One Size Fits All: DC/DC Converter Modules for a Broad Range of Applications
Efficient Power Solutions for a Wide Range of Applications

In the realm of DC/DC power modules, the trend has been away from specialization and toward a “generalist” strategy. This means that the power modules no longer require a singular distinguishing feature for use in a specific application but rather have a variety of features that make them desirable for a wide range of applications. Timur Uludag, senior technical marketing manager at Würth Elektronik, looks at the individual requirements and gives an overview of how a DC/DC power module can fulfill the main requirements. Monolithic GaN integration has matured to the point that complex circuits like a half-bridge gate driver with various features, such as cross-conduction protection, can now be realized. These complete circuits are packaged into a single and simple-to-use component. This issue will also cover DC-to-DC and BLDC motor drive application examples that benefit from monolithic half-bridge integration. As the market forecasts a steady growth in sales of electric vehicles in the next decade, several government initiatives toward climate change also deal with discontinuing fuel-based vehicles. The growth of the EV is powered by electric rechargeable batteries, the basic structure for using clean and renewable energy. Producing EV powertrain batteries has proven to be environmentally costly. The raw materials used in making these batteries are lithium and its variants. This issue explores the workings of Li-ion batteries. Moreover, to meet the demands of these highly capable and efficient EV charging designs, the industry offers a broad product portfolio of active and passive electronic devices specifically tailored to EV charging applications. In particular, silicon carbide solutions, along with supporting gate drivers, have yielded a strong competitive advantage in terms of price and performance. Other topics are wireless-power–transfer systems, battery management systems, characterization of GaN FETs, high-voltage electroporation, a new power-switching technology that, compared with conventional power switches like SCRs, IGBTs and MOSFETs, should offer significant performance improvements. Semiconductor power switches play a critical role in enabling the efficient and clean conversion of power in a variety of applications. From electric vehicles to renewable-energy generation and energy storage, these components are crucial for achieving high efficiency and low emissions in the transition to a greener future.

Yours Sincerely,
Maurizio Di Paolo Emilio
Editor-in-Chief, Power Electronics News
One Size Fits All: DC/DC Converter Modules for a Broad Range of Applications

Various applications have different requirements in terms of input voltage range, switching behavior, high efficiency and power sequencing. Advanced DC/DC power modules must cope with these requirements.

By Timur Uludag, senior technical marketing manager at Würth Elektronik eiSos

The trend in the field of DC/DC power modules has been moving away from specialization and toward a “generalist” approach. This means that the power modules no longer have just one standout feature that they need for use in a specific application but instead have a bouquet of features, making them appealing for a wide range of applications.

Battery-powered applications like wearables and portable devices require a highly efficient power supply to ensure long battery life. The internal battery is supplied by a DC/DC power module that generates 3.6 V to charge the battery out of the 5 V.

Oscilloscopes need analog-to-digital converters (ADCs) as an essential part of measuring the voltages and converting them to a digital value. The 5 V for the ADC is generated with a power module that is supplied from the internal 12-V DC bus of the oscilloscope.

Control units for warehouse logistics are directly connected to a 24-V DC bus. They must be robust against transients that are always present on the supply bus.

Each of the applications described has a specific requirement for the supplying DC/DC converter. This article looks at the individual requirements and gives an overview of how a DC/DC power module can fulfill these requirements.

Figure 1 shows a typical variety of applications for non-isolated miniaturized DC/DC converter power modules in different environments. The power module in a camera system for security purposes is supplied by 5 V. The DC/DC module generates then the needed 3.3 V for the image processor IC. The current consumption is time-dependent; the system needs energy only when a picture is taken.
Considering the main requirements for the DC/DC converter of the described applications, these can be summarized into the following four categories:

- Wide input voltage range
- Adaptive switching behavior
- High efficiency
- Power sequencing

**WIDE INPUT VOLTAGE RANGE**

The input voltage range of the described applications extends from a 5-V point-of-load (PoL) supply via a 12-V intermediate voltage, generated in the device itself for a direct connection to the 24-V DC bus. Each rail voltage has its own tolerance range. If one were to use a separate DC/DC converter for each rail voltage, the respective design would have to be conceived, configured, tested, checked for EMI conformity, built and logistically handled.

