162 demo board ensures that the battery power is redirected to the output port and hence maintains power to the CN0509 and USB ports. The available charge current in this mode drops, as per the graph in Figure 4, as the input source to the CN0509 is now the battery voltage, which is a nominal 7.4 V.

NEXT STEPS

Once the application has been proven to work using some simple, readily available demo boards, the next reasonable step is to develop a product prototype that takes learnings from the initial prototype work and integrates this into the end solution. Part of this would be to modify the existing schematics from the boards used to remove the superfluous items (test points, connectors, etc.). The user could then get started on the PCB development, which would then show off the importance and usability of the resources we provide with each of our devices. For example, the optimized demo board layout is a freely available resource provided for each of our devices. While the demo board generally looks to be quite large, this is simply to aid the testability and usability of the device.

Closer inspection of the board layout reveals that the IC for which the board was developed and the enabling circuitry (resistors, capacitors, inductor, etc.) are all designed into as small a space as possible to allow customers to bring this into their own layout. This will then provide confidence to the customer, as they know that this is a tested design, which they can verify on the bench before building their own version.

For the end application, a larger-capacity battery with a higher voltage would help to optimize the amount of charge current provided to the USB ports.
The CN0509 is a fantastic design and fulfills its requirements perfectly; however, for this application, a more slimmed-down design could be utilized to reduce the overall battery bank cost. For example, the **LTC7103** and input polarity-protection circuitry would not be necessary for this design, and the isolated flyback could be powered directly from the output of the LTC4162 (either 12 V from the AC-to-DC wall wart or the battery voltage once mains power has been removed).

**CONCLUSION**

You can certainly prototype a power bank charger, or any other power supply design for that matter, using some readily available hardware and simple power sources. This highlights that using available demo board hardware can quickly provide a proof of concept for potential projects without spending much on development. Furthermore, this relatively small but valuable step will provide the user with confidence before committing to a more integrated design. Another point worth reiterating is that power supply design and, more specifically, the layout of a power design can be challenging, so it is worth utilizing the resources available to reduce the overall development time.

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Power Electronics Simulation Accelerates SMPS Development

By Stefano Lovati, contributing writer for Power Electronics News

In power-conversion circuits, such as converters, inverters and switching power supplies, the operating frequency has increased considerably, thanks in part to the introduction of wide-bandgap components like silicon carbide and gallium nitride.

While this allows for signals with very short rise and fall times and consequent improvement in efficiency, it has also increased the effect of printed-circuit-board (PCB) parasitics brought about by the high di/dt value. The number of devices on a PCB has also increased in density due to advancements in semiconductor technology. This rise in density and decreased available space has made parasitics more important when designing PCBs. Inductive, capacitive or resistive parasitics are all possible.
Because parasitic elements can increase power losses, reduce efficiency and impact the stability of the converter, it is important to consider them in power-converter design to ensure efficient and reliable operation.

This article will discuss how to simulate and estimate the value of parasitics using Keysight’s PathWave Power Electronics Professional (PEPro) software tool. PEPro is a switch-mode-power-supply next-generation electromagnetic (EM)-circuit co-simulation platform that predicts the values of the parasitic inductance on the layout.

Three significant applications will be presented below in which the simulation provided by the PEPro tool yielded significant results in assessing the effects of parasitics, contributing to their reduction through appropriate layout design.

**T-TYPE INVERTER**

The T-type is a multilevel inverter similar to the three-level neutral-point-clamped inverter but with fewer components. The multi-level inverter design is primarily concerned with high-power conversion. The multi-level inverter provides a low device stress level, tiny output voltage harmonic and reduced switching losses compared with the conventional two-level inverter. Applications requiring high voltage and power frequently use this architecture.

Initially introduced to avoid the high-voltage stress of H-bridge circuits, the T-type topology can be used in both single-phase and three-phase configurations and is suitable for applications in which high efficiency and reduced components are key factors. Due to its high current gain, high power, low conduction loss and quick switching speed, the T-type topology is becoming increasingly popular.

The schematic of the three-level T-type inverter used for reference is shown in Figure 1. Starting from the schematic, the first step is to develop the relevant layout design. Once we have the layout file, we can execute the simulation to determine how parasitic inductance impacts the inverter’s performance.

![Figure 1: Schematic of a three-level T-type inverter (Source: Keysight Technologies)](https://example.com/schematic.png)
Setup panel and then running the EMI simulation. After that, we can use Generate Sub Circuit with EMI results in the transient simulation. The flow chart describing the actions required to perform the post-layout simulation is shown in Figure 2.

Comparing the pre-layout and post-layout simulations (see Figure 3), we can clearly see a difference in the current, switching noise and switching imbalance because of parasitic resistances and inductances.

Figure 2: Steps performed in the post-layout simulation (Source: Keysight Technologies)

Figure 3: Transient simulation results compared between pre- and post-layout (Source: Keysight Technologies)
It should be noted that, in schematic-level–only simulation, this information is not available. If the post-layout simulation exhibits some unwanted behavior, the designers can modify the layout and execute the post-layout simulation again until the desired layout design is obtained.

For instance, after modifying the connections to some transistors in the layout, we can analyze the changes occurring in parasitic resistances and inductances in the gate and power loop running the simulation. PEPro simulates the effect of both individual inductance/resistance and mutual inductance.

After running the simulation on the modified layout, the value of parasitics in the gate loop is available in the S-parameters under Results. These include the simulated parasitics’ individual resistance and inductance versus frequency. The obtained parasitics results can then be used to rerun the transient simulation.

Figure 4a shows the circuit with the power-loop module, including EMI results, while Figure 4b shows the drain current of each transistor. In this case, we can observe a current imbalance phenomenon, demonstrating that both individual and mutual inductance significantly impact the current imbalance.

![Figure 4](image1.png)

*Figure 4: (a) Three-level T-type circuit including the estimated EMI results; (b) simulation results of current versus time (Source: Keysight Technologies)*

![Figure 5](image2.png)

*Figure 5: Schematic of the three-level/three-phase Vienna rectifier (Source: Keysight Technologies)*
VIENNA RECTIFIER

This use case shows how parametric EM simulation helps to optimize the layout of an electric-vehicle on-board charger (OBC). The OBC typically has two power stages: a DC/DC stage for output voltage/current regulation and an AC/DC stage for voltage rectification and power-factor correction (PFC). In our example, the PFC stage will be based on the classic Vienna rectifier topology (Figure 5).

SiC devices have been used in the rectifier to enable larger blocking voltages, switching frequencies and junction temperatures. Additionally, passive component size and cost can be significantly reduced through higher switching frequencies, ranging from 70 to 200 kHz. However, due to unwanted stray inductance created by these non-negligible parasitic PCB layout effects, the performance of the entire converter is hampered and the device may even be damaged.

A four-layer PCB has provided significant improvements in this area, reducing the ringing and the over-/undershoot behavior caused by different inductive paths on the gate-source connections of the three phases. Further board layout optimization in the gate and source connections can be achieved with the PathWave Advanced Design System (ADS) simulation suite, a commonly used EDA tool for circuit simulation and EM extraction.

The approach uses EM simulation of the PCB layout and the co-simulation of the EM-extracted model with the circuit components. The process is built on a toolchain that combines circuit simulators and EM solvers in a single design environment.

The required simulations are run in a straightforward three-step process while establishing the ports on the relevant nets. The energy (voltage, current) is automatically exchanged between the domains of the SPICE-based circuit simulator and the EM-based extraction tool for S-parameter creation via these ports, which connect to the circuit simulation parts.

![Figure 6: Simulation results: (a) input current; (b) ground bounces; (c) oscillations for Q3 and Q4 (Source: Keysight Technologies)](image-url)
The simulated circuit is fed by three sinusoidal sources \( V_{RMS} = 220 \text{ V} \) operating at 50 Hz, in a classical three-phase \( \Delta \) configuration. To provide the expected 800-V rectified voltage across the 60-\( \Omega \) load with a three-phase sinusoidal current waveform in accordance with a power factor close to 1, control signals for the SiC switches are generated separately and applied to the three phases of the circuit with the proper relative phase and duty cycle.

The simulator tool automatically reconnects the electrical models of the circuit components with the S-parameter model of the board while modeling the effects related to the presence of stray inductances and other coupling effects on the board with the corresponding S-parameter matrix. The simulation results for the four-layer PCB are shown in Figure 6.

To reduce the stray inductance as much as possible, the original four-layer PCB design has been modified, widening and coupling the traces and merging the ground nets. These improvements, summarized in Figure 7, reduce roughly 30% of the stray inductance (from approximately 22 to 15 nH).

**SIMULATION OF WOLFSPEED’S REFERENCE DESIGN**

As described in an application note, the PathWave ADS workspace can also be used to simulate a virtual version of a physical reference design from Wolfspeed (Model CRD-HB12N-J1), based on the C3M0032120J1 SiC power transistors series from Wolfspeed.

The CRD-HB12N-J1 is a half-bridge with two transistors connected in parallel on each side. To operate, the half-bridge needs to be included in an external circuit. Two kinds of circuits are used. First, a straightforward boost converter needs a DC source, an inductor, a capacitor and a load. The second option consists of a DC source, an inductor and a clamped inductive switching network.

The virtual prototype is more cost-effective for exploring the design space and undertaking a “what if” analysis than a series of costly and time-consuming “solder and see” hardware prototypes. The reference design can get close to meeting your needs, but not exactly. However, if you change it,
there's a chance that you'll introduce undesirable side effects like high-voltage spikes and EMI issues. You gain insight into how to alter it while reducing negative consequences from the virtual prototype.

Consider swapping out some of the components for cheaper, lower-performing ones. As an illustration, consider a capacitor with a lower self-resonant frequency and larger series inductance or resistance. Rerouting PCB traces is the next thing to try, particularly those in the switched loop with the high-di/dt trapezoidal waveforms. You can then view the impact on the ringing and EMI.

Virtual prototypes are complementary to real prototypes. Although physical prototypes are the industry standard for compliance and measured qualities, they have some limitations:
- It's difficult to insert a measurement probe onto inner nodes, making it difficult to detect what is happening inside.
- They are expensive and time-consuming to design, manufacture and measure.
- They are prone to failure.

CONCLUSION

Keysight's PathWave ADS and PEPro simulation tools emphasize the value of post-layout simulation anticipating layout parasitics and how they will affect a power-conversion circuit's overall performance. As a result, time to market is accelerated. With the help of Keysight's simulation tools, designers can accomplish their objectives more quickly.

References


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Silicon Never Fails to Surprise: The Case for Superjunction MDmesh

By Filippo Di Giovanni, director of strategic marketing, innovation and key programs for the power transistor subgroup at STMicroelectronics

In the last few years, the semiconductor power market has experienced increasing interest in adopting wide-bandgap (WBG) power devices like silicon carbide and gallium nitride. Especially in SiC, STMicroelectronics has raced to undisputed global leadership via early entry and customer success in electric vehicles. Moreover, the need for increasingly efficient products from the industrial sector will continue to propel the market. Interestingly, while much of the industry’s excitement has focused on success in these emerging technologies, ST has continued to innovate and invest in advanced, high-voltage, silicon-based power MOSFETs using its high-voltage (i.e., above 250 V) proprietary technology called MDmesh, where “MD” stands for “multiple drain” and “mesh” refers to its specific horizontal structure.
Many reasons support continued investments in silicon. First, power electronics require a complete set of solutions, and silicon still meets specific requirements, owing to its very good balance of cost to performance, which is crucial to many high-volume applications. Second, by continuing to improve silicon, we can design and implement novel technology processes that could eventually be adapted and moved to WBG products. The superjunction concept is one of these improved processes.

Market research firm Yole Group forecasts that the total market for discrete power devices (transistors and rectifiers), excluding power modules, will reach a value of $17.1 billion in 2026, up from $14.1 billion in 2022, with silicon MOSFETs (including low voltage) accounting for 53%. Omdia, another market research firm, forecasts that silicon MOSFETs, in units, will still represent the vast majority of the market for power supplies for servers and data centers (see Figure 1). From its analysis, Omdia predicts that two out of three systems will use silicon power devices in 2026.

ST’s proprietary MDmesh technology is based on the superjunction concept, which enables higher blocking voltages without increasing the thickness and resistivity of the epitaxial layer in the way this is done on conventional planar technologies. By maintaining epitaxial-layer thickness and resistivity, superjunction devices improve a device’s specific on-resistance. This figure of merit is defined as the product of on-resistance multiplied by the chip area. In practice, better on-resistance is achieved by “extending” the MOSFET’s p-body region through the realization of pillars with successive epitaxy steps, as Figure 2 shows schematically.

Despite the attention SiC has drawn and its market success, ST’s family of MDmesh MOSFETs is among the most successful STPOWER products ever introduced. In fact, by the end of 2023, ST will have produced and shipped more than 9.5 billion units over the last 23 years.