The VDLM series 171013801, 171023801 and 171033801 (Figure 2) come with an input voltage range from 3.5 to 38 V. This makes the power modules suitable to cover all common voltage rails.

**ADAPTIVE SWITCHING BEHAVIOR**

Battery-powered applications like portable devices do not always operate under full-load conditions. For example, a measurement application has a higher power demand during measurement and a lower power demand between measurements.

Two load states are very common:

- Light load, in which the application operates in idle or standby mode (reduced energy consumption)
- Full load, in which the application operates under nominal conditions (normal energy consumption)

What would be the best switching behavior for each load condition? If the two characteristics mentioned are related to a DC/DC power module, that means little or no switching takes place at light loads and switching is responsible for most of the losses. In order to realize this, adaptive switching behavior is needed, i.e., two modes with different switching behavior and a system intelligent enough to transition between modes based on the load demands.

In Figure 3 (left), we can see the “typical” behavior that we expect from standard buck converters operating in pulse-width-modulation (PWM) mode. A variable pulse width will be generated while the switching frequency remains fixed. $T_s$ is the same for all cycles. PWM mode is widely used, and this mode is present in most industrial power supplies. This mode is satisfactory for these types of applications, as they work in heavy load conditions for the majority of their operating lifetime.

However, applications like sensors have a different load behavior. Here, the light-load condition is the predominant operating situation. Therefore, the switching behavior must be adapted to perform optimally during this load situation. With pulse-frequency-modulation (PFM) mode, the frequency varies. If we compare PWM mode and PFM mode, shown in Figure 3 (right), then it is obvious that PFM mode offers higher efficiency values, as there is less switching in a given time period and therefore decreased switching losses. During the idle time in PFM mode, the module produces no losses compared with PWM mode.

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**Figure 2: Typical rail voltages with tolerances**

**Figure 3: Different switching behavior under different load conditions—PWM mode under full load (left) and PFM mode under light load (right)**
Example calculation:

- Battery with 2,800-mAh capacity
- Application load current of 10 mA
- Output voltage power module of 1.8 V
- Three DC/DC converter efficiencies (20%, 45% and 85%)

The efficiency is given by the following equation:

\[ \eta = \frac{P_{\text{OUT}}}{P_{\text{IN}}} = \frac{V_{\text{OUT}} \times I_{\text{OUT}}}{V_{\text{IN}} \times I_{\text{IN}}} \]

where \( \eta \) is the efficiency, \( P_{\text{OUT}} \) is the output power, \( P_{\text{IN}} \) is the input power, \( V_{\text{OUT}} \) is the output voltage, \( V_{\text{IN}} \) is the input voltage, \( I_{\text{IN}} \) is the input current and \( I_{\text{OUT}} \) is the output current.

\( P_{\text{IN}} \) and \( I_{\text{IN}} \) are given by the following equations:

\[ I_{\text{IN}} = \frac{P_{\text{IN}}}{V_{\text{IN}}} \quad P_{\text{IN}} = \frac{V_{\text{OUT}} \times I_{\text{OUT}}}{\eta} \]

The battery life is given by the following equation:

\[ T = \frac{Q}{I_{\text{IN}}} \]

where \( Q \) is the battery capacity (in milliampere hours) and \( T \) is the battery lifetime (in hours).

Example calculation with \( \eta = 20\% \), \( \eta = 45\% \) and \( \eta = 85\% \) is as follows:

- \( \eta = 20\% \): \( T = 112 \) hours
- \( \eta = 45\% \): \( T = 264 \) hours
- \( \eta = 85\% \): \( T = 480 \) hours
The number of hours the battery will last is shown in Figure 4 based on the efficiency of the DC/DC converter. A jump in efficiency from 20% to 85% results in an over 400% increased battery lifetime. This results in longer operating time between charges, longer intervals between maintenance, etc.

POWER LOSSES AND THERMAL DERATING

Another impact of higher efficiency, especially relevant in space-constrained applications, is a lower temperature rise of the converter. By comparing the derating curves of the VDLM with an LDO in a similar package design, the negative effect of the losses on the performance becomes apparent.

Figure 5 shows the negative influence of the power dissipation on the output current capability of the LDO. The LDO used in the comparison is rated for $V_{IN} = 40\, \text{V}$ and $I_{OUT} = 1\, \text{A}$.