One measure of the market’s demand and the technology’s success is that through more than 20 years...
of production, ST has been able to introduce multiple refinements, resulting in a range of technology iterations and a dedicated series to match all requirements. These requirements could be for hard-switching, soft-switching or even new topology circuits. Moreover, the refinements have allowed the company to optimize for critical parameters, such as dV/dt (both static and dynamic), di/dt, body-diode recovery’s reverse-recovery time and reverse-recovery charge. With the range of optimizations, system designers can reach their goals for improved efficiency, reliable operation and high-volume manufacturing capability.

In addition, the MDmesh lineup covers a wide range of voltages and package options—600 V, 650 V, 800 V and 1,700 V—and the devices come in both a standard version and enhanced body-diode variants.

One way to appreciate the MDmesh capabilities is to look at the latest-generation devices, which were introduced in 2022. This M9 technology iteration enables efficiency maximization at both low and high power. As Figure 3 shows, ST achieved this efficiency by drastically reducing power dissipation with respect to the previous (M5) generation.

Note that the reduction of losses also includes those associated with output

Figure 2: The superjunction concept and vertical pillars are built from successive epitaxy steps.

Figure 3: The M9 generation improves low- and high-power efficiency.
capacitance \( (C_{\text{oss}}) \). \( C_{\text{oss}} \) losses depend upon the capacitance’s non-linearity, which in turn leads to a hysteresis effect because charging and discharging follow two very different paths. Such a phenomenon is illustrated conceptually in Figure 4. We’ve been able to better balance charging and discharging in M9 to significantly reduce the imbalance.

MDmesh products address a large spectrum of applications, including servers; data centers; adapters for mobile phones, PCs and tablets; renewables; energy systems; charging stations; DC/DC converters (including EVs); and power supplies as diverse as those used in 5G base stations. In fact, MDmesh products can be found in all equipment we encounter daily. They have also proven suitable for indoor and outdoor LED lighting applications, in stadiums, in shopping malls and for street lighting.

With its increased power density, M9 can be a good match for newer applications, including light fidelity (Li-Fi), which transmits data using luminous waves emitted by LED lamps rather than radio waves. Li-Fi platforms are very promising as an alternative to conventional Wi-Fi, as they offer greater bandwidth, higher efficiency, more secure operation against cyberattacks and higher transmission speed.
Optimizing DCM PFC to Provide High Efficiency Across Load and Shrink Power Components

*By Andrew Smith, director of technical outreach at Power Integrations*

USB-PD chargers are getting smaller. Various techniques have been employed to reduce their size, yet certain power components—specifically, the boost inductor, boost diode and integrated boost switch—remain stubbornly space-consuming. A new IC, used in boost power-factor-correction (PFC) topology designs, addresses this issue.

Typical boost PFC circuits fall into one of three categories, depending on how current flows in the boost inductor during each switching cycle: discontinuous-conduction mode (DCM), critical mode (CrM, sometimes referred to as boundary mode) and continuous-conduction mode (CCM). The basic circuit is the same for each mode of operation: A boost inductor stores energy when a power switch is turned on, and this is transferred to the output via a boost diode when the boost MOSFET turns off. Input
current tracks the input voltage sine wave, ensuring a good power factor. Distortion during zero-voltage crossing at the end of each line cycle and the effect of EMI filter capacitance (at light load) become more pronounced at the high line and distort the current wave shape, increasing total harmonic distortion.

DCM is fixed-frequency conversion, and the control engine allows the boost-inductor forward current to fall to zero each time the boost MOSFET is turned off. After a delay, the power MOSFET turns on and the current again begins to rise in the boost inductor. The dead time, where no inductor current is flowing, means that the boost diode commutates when zero current is flowing and can be a low-cost type without an exotic reverse-recovery characteristic. Control is easy to implement, being driven by a simple feedback loop from the output stage. The average switch current is high, necessitating larger and larger boost MOSFETs as power increases. For this reason, conventional DCM boost PFC circuits are typically limited to power supplies delivering less than 150 W. DCM boost circuits must also create a slightly higher minimum boost voltage than CrM or CCM boost PFC circuits (Figure 1).

CrM boost conversion differs from DCM in that the boost MOSFET is turned on as soon as the boost inductor current reaches zero. In this manner, the boost diode avoids any losses imposed by reverse recovery (again, a simple diode can be used). CrM has a lower RMS inductor current than a DCM, making it the preferred choice for higher power conversion, up to approximately 250 W (although the implementation of interleaved CrM techniques has increased this power limitation). As switch cycles are governed by the ramp and decay of the inductor current across the line cycle, CrM is a variable-frequency PFC implementation, with minimum frequency at the peak of the line voltage each cycle (Figure 2). The controller function is more complex than in DCM, as inductor current must be monitored to trigger switching.

The third typical implementation of boost PFC is CCM (Figure 3). In this technique, the boost MOSFET is turned on before the inductor current has fallen to zero. This leads to lower average switch and inductor currents, but the boost diode commutates while the current is flowing, leading to significant reverse-recovery losses, which manifest themselves as heat in the boost MOSFET.
To mitigate this problem, low-reverse-recovery diodes are typically used in CCM circuits, which add a significant cost burden to the design. Because the average switch and inductor current is lower than for the other approaches, CCM becomes increasingly attractive for higher-power systems, in which the lower switch cost can compensate for the more expensive boost diode. CCM switching is typically fixed-frequency.

The largest component in the boost PFC circuit is the boost inductor. The boost inductance must store sufficient energy to power the PFC circuit across the line voltage. The worst-case condition that controls minimum boost inductance is the lowest input line voltage and maximum load. Boost inductance is inversely proportional to switching frequency (Figure 4).
Increasing the switching frequency to reduce inductor size is an option, but increased switching losses and EMI tend to limit the switching frequency range to less than 150 kHz. To avoid the audible noise range, the minimum switching frequency is also limited to about 20 kHz. As noted above, CrM designs tend to approach the minimum frequency at a phase angle of \( \pi/2 \), where the line voltage is maximum (Figure 5). This is also the defining point for minimum boost inductance. DCM circuits with fixed frequency fare slightly better, as they have a higher frequency at this set point. While pushing up the switching frequency of a DCM boost PFC circuit to limit the inductor size is attractive (especially given the fact that winding wire must be thicker to compensate for higher average current), switching losses tend to compound with the topology’s higher conduction losses, limiting switching frequency to less than 50 kHz. CCM circuits are more flexible (especially variable-frequency CCM circuits, such as those used in the HiperPFS-4 ICs from Power Integrations) but are typically cost-effective only at a higher power.

**VARIABLE-FREQUENCY DCM CONTROL AND THE ADVENT OF POWIGaN TECHNOLOGY**

Gallium nitride–based power switches have changed the way we consider switching in power supplies. The low \( R_{\text{DS(on)}} \) of GaN devices enables DCM boost PFCs to operate at higher power levels without reducing efficiency due to conduction loss (or imposed switching loss if the switch is made larger to compensate).

Designers must also factor in a variable-frequency control engine (amp-second on-time and volt-second off-time control), plus valley switching of the power switch, so DCM becomes an attractive option for boost PFC. By adjusting the operation of the DCM control engine so that it just approaches CrM at the peak of low-line operation (full load), optimum performance can be achieved.
We will discuss in a separate article the control approach that enables spread-spectrum switching for reduced EMI and frequency sliding to increase efficiency at light load, as well as valley switching for reduced turn-on switching loss. However, it is worth taking a moment to consider the effect of variable frequency on the largest PFC component: the boost inductor.

The equation in Figure 6 shows the calculation for minimum boost inductance and is calculated at the low line. For now, we will look at the impact of variable switching frequency on inductor size. Ideally, the frequency should be high at the peak of the sine wave to minimize the boost inductor size. Unfortunately, the control algorithm in conventional CrM control forces switching frequency down at the peak of the sine wave (π/2). This is because the switch current required from the boost circuit is maximum at that point, and with the finite slope of current change (defined by the boost inductance), the frequency must decrease to allow sufficient time for boost-inductor current ramp and relaxation. With the variable-frequency DCM approach, peak frequency is reached at π/2.

The difference in switching frequency has a significant impact on inductance. In the example shown (Figure 7), the DCM approach reduces inductance by more than 50%, allowing the use of a significantly smaller inductor with fewer turns. It is not uncommon for CrM designs to operate at approximately 20 kHz (minimum frequency) at π/2 90 VAC and full load, whereas a variable-frequency DCM engine will operate at 80 kHz under similar conditions (220-W load). This would reduce boost inductance by two-thirds.

The benefit of this approach can be seen in the new HiperPFS-5 family of ICs from Power Integrations. The highly integrated PFC switcher IC dramatically reduces component count and simplifies design, while the variable-frequency DCM control engine employs...
valley switching and a low-\(R_{\text{DS(on)}}\) 750-V PowiGaN FET to achieve more than 98% efficiency at 250 W. Frequency sliding means that efficiency is flat above a 20% load. The addition of a power-factor–enhancement circuit, which compensates for filter components at a light load, ensures that PF is greater than 0.96 above a 20% load.

This circuit technique employed by Power Integrations’ HiperPFS-5 family results in a PFC stage that uses a very small and low-cost boost inductor, simple boost diode and integrated boost switch. The new family is ideal for high-power USB PD chargers, tool chargers and LCD TV/monitor applications. The high PF at light load and flat efficiency across the load range also makes the family ideal for PC 80 Plus Platinum and Titanium power supplies.

Figure 8: HiperPFS-5 variable-frequency DCM converter IC family from Power Integrations—very low component count and high efficiency across the load
How Will LA Achieve a 100% Renewable-Energy Power System by 2045?

The report assists city stakeholders in establishing long-term policy objectives toward achieving a clean and sustainable energy power system.

By Abhishek Jadhav, contributing writer for Power Electronics News

The significance of developing a renewable-energy power system is directly associated with addressing climate change issues around the globe. The consequences of climate change have economic implications, which impact diverse sectors and regions. As global temperatures continue to rise and extreme weather events become more prevalent, crucial elements like agricultural productivity, water resources and supply chains are directly affected.
Through a shift toward clean energy sources and moving away from fossil fuels, there can be a significant reduction in greenhouse gas (GHG) emissions. Stakeholders have started to believe in a future where renewable energy takes the lead and guarantees not only sustainability and resilience but also prosperity for generations to come.

There is a need for cities to prioritize the planning of their power systems to ensure a sustainable future in the fight against climate change, emissions reduction and the promotion of environmental responsibility. One city that has taken significant steps in this direction is Los Angeles.

This article explores a report by the Los Angeles Department of Water and Power, in partnership with the National Renewable Energy Laboratory (NREL), which outlines an ambitious plan to achieve a fully renewable-energy power system by 2045. The report comprehensively addresses various factors that must be considered to accomplish this objective.

**WHAT IS THE LA100 PROJECT?**

The Los Angeles 100% Renewable Energy Study (LA100) was conducted to assist city stakeholders in establishing long-term policy objectives through a thorough understanding of feasibility and cost benefits.

The report primarily focuses on the considerations necessary to achieve 100% renewable energy, excluding biofuels, by 2030, as well as the associated costs and GHG emissions, while minimizing the expenses of deep decarbonization. It is important to note that the report does not make definitive predictions about future outcomes; rather, it offers policy recommendations aimed at aiding the city in attaining its goal.

The study aims to provide insights into various aspects related to the transition toward a renewable-energy future. It addresses key concerns around potential shifts in electricity demand, the necessary upgrades to grid infrastructure and the reliability of renewable technologies during extreme events.

**ASSESSMENT OF ELECTRICITY DEMAND IN THE FUTURE**

The assessment of customer choices and their impact on electricity demand is a crucial aspect of the LA100.
The moderate projection takes into account improvements in energy efficiency, both above the standard code requirements, and moderate growth in electricity demand. This growth is primarily driven by the increasing adoption of electric vehicles and electric-powered consumer products like stoves.

It is important to note that while the moderate projection indicates the least change in electricity demand compared with the present scenario, it should not be mistaken for “business as usual.” Instead, it envisions significant shifts in consumer behavior and technological advancements.

The forecasts show that approximately 1 million light-duty EVs will be on the roads of Los Angeles by 2045. Additionally, there will be greater utilization of electric and heat-pump technologies in the building sector, highlighting the city’s commitment to sustainable-energy practices.

**DOES EV CHARGING INFRASTRUCTURE RESPOND TO ELECTRICITY DEMAND?**

To optimize the supply of electricity to meet future demand, the report explores various strategies. Among these strategies, one approach involves establishing solar charging (EVs) at workplaces. By encouraging the adoption of workplace charging and providing incentives for its utilization, EV charging can be synchronized with peak solar energy generation. This helps in reducing the strain on the grid during periods of high electricity demand.

While the potential of demand response is evident, the exact extent to which it can be achieved remains highly uncertain. There are various factors that contribute to this uncertainty, including infrastructure buildout, the precise technical capabilities required, and human behavior and preferences.