The derating of the LDO sets in right from the start. Due to the working principle of the LDO, the losses are too much at a ratio of $V_{IN} = 24\, \text{V}$ to $V_{OUT} = 5\, \text{V}$. This means it can deliver only 0.1 A, although it is rated for 1 A. In contrast to the power module, there will always be a need for additional means of cooling, which must be provided to allow the proper operation of an LDO for higher ratios of $V_{IN}$ to $V_{OUT}$.

In contrast, the VDLM 171013801 has no derating up to $105^\circ\text{C}$ with an output current of 1 A for $V_{IN} = 24\, \text{V}$ to $V_{OUT} = 5\, \text{V}$, meaning the solution size, weight and cost are much lower compared with a solution based on an LDO.

Over 90% of the power that is put into the 171013801 will be used for supplying the application. In comparison, the LDO uses only 20% of the input power for this task, while the remaining 80% of the power will be converted into heat that has to be dissipated by the LDO.

Operation under low efficiency results in five penalties:

- Additional energy consumption to run the application
- Higher energy consumption for the additional cooling effort (active cooling)
- Less reliability due to high-temperature stress on the device
- Higher design effort and costs for thermal management
- Larger total solution size

POWER SEQUENCING

In systems with the demand for multiple rail voltages like microcontrollers and DSPs, the voltages have to be applied in a defined time sequence. Figure 6 shows this behavior as an example.

The three voltages $V_1$, $V_2$, and $V_3$ are not connected at the same time to the load, e.g., DSP. Each of the voltages will be connected to the DSP after a defined time sequence. $V_1$ is connected after the time $t_1$. The second voltage starts rising after $V_1$ has reached its nominal value. $V_2$ will be the last one. The voltage starts rising after $V_2$ has reached its nominal value. However, $V_3$ must be double the time of $V_2$ at its nominal value before $V_3$ starts rising.

To realize such a kind of power sequencing, the power module needs two features that support this:
Enable feature: This sets the converter to start switching when the threshold is reached.

Power Good feature: Once $V_{\text{out}}$ is above a certain threshold—e.g., 90%—the PG pin transitions to a high state.

Figure 7 shows the power module 1 switched on by the EN pin, which is connected to $V_{\text{in}}$. As soon as the output voltage $V_{\text{out}}$ of module 1 has reached 90%, the PG pin transitions to a high state. If the PG pin of module 1 is connected to the EN pin of module 2, the PG signal will enable module 2. This leads then to a sequential increase in the output voltage from module 1.

Another positive effect of sequentially starting the modules is that the input peak current supplied by the upstream supply is also controlled. If the modules would start up simultaneously, then their input currents would be combined, potentially exceeding the limit of the upstream source.

ONE SIZE FITS ALL

“One size fits all” means one power module solution that fulfills the needs of many applications. The VDLM 1710X3801 supports this strategy in two ways. First, the pure performance data covers many applications, from the low-power range to the mid-power range, whether it is a PoL application or a 24-V DC bus application.

- $V_{\text{in}}$ = 3.5 to 38 V
- $I_{\text{out}}$ = up to 3 A
- $V_{\text{out}}$ = 0.85 to 13 V
- LGA-12EP package

Second, the use of an integrated power module that can be easily inserted into an application as a ready-made solution provides a remedy here. The power module comes fully tested in all areas that are essential for a DC/DC converter.
Battery Management Systems: The Most Commonly Used Cells

By Ulrich Lentz, technology field application engineer at Arrow Electronics

Batteries are widely used in many applications, such as electric vehicles with different categories (battery EVs, hybrid vehicles and fuel-cell EVs), as well as energy storage for various purposes, such as grid stability, peak shaving and renewable-energy time shifting. In these applications, lead-acid, nickel metal hydride (NiMH) and lithium-ion (Li-ion) batteries are commonly used. The proper management of these battery packs is a highly important task that requires both hardware and software components. This task is typically implemented by a battery management system (BMS), which IEEE Standard 1491 defines as “a permanently installed system for measuring, storing and reporting battery operating.”

This article proposes a global overview of the different chemistries used in power batteries and the main purpose of implementing a BMS.