**HOW DID LA100 MODEL GHG EMISSIONS?**

Within the LA100 study, the assessment of GHG emissions in the power sector was conducted, with a focus on two scopes: combustion-only CO₂ emissions and lifecycle GHG emissions.
NREL calculated the lifecycle GHG emissions associated with electricity generation in the LA100 study. These lifecycle emissions include CO$_2$ along with other greenhouse gases, such as methane, nitrous oxide and sulfur hexafluoride.

In addition to analyzing emissions from the power sector, the study also considers emissions from non-power sectors. This includes residential, commercial and transportation sectors, such as emissions from buildings and vehicles. By doing this, the report provides a comprehensive understanding of the overall GHG emissions associated with the energy system in Los Angeles.

These findings can inform decision-makers and stakeholders in developing strategies and policies that effectively reduce GHG emissions and mitigate climate change in the pursuit of a more sustainable and environmentally friendly energy landscape in Los Angeles.

KEY INSIGHTS FROM THE LA100 REPORT

A significant insight from the study is the anticipated substantial growth in rooftop solar installations. It is estimated that the city will have a rooftop solar-generation capacity of about 3–4 GW by the end of 2045.

The Los Angeles Department of Water and Power may also deploy an additional 300–1,000 MW of non-rooftop, in-basin solar installations. These solar energy sources will play a crucial role in meeting the rising electricity demand and transitioning toward a cleaner and more sustainable energy mix.

The study also highlights the positive impacts of the overall electrification of vehicles and buildings on air quality and public health. By reducing reliance on fossil fuels and transitioning to EVs and buildings, the city can experience significant improvements in air quality, leading to numerous associated health benefits for its residents.

References

Self-Driving Semi-Trucks Increase Safety, Efficiency

By Maurizio Di Paolo Emilio, editor-in-chief of Power Electronics News

The future of goods transportation is being transformed by self-driving technology developed by Kodiak Robotics. Founded in 2018, the company has been working toward developing innovative solutions that help businesses transport goods more efficiently and safely.

Kodiak Robotics has developed self-driving systems for semi-trucks (Figure 1), enabling them to operate safely on highways without requiring a human driver. The company uses various technologies, including radar, LiDAR and artificial intelligence, to develop cutting-edge autonomous systems.

Kodiak is trying to spread the adoption of self-driving technology, which it believes will ultimately save lives and enhance the quality of life of truck drivers. There is an ongoing shortage of qualified truck drivers today. The average American truck driver is about 48 years old, and for long-haul truckers, the average age is even higher. Fewer people are choosing trucking as a career because of the long, fatiguing hours on the road and the pressure to deliver. Kodiak’s vision is to bring relief to drivers and redirect the industry onto a better path.
The self-driving technology, known as the kodiakDriver, is designed to detect potential obstacles and respond appropriately by slowing down, changing lanes, nudging within a lane or stopping to prevent accidents.

Kodiak’s highly modular fifth-generation truck now includes even fewer required modifications and touchpoints. This enables a more cost-effective integration into trucks, which marks a significant step toward the commercial deployment of Kodiak self-driving technology.

**KODIAK’S SENSORPODS RETROFITTED FOR FLEETS**

The self-driving solution from Kodiak has a modular hardware system called the Kodiak SensorPod that incorporates all of the sensors required to “see” its surroundings using the truck’s conventional mirror-mount locations. The modular architecture of the pods makes it possible to install them in a matter of minutes without requiring specialists to set up the equipment and calibrate the sensor network.

According to Jamie Hoffacker, Kodiak’s vice president of hardware, the computing system, networking and power distribution have been modularized, which makes integration and servicing easier, as components can be swapped out as necessary, thus maximizing uptime. This modular approach simplifies the integration of the system into the truck, making it easier to manage when the trucks are incorporated into a customer’s fleet.

“Kodiak’s fifth-generation autonomous truck has an increased number of sensors for added redundancy,” Hoffacker said. “The sensors that were previously located in the rooftop ‘unibrow’ were relocated to the SensorPods on the easy-to-reach side-mounted mirrors, eliminating the need to access the roof for sensor maintenance. The fifth-generation truck also has more GPU processing power, central processing power, [and] system redundancy [as well as] reduced power consumption.”

Kodiak has reduced the electrical power requirements while improving the system’s processing power. The company rebuilt the high-performance computer entirely, adding a newer generation...
of processing chips that are more efficient and powerful than the last. Power consumption has been cut in half in a new system using power modules, limiting cooling demand and increasing efficiency.

Kodiak’s proprietary SensorPods are pre-calibrated, pre-built hardware enclosures that replace the truck’s stock side-view mirrors. Roads are designed around a human driver’s line of sight. The SensorPods, located at the same height as a driver, offer a better dual vantage point, as they provide visibility on either side of the truck as opposed to the single vantage point above the cab. In the event of sensor damage, such as a rock or other piece of debris damaging a sensor, redundant sensors are onboard.

“If one sensor is damaged or blocked by an object, the system will still have visibility from the other side,” Hoffacker said. “This ultimately maximizes road safety and improves perception.”

Furthermore, an on-the-fly replacement of a SensorPod can be performed in as little as 10 minutes. The SensorPod houses multiple sensors and can be completely removed and easily replaced while on the road by a mechanic without specialized training, maximizing the time the vehicle is utilized and, ultimately, customers’ revenue generation.

**RIGOROUSLY ROAD-TESTED TECHNOLOGY ENSURES SAFETY**

The system’s robustness has been assessed with tests performed under various real-world and lab conditions. Key components have been designed to the ASIL-D standard, the highest automotive standard for safety and reliability. Moreover, the main connector for data and power in Kodiak’s SensorPods and compute system is designed for use in aviation, aerospace and military applications. The increased robustness of the hardware system is another step forward for Kodiak’s deployment readiness and unrelenting diligence to ensure safety.

Kodiak has been performing autonomous freight deliveries for IKEA in Texas since August 2022. It runs seven days a week between a Baytown distribution center and a Frisco IKEA store. Other collaborations include Pilot Company and Werner Enterprises. In March 2023, Kodiak and Forward announced they are running three weekly autonomous round-trips between Dallas and Atlanta 24 hours a day, six days a week.

Additionally, the U.S. Department of Defense (DoD) awarded Kodiak a $49.9 million, 24-month contract in December 2022 to assist with automating future U.S. Army ground vehicles intended for reconnaissance, surveillance and other high-risk tasks.