Table 1: Characteristics of the most used cells

<table>
<thead>
<tr>
<th></th>
<th>Ni-Cd battery</th>
<th>Ni-MH Battery</th>
<th>Li-ion battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average operating voltage (V)</td>
<td>1.2</td>
<td>1.2</td>
<td>3.6</td>
</tr>
<tr>
<td>Mass energy density (Wh/kg)</td>
<td>50–80</td>
<td>70–95</td>
<td>118–250</td>
</tr>
<tr>
<td>Volume energy density (Wh/L)</td>
<td>50–150</td>
<td>140–300</td>
<td>250–693</td>
</tr>
<tr>
<td>Mass power density (W/kg)</td>
<td>200</td>
<td>200–300</td>
<td>200–430</td>
</tr>
<tr>
<td>Volumetric power density (W/L)</td>
<td>200</td>
<td>300</td>
<td>800</td>
</tr>
<tr>
<td>Self-discharge (months @ 20°C)</td>
<td>10%</td>
<td>20%</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Operating temperature (°C)</td>
<td>-20° to 50°</td>
<td>-20° to 60°</td>
<td>-20° to 60°</td>
</tr>
<tr>
<td>Cycle life</td>
<td>&gt;800</td>
<td>&gt;800</td>
<td>&gt;1,000</td>
</tr>
<tr>
<td>Environmental impact</td>
<td>Heavy cadmium pollution</td>
<td>Heavy metal pollution</td>
<td>Relatively low</td>
</tr>
<tr>
<td>Safety</td>
<td>Good</td>
<td>Good</td>
<td>Medium</td>
</tr>
<tr>
<td>Production cost</td>
<td>Lowest</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

Nickel cadmium (NiCd) batteries have been developed for over a century. They are known for being relatively cheap and robust and have been widely adopted for their high capacity, easy maintenance and low cost. The average cell voltage is about 1.2 V. These characteristics make NiCd batteries very popular for power tools. The energy density and specific energy are relatively low, which are drawbacks to NiCd batteries. In addition, NiCd batteries suffer from the so-called “memory effect.” Finally, the use of cadmium results in serious environmental problems.

Unlike NiCd batteries, NiMH batteries, introduced in 1990, have a higher energy density and specific energy. NiMH batteries have been widely used in applications like notebook computers, cellphones and shavers. They also bring improvements when it comes to the memory effect and metal pollution. When it comes to drawbacks compared with NiCd batteries, NiMH suffers from a higher self-discharge rate, is less robust to overcharging and has a more complex charging process.

Compared with nickel-based batteries, Li-ion batteries support a higher C-rate, higher energy density and longer cycling lifetime. In addition, Li-ion cells offer the advantage of a high average operating voltage of 3.6 V. Li-ion batteries also have considerably lower self-discharge rates than nickel-based batteries. They also do not suffer from the memory effect and are less capable of delivering large currents, expressed in C-rate, than nickel-based batteries. Over-discharging Li-ion batteries leads to a decrease in cycle life. Without further precautions, overcharging Li-ion batteries...
leads to dangerous situations and may even cause a fire or an explosion of the battery. Hence, it can be generally stated that overcharging and over-discharging of Li-ion batteries is not allowed.

Based on the used cathode, LiFePO$_4$, LiMn$_2$O$_4$, NCM and Li-ion batteries have varieties that propose different performance levels when it comes to charge rate, safety, cost, charge, discharge and environmental impact. Applications include notebook computers, cellphones and EV batteries.

The performance of power batteries is essential for market acceptance. For example, when it comes to EVs, energy density is a key factor. Li-ion batteries have higher energy density, power density and lifetime and are more promising for the future compared with nickel-based batteries. There is ongoing research to improve different aspects of the batteries, namely on cost, charge rate and safety.

There are many other aspects to consider when choosing a battery, and it is best to be advised by an FAE or an expert. You can always reach out to your local BMS and battery expert at Arrow Electronics to help you out.

HAZARDS TO BE PROTECTED FROM

BMSes are made to regulate and monitor the charge and discharge of batteries. There are several characteristics to be monitored, including temperature, current, voltage, battery type, isolation in high-voltage systems, state of charge (SOC), state of health (SOH) and extreme high-current flow. All of those monitored values are necessary for the tasks of a BMS. In principle, a BMS is suited to maximize SOC, optimize SOH and protect the battery against deep discharge and overvoltage by keeping the values inside the given window, as shown in Figure 1.