**HIGHLY RELIABLE VICOR POWER MODULES USED FOR ‘SEEING’ SENSORS**

The kodiakDriver solution has been implemented using power modules developed by Vicor.
“Driving down energy usage and reducing the size of Kodiak’s subsystems is essential to producing a commercial product,” Hoffacker said. “Vicor modules provide high-efficiency DC/DC conversion, enabling Kodiak to maintain a small module size and reduce cooling demands.”

Vicor power modules support the kodiakDriver’s sensors that require 12-, 24- and 48-V power supply buses. Figure 2 shows the Vicor BCM6123 (voltage bus converter), an array of PRM buck/boost regulators and VTM current multipliers. All power modules deliver reliable and highly efficient power conversion in small packages.

According to Kodiak, Vicor’s BCMs are key elements in providing isolation with a very accurate voltage ratio and high power density. Moreover, high-frequency conversion using the unique planar packaging of Vicor power modules minimizes power losses while converting many thousands of watts. This allows for smaller packing, minimal airflow/heatsink requirements and the ability to operate in higher ambient conditions.

A vast array of information across the Kodiak system is available on one CAN bus isolated from the vehicle CAN bus. The power supply, for instance, has approximately 40 individually controllable outputs. Each output has on/off control, current and voltage monitoring, control over current thresholds and status monitoring. The CAN bus improves noise immunity due to its differential inputs while allowing for many elements on the bus.

“Our system is extremely complicated, and the multi-kilowatt power conversion involves about 40 controllable outputs, all microprocessor-/CAN-controlled,” Hoffacker said. “The overall challenge was to fit the power conversion and control into one 2U rack enclosure with all interconnects, heatsinking and cooling.”

Moreover, the control circuit must work in the presence of noise generated by the power conversion. The power-dense conversion allowed the power section to be individualized in small volumes to help manage high-frequency interference. Also, the high-frequency switching made it possible to apply filtering where necessary.

Figure 2: To support its mission-critical sensor needs, Kodiak currently uses several highly reliable Vicor power modules. (Source: Vicor Corporation)
How SiC Can Enable Next-Gen Solid-State Circuit Breakers

By Sravan Vanaparthy, senior director of the industrial solutions business unit for the power solutions group at onsemi

The performance benefits that silicon carbide devices are bringing to electric vehicles and solar photovoltaic applications are well-known. However, the material advantages of SiC can potentially be exploited in other applications, and circuit protection has been proposed as one such area. This article reviews developments in this field, including the merits of mechanical protection versus solid-state circuit breakers (SSCBs) implemented with different semiconductor devices. We will also discuss why SiC will become an increasingly attractive option for SSCBs.

PROTECTING ELECTRICAL INFRASTRUCTURE & EQUIPMENT

Electrical transmission and distribution systems and sensitive equipment require protection against extended overload and transient short-circuit conditions. With electrical systems and EVs using increasingly higher voltages, the maximum potential fault currents are higher than ever. Protection against these high-current faults requires ultra-fast AC and DC circuit breakers. While mechanical circuit breakers have traditionally been the most popular choice for this application, the increasingly
demanding operating requirements have made SSCBs more popular. They have several advantages over mechanical approaches:

▶ Robustness and reliability: Mechanical circuit breakers contain moving parts, which make them fragile. This means they can be easily broken or accidentally trip due to movement and are subject to wear and tear each time they are reset over the course of their lifetime. In contrast, because SSCBs contain no moving parts, they are more robust and much less likely to suffer accidental damage, enabling them to be used repeatedly over thousands of cycles.

▶ Temperature flexibility: The operating temperature of mechanical breakers depends on the material used in their construction and limits the operating temperature. The operating temperature of SSCBs is higher than that of mechanical breakers and is settable.

▶ Remote configuration: Once tripped, a person must reset a mechanical breaker manually, which can be both time-consuming and costly, especially when scaled across multiple installations, and it may also have safety implications. SSCBs can be reset remotely using either a wired or wireless connection.

▶ Faster switching and no arcs: When a mechanical breaker is switched, arcing and voltage fluctuations large enough to damage load equipment can occur. The effects of these inductive voltage spikes and capacitive inrush currents can be protected against using soft-start methods in SSCBs, with much faster switching, in the order of a few microseconds, if a fault occurs.

▶ Flexible current rating: Mechanical circuit breakers have a fixed current rating, whereas current ratings are programmable for SSCBs.

▶ Reduced size and cost: Compared with mechanical breakers, SSCBs reduce weight, are significantly lighter and take up less space.

LIMITATIONS OF EXISTING SSCBs

While SSCBs have advantages over mechanical breakers, they have some disadvantages, including limited voltage/current ratings, higher conduction losses and being more expensive. SSCBs are commonly based on TRIACs (silicon-controlled rectifiers) for AC applications or standard planar MOSFETs for DC systems. The TRIACs or MOSFETs implement the switching function, while optically isolated drivers act as the controlling element. However, high-current MOSFET-based SSCBs require heatsinks at high output currents, meaning they cannot realize the same power density levels as mechanical circuit breakers.

Similarly, heatsinks are also required for SSCBs implemented using insulated-gate bipolar transistors (IGBTs), where saturation voltage causes excessive power loss for currents exceeding a few tens of amps. For example, at 500 A, a voltage drop of 2 V across an IGBT would dissipate 1,000 W. For this amount of power, a MOSFET would require an on-resistance of approximately 4 mΩ.
resistance level is not currently achievable with single devices with voltage ratings now heading for 800 V (and beyond) in EVs. While this figure could theoretically be realized by connecting devices in parallel, such an approach would substantially increase solution size and cost, even more so where bidirectional current flow must be accommodated.

**USING SiC POWER MODULES TO REALIZE NEXT-GEN SSCBs**

A SiC die can be up to 10× smaller than its silicon equivalent for the same rated voltage and on-resistance. Furthermore, SiC devices can switch at least 100× faster and operate at peak temperatures more than twice that of silicon. At the same time, its superior thermal conductivity makes it more robust at high power levels. Onsemi has exploited these properties in its range of EliteSiC power modules with on-resistance values as low as 1.7 mΩ for 1,200-V devices. These modules integrate between two and six SiC MOSFETs in a single package.