**Over- and undervoltage protection (cell balancing)**

In a multi-cell battery, the cell with the lowest charge determines the capacity of the entire system. As shown in Figure 1, the battery will suffer irreversible damage if the voltage drops below or rises higher than the threshold voltage for which the battery is designed. In case of a lower voltage, the anode copper dissolves. In case of a higher voltage, lithium plating will occur, and if the voltage rises even more, the cell will start outgassing and ignite.

Cell balancing is normally performed by an integrated circuit (IC) with high-precision analog-to-digital converters. The main types of cell balancing are active and passive balancing. In active balancing, a higher charge of a single cell can be transmitted to another single cell, while in passive balancing, the charge is dissipated with the help of a resistor. The individual cell controllers can perform specific, particularly energy-saving housekeeping functions, such as periodic cell measurements and condition analysis necessary for functional safety, independent of the main BMS controller. Safety functions for signaling over- or undervoltage are triggered autonomously.

**Over-discharge protection/low-voltage cutoff**

Over-discharge protection, also known as low-voltage cutoff, is an important safety feature that many, and normally all Li-ion, battery packs have. It is meant as a protection against a voltage drop below a certain level.

The consequences of a deeply discharged battery are diverse, but in nearly all cases, it leads to irreversible damage. For example, reduced life-cycle performance or even thermal runaway can then lead to fire.

Hence, different cell chemistries have different safety operating areas. In general, we use the IC to determine the safe operating range and provide the necessary protection for the cell/pack in the application.

**Short-circuit protection**

Overcurrent protection is needed when a short-circuit occurs on the battery. This leads to extreme discharge behavior; hence, there is a high-current flow, the battery heats up rapidly and a thermal runaway event occurs.

There are three ways to protect the battery: thermal cutoff, pyro fuse and circuit breaker. BMS
manufacturers can use one or all features in one system, depending on the required safety level.

The thermal cutoff kicks in when the battery pack reaches a certain temperature level. In high-voltage systems like EVs, this feature is normally activated by a digital processor, whereas in low-voltage applications, it is possible to implement this protection to be triggered by itself based on a predefined threshold.

In environments where humans can be harmed, protection against fire and explosion is especially important. Therefore, a digitally triggered pyro fuse comes into play. The fuse is connected to the high-voltage path on either minus or positive or on both. The fuse gets triggered as the last defense line to prevent significant damage to the battery.

In special environments like trucks, where service continuity is important, we tend to use more elaborate and expensive solutions. A circuit breaker based on back-to-back SiC MOSFETs is one possible way to protect the battery pack system from damage in case of a short-circuit. The drawback of this solution is the price and size. The functionality is the same as a pyro fuse, but it can be turned on after the event.

Overcurrent protection
As explained earlier, the cells get balanced with the help of a current flow. Depending on the charge capabilities of the battery, this current flow is in the range of 100 mA and 500 mA. The overcurrent protection is a specific current limit that the balancing IC shall not exceed. Mostly, this limit can be set individually and helps to protect the battery against irreversible damage, fire or explosion.

The current consumption depends on the ambient temperature, which should be considered when defining thresholds. Furthermore, it is necessary that the current-level limit is set below the real battery current-draw level. Normally, the level is charged with an additional safety factor of 2 to 3. In case of small current fluctuations, false triggering of the BMS overcurrent protection can occur.

To prevent the system from doing this, some BMSes have a feature called hysteresis and digital filters.

Thermal runaway protection
Batteries can support temperatures as high as 60°C based on the used chemistry. The temperature of a hot cell can spread to the neighboring cells and the entire battery pack can heat up in no time. The heat triggers a chain reaction that can set the whole battery pack on fire through different chemical reactions that can release inflammable gas.

The thermal runaway protection gets triggered when the predefined temperature threshold is met. It shuts down the battery and prevents the battery from going into the thermal runaway.

The primary role of a BMS is to protect and communicate the status of the battery. The variety of hazards to be protected from is huge. The safe operating area in green (Figure 1) illustrates the limited conditions in which a battery can be used. We need to make sure that the battery pack is not used outside of the design operating range. Complex and safe mechanisms are necessary to keep a battery in this area and to make it safe for humans. The software portion used in a BMS is a huge part of the design and needs to be considered in the early project stage. There’s a cost associated with the choice of IC, architecture, software and battery packs, and without deep knowledge, it’s hard to make the “best” choice. Don’t hesitate to reach out to Arrow if you need any advice or support.

References

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- "Tritek. (2022). “What is a BMS protection board of lithium battery?”"
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.
Performance Benefits of Next-Gen Monolithic Integrated GaN Half-Bridge Power Stages in DC-to-DC and BLDC Motor Drive Applications

By Michael de Rooij, vice president of applications engineering; Alejandro Pozo Arribas, senior applications engineer; Federico Unnia, applications engineer; Marco Palma, director of motor drive systems and applications; and Brandon Perez, applications lab assistant, all at Efficient Power Conversion (EPC)

Enhancement-mode gallium nitride (eGaN) FETs from EPC have demonstrated higher performance over silicon MOSFETs in many applications, and the lateral structure of eGaN FETs makes it possible to monolithically integrate several FETs on a single die. Monolithic GaN integration has matured to the point that complex circuits like a half-bridge gate driver with various features, such as cross-conduction protection, can now be realized. These complete circuits are packaged into a single and simple-to-use component. This article will cover DC-to-DC and BLDC motor drive application examples that benefit from monolithic half-bridge integration.

INTRODUCING THE ePOWER STAGE eGaN IC FAMILY

The EPC23102, EPC23103 and EPC23104 form a family of next-generation monolithically integrated half-bridge ePower Stages, as shown in Figure 1. The devices are rated at 100 V and are available in a 3.5 × 5.0-mm PQFN package that makes layout and design simple.

EPC monolithic ICs combine the excellent switching performance of GaN transistors with the good thermal capabilities of QFN packages; as a result, GaN monolithic ICs make it possible to increase the switching frequency of the converter, keeping the switching losses and the temperature increase low. The EPC2310x family includes enhanced features like switch-node slew-rate programming; 3.3-V and 5-V logic-compatible, synchronous bootstrap supply; and enable function.

Monolithic ICs allow designs to shrink to a single QFN component, the half-bridge cell, which is composed of at least one gate driver and two discrete FETs in conventional Si MOSFET-based inverters. Moreover, increasing the switching frequency allows reduction of the input filter, so the overall weight and volume of the converter are reduced.
DC-to-DC CONVERTER EVALUATION

The system integration provided by the EPC2310x family enables the design of high-efficiency and high-power-density DC-to-DC converters, including hard-switched topologies. The common QFN package for all family members, with compatible pinout and footprint, provides multiple design choices for optimum performance across a wide range of operating conditions and cost targets. For simple evaluation of each product, EPC offers dedicated development boards—EPC90147, EPC90151 and EPC90152—with the critical components needed to test them in most existing converter topologies. Figure 2 shows three examples comparing efficiency and power losses in 48-V to 12-V power-conversion and USB-PD applications tested using the development boards.

The left graph compares the three ePower Stages in a 48-V to 12-V buck converter switching at 500 kHz, with a 2.2-µH inductor (IHTH1125KZEB2R2M5A). In this application, the high inductor current ripple favors the lowest-on-resistance member of the family, EPC23102, with efficiencies exceeding 96% up to 240 W of output power. The same three products are also compared in the center graph in a 12-V to 48-V boost converter operating at 2 MHz with a small and low-profile 1-µH inductor (PA5405102NLT). The results highlight the performance advantage of the smallest member of the family, EPC23104, in a switching-loss-dominated application.

The right graph shows the difference between EPC23103 and EPC23104 in a 28-V to 12.3-V buck converter suitable for USB-PD, switching at 1.8 MHz using a 1-µH inductor (PIMB103E-1R0MHU). Both parts greatly exceed 96% efficiency, with EPC23104 outperforming EPC23103 until approximately 140-W output power. In this case, adding a heatsink and/or some forced-air cooling would enable higher output powers, favoring the EPC23103 beyond 140-W output power.

To further demonstrate the suitability of ePower Stages to develop simple, compact and efficient converters, EPC recently released the EPC9177 reference design featuring a synchronous buck converter. The design, shown in Figure 3, uses the EPC23102 to achieve over 97% efficiency when delivering 180 W into 12 V from a 24-V supply—all possible in a 21 × 13 × 7.5-mm volume with over 1,400 W/in.³ of power density in a simple and easy-to-use and control buck converter that can also accommodate 48-V to 12-V conversion ratios, owing to the 100-V rating of the EPC23102.