Sintered die technology (which joins two individual dies inside a package) offers reliable product performance even at high power levels. This device’s fast-switching behavior and high thermal conductivity allow it to quickly and safely “trip” (open-circuit) an end application if a fault occurs, stopping the current from flowing until normal operating conditions are restored. Modules like this show how it is increasingly possible to integrate multiple SiC MOSFET devices into a single package to deliver the low on-resistance values and small form factors required for practical circuit breaker applications. Furthermore, onsemi offers EliteSiC MOSFETs and power modules, which withstand voltage ranging from 650 V up to 1,700 V, meaning they can also be adapted for SSCBs in single- and three-phase domestic, commercial and industrial applications. Onsemi’s vertically integrated SiC supply chain offers near-zero–defect products, which undergo exhaustive reliability testing by SSCB manufacturers.

Figure 2 shows the implementation of an SSCB in a module with multiple 1,200-V SiC dies with multiple switches in parallel in a back-to-back configuration to achieve the lowest on-resistance and optimized thermal dissipation. Fully integrated modules (Figure 3) with optimized pin position and layout will help reduce parasites and improve switching performance and fault response times.
Onsemi offers a wide portfolio of SiC modules with 650 V, 1,200 V and 1,700 V rated with modules with and without a baseplate, based on the end-application requirements and efficiency needs.

**SiC & SSCBs WILL CO-EVOLVE**

Mechanical circuit breakers have low power losses and higher power density and are currently less expensive than SSCBs. Still, they are prone to wear and tear from repeated use and require costly manual maintenance associated with resetting or replacement. The demand for circuit breakers and SiC devices will continue to grow in line with increasing EV adoption, making this wide-bandgap technology increasingly cost-competitive and increasing its attractiveness for use in SSCB solutions. As SiC process technology advances and the resistance of standalone SiC MOSFETs falls further, eventually reaching comparable levels to mechanical circuit breakers, power losses will become even less of an issue. Providing the benefits of fast switching, no arcing and significant cost savings through zero maintenance, SSCBs constructed from SiC-based devices will inevitably become the norm.
The State of GaN Adoption

By Alex Lidow, CEO and co-founder of Efficient Power Conversion (EPC)

What are the factors impacting gallium nitride’s adoption across a wide range of power management applications? In this article, we will explore the feedback that EPC has received from customers we have visited over the last 13 years that the company has been in volume production. Hundreds and hundreds of customers have both adopted EPC’s GaN devices and given feedback as to what difficulties they have had along the way:

▶ Will the tiny GaN devices perform in circuits as well as larger silicon MOSFETs?
▶ How easy is it to use a device that’s 10× smaller than the MOSFET it replaces?
▶ Are the devices reliable?
▶ Does GaN cost more?

Let’s first look at where GaN is used today. The pie chart in Figure 1 shows a breakdown of EPC’s revenues in 2022 by market segment. As you can see, the largest segment is space. Over 100,000 GaN units were sent up into space between low Earth orbit and geosynchronous orbit in 2022. In 2023, we expect over 200,000 units to be sent into space.

The second-largest segment is automotive and e-mobility, another very demanding application. The third most utilized segment is enterprise computing—usually very demanding, particularly at the high end. And the fastest-growing application is solar, in which changes in topology for residential solar installations are driving rapid growth.
**SMALLER SIZE, BETTER PERFORMANCE**

Figure 2 shows a comparison of the EPC2619 FET against a benchmark silicon device that is 8× larger in size and 30% lower in $R_{DS(on)}$. Despite these factors, the efficiency of the GaN device is two percentage points higher than the MOSFET—a 40% lower power loss!

**EASE OF USE**

EPC has recently introduced a complete family of power devices in PQFN packages that reduce sensitivity to handling without degrading thermal performance. There is also a line of integrated circuits from EPC that eliminate the problems of layout and parasitic inductance that are amplified by the high switching speed of GaN compared with silicon.

The EPC website hosts the Power Bench set of design tools that help designers get the design working the first time with minimal cost. Included in the Power Bench are tools for selecting the correct component, a cross-reference that allows a designer to compare cost and power loss against similarly rated MOSFETs, and a thermal design assistant that helps create a thermal system that squeezes the maximum performance out of the GaN design.
RELIABILITY
GaN is a wide-bandgap semiconductor and consequently has a tighter chemical bond between the gallium and the nitrogen atoms than there is between silicon atoms in a silicon device. That has led to devices that are smaller, more rugged, more reliable and less sensitive to thermal effects.

The mass adoption of GaN in satellites mentioned earlier is one example of demonstrated reliability. Satellite designers are notorious for being very conservative with new technologies. GaN devices have been in space for several years after going through millions of hours of testing and trials. Automotive designers are also very conservative. GaN devices have proved their efficiency but also their reliability in automotive applications and have been on vehicles for more than eight years.

COST
There is still an outdated belief that GaN is more expensive than silicon, which is simply not true. To dispel this myth, in 2023, EPC set up a booth at both APEC and PCIM Europe challenging engineers to bring their MOSFET part number so we could compare prices against equivalent GaN devices. Here are the results: Of the 154 people who took the challenge, 65% found that EPC’s prices were lower, 12% picked parts that were out of EPC’s product range and in only 23% of the cases was the EPC price higher.

CONCLUSION
GaN device adoption is paced by customers’ perceptions and myths. These myths are mostly based on older and earlier generations of GaN technology but are still ringing in designers’ ears.

All of that is quickly disappearing, and the early adopters are the ones who have a distinct advantage over the late adopters. When technology changes, those that do not adapt find themselves in a position behind their competition.
Recyclable PCBs Drive Pathway Toward E-Waste Reduction

By Stefano Lovati, contributing writer for Power Electronics News

In a world where technology is advancing swiftly, the disposal of electronic waste (e-waste) is a growing concern. The impact of improperly discarded electronic components, especially printed-circuit boards (PCBs), on the environment cannot be ignored. However, a significant innovation has emerged in recent years: recyclable PCBs. Jiva Materials, a company that has developed an innovative recyclable substrate for PCBs, is among the pioneers in this field.

Recently, Infineon Technologies announced it will use recyclable PCB substrates from Jiva Materials in its demo and evaluation boards, thus reducing e-waste and helping preserve valuable resources. In this article, we will investigate the concept of recyclable PCBs and how Infineon’s decision could pave the way to wider adoption of this revolutionary technology.
THE RISE OF RECYCLABLE SUBSTRATES

PCBs serve as the backbone of any modern electronic device. Providing a platform for connecting various electronic components, they allow devices, from smartphones to satellites, to operate, ensuring electrical and mechanical reliability over time. Nevertheless, conventional PCBs comprise non-recyclable materials like fiberglass, copper and solder.