The reference design requires only a 5-V external supply. Included on the board are a linear regulator, used to power the digital controller, and a current shunt amplifier, with bidirectional current flow supported, which allows operation of the module in either buck or boost modes. The digital controller is a 16-bit dSPIC33CK32MP102 controller from Microchip with integrated high-speed ADC, comparators and high-resolution PWM. By default, it is pre-programmed for buck operation with a regulated 12-V output, operating at 720 kHz. The board also has a pre-installed heatsink that increases the current capability by 30%, taking advantage of the convenient and efficient QFN package with exposed top that can be used for enhanced cooling.

Read the complete article at Power Electronics News
Day 1

(LE1) The Ascent of GaN

This Lecture/Tutorial is presented by Alex Lidow, CEO, Efficient Power Conversion

After more than 13 years of mass production, GaN-on-Si has gained widespread acceptance as the successor to the aging silicon MOSFET for voltage ranging between 40 V and 650 V. What, therefore, are the variables controlling the rate of growth of GaN power devices. We will dig into the experience, and lessons learned from the power MOSFET as well as the recent experiences with GaN in applications ranging from DC-DC conversion...

(LE2) Industrial Drives: A New Horizon for Real and Relevant Higher Efficiency Industrial Drives Enabled by Today’s SiC

This Lecture/Tutorial is presented by Guy Moxey, Senior Director Power Products, Wolfspeed

5% of all electricity generated is used to turn a motor so ensuring that the motor to drive system is highly efficient and optimised for performance is key to ensuring better energy conversion. Regional and end equipment...

(LE3) Bidirectional SiC and GaN Switch Technology

This Lecture/Tutorial is presented by Dr. Victor Veliadis is Executive Director & CTO of PowerAmerica

There are numerous mass volume power applications where it is necessary to control the flow of bidirectional power. Today, monolithic bidirectional SiC and GaN power semiconductor switches are not commercially available. Instead, back-to-back (anti-series) connection schemes of unidirectional power devices are typically used, resulting in a 4X penalty in chip area and high cost. However, various...

(LE5) Panel Discussion about SiC & GaN Solutions: Recent Developments and the Next Challenges to Overcome

Panel Discussion with Industry Experts, moderated by EE Times Editor Maurizio Di Paolo Emilio

The global wide-bandgap landscape has been marked by growth and increasing industrial acceptability. Companies are developing an extensive portfolio of devices that promise benefits in a variety of applications for industrial, automotive and consumer markets, among others, as technology...
Day 3

(PC1) Power Adapter
Intelligent Power Sharing: Power Efficiency

These Opening Remarks are presented by Hubie Noto, Director of Marketing, Silanna Semiconductor

Power adapters with multiport power sharing are devices that allow multiple electronic devices to be charged or powered simultaneously. These adapters typically have multiple output ports, each capable of delivering power to different devices including smartphones, tablets, laptops, or other USB-powered consumer electronics, smart home...

(PC2) Silicon Never Fails to Surprise: The Case for Superjunction MDmesh

This Keynote is presented by Filippo Di Giovanni, Innovation and Key Programs Manager, Power Transistor MACRO Division, STMicroelectronics

Silicon has been the main material in manufacturing semiconductors. It has been used for decades and has become pervasive in our everyday life, used in practically everything we touch. Despite being so well-established, engineers and designers still...

(PC3) How Advanced Power Technology Makes Polymerase Chain Reaction (PCR) Tests Possible

This Keynote is presented by Patrick Le Fèvre, Chief Marketing and Communications Officer, and Technology Evangelist, Powerbox

During the past two years or so, in one way or another the world population has been affected by the Covid-19 virus, and the polymerase chain reaction (PCR) test has entered into our daily lives. At this point we could quite easily question what a power...

(PC8) Panel Discussion: Technical Trends with Power Conversion

Panel Discussion with Industry Experts, moderated by EE Times Editor Maurizio Di Paolo Emilio

Innovative power management devices improve power-factor correction and lower standby power consumption to offer energy-efficient solutions across all industrial, consumer and automotive applications. Almost