Due to the discharge of toxic substances into the soil and water, improper disposal of PCBs poses a significant environmental threat. Lead, mercury and cadmium can leach into the environment, threatening human health and ecosystems. This has intensified the pressing need for environmentally friendly alternatives in electronics.

**Jiva Materials**, a U.K.-based company primarily focused on sustainability and environmentally friendly solutions, was founded by a team of scientists and engineers with expertise in materials science, chemistry and electronics. Their collective vision is to revolutionize the electronics industry by introducing recyclable and eco-friendly alternatives to conventional PCB substrates.

Jiva Materials’ innovative PCB substrate, named Soluboard, is fully recyclable. Its innovation resides in using a patent-protected, flexible, durable and environmentally friendly material. This substrate, comprised of a mixture of polymers and natural materials (Figure 1), offers an alternative to the conventional non-recyclable substrates currently used in PCB production.

Soluboard is made from a plant-based material, specifically natural fibers, with unique properties. The key advantage of Soluboard is its ability to be fully recycled. Unlike traditional PCB materials that end up as e-waste, Soluboard is designed to break down completely through a dissolution process. This means that when it reaches the end of its lifecycle, it can be dissolved safely, allowing for the recovery of valuable resources and minimizing waste.

*Figure 1: Jiva Materials’ recyclable PCB (Source: Infineon Technologies)*

**Design**
The Soluboard material exhibits excellent thermal and electrical properties, making it suitable for various electronic applications. Moreover, Jiva Materials' recyclable PCB substrates are compatible with existing manufacturing and assembly processes, meeting performance standards while addressing environmental concerns.

PARTNERSHIP WITH INFINEON

By partnering with electronics manufacturers, Jiva Materials aims to accelerate the transition to a more sustainable electronics industry that prioritizes recyclability and resource efficiency without sacrificing functionality.

The prospects for PCB recycling are positive. As the environmental impact of e-waste becomes increasingly apparent, the demand for sustainable alternatives increases. In addition to reducing the environmental impact of the electronics industry, the development and adoption of recyclable substrates will encourage innovation and entrepreneurship in sustainable manufacturing practices.

Taking up this challenge, Infineon Technologies has announced another important step toward a greener future: introducing the Soluboard recyclable and biodegradable PCB substrate based on natural fibers and a halogen-free polymer.

The Soluboard PCB substrate is composed entirely of natural fibers, with a much smaller carbon footprint than traditional glass-based materials. Moreover, its organic structure is enclosed in a non-toxic polymer that dissolves when immersed in hot water, leaving only compostable organic material. This eliminates PCB waste and enables the recovery and recycling of electronic components soldered to the board (Figure 2). By utilizing Soluboard for its demo and evaluation boards, Infineon is making a significant contribution to testing environmentally friendly designs in the electronics industry.

According to Infineon, the company is also conducting extensive research on the reusability of discrete power devices at the end of their service life. It would be an additional significant move toward promoting a circular economy in the electronics industry. Currently, Infineon uses biodegradable material to reduce the carbon footprint of demo and evaluation boards; however, the company is also investigating the possibility of using the material for all boards to make the electronics industry more environmentally friendly.

Infineon is following the “Green Deal” agenda of the European Commission, which seeks to achieve carbon neutrality by 2050 by mainstreaming circularity and accelerating the greening of the EU economy. Additionally, the company is committed to collecting and recycling Infineon-manufactured electronic products following the EU Directive on Waste Electrical and Electronic Equipment (WEEE).
According to Jiva Materials, adopting a water-based recycling process could result in greater metal recovery yields. Additionally, replacing FR-4 PCB materials with Soluboard would result in a 60% decrease in carbon emissions; more specifically, 10.5 kg of carbon and 620 grams of plastic can be saved per square meter of PCB.

As Soluboard grows in popularity and economies of scale are realized, Jiva Materials anticipates its price will become more competitive, further promoting its use in the industry. Soluboard represents an important step toward reducing electronic debris and conserving precious resources. Due to its wholly recyclable nature and superior performance characteristics, it can revolutionize the PCB industry and contribute to a more environmentally conscious future.

Infineon has created three distinct demo boards utilizing Soluboard technology, and the company intends to expand its offerings in the coming years. More than 500 units are already used to demonstrate the company's portfolio of power discretes, including a board with components designed for refrigerator applications. The company plans to guide the reuse and recycling of power semiconductors removed from Soluboard based on the results of ongoing stress tests, which could substantially extend the lifespan of the electronic components.

CONCLUSION
Recyclable PCBs represent a promising solution to the growing problem of e-waste. By replacing non-recyclable materials with sustainable alternatives, recyclable substrates offer a pathway toward reducing e-waste and preserving valuable resources. Developing and adopting recyclable PCBs requires collaboration, research and continued innovation. As the world seeks sustainable solutions to address the challenges of e-waste, Infineon's decision to adopt Jiva Materials' recyclable PCB substrates on a wide selection of its demo boards paves the way for a more environmentally conscious future.
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Silanna Semiconductor has introduced an evaluation board that enables engineers to rapidly develop and evaluate 100 W end-to-end fast charging applications based on the company’s CO2 Smart Power™ family of wide-voltage, high-frequency point-of-load converters.

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On July 25, the EU Council approved the Chips Act, the final step in the decision-making process. This Act aims to improve Europe’s semiconductor ecosystem and industrial base...

Decarbonization Opens Pathway to a Sustainable Future

Decarbonization is a crucial global initiative that aims to reduce greenhouse gas (GHG) emissions to mitigate climate change and transition to a sustainable, low-carbon...

U of Arkansas to Build Ground-breaking SiC Research Facility

With $18 million from the National Science Foundation (NSF) and additional support from the Army Research Laboratory, the University of Arkansas has broken ground on a national silicon carbide...
Getting Started with Transformers

Transformers are widely used to efficiently transfer both power and data in switching power supplies, MOSFET gate drivers, and isolation circuits.

The Fundamentals of Power Inductors

Understanding the fundamentals of power inductors is critical for both newer engineers and savvy veterans as they attempt to obtain performance data critical to their design.

Challenges in the Development of Next-Generation Motor Control Systems

Many of today’s motor control systems are implemented by programming motor control algorithms on the MCU. However, due to the diversification of needs, control algorithms are becoming more and more complicated, and it is required to realize not only motor control but also communication and control of the entire system with one MCU.

How to Design a Simple, Uninterruptible Power Supply with Supercapacitors

How can you more easily ensure a continuous, reliable power supply in power-critical applications? In many applications, it is important for the supply voltage to be continuously available no matter what the circumstances. This isn’t always easy to ensure.

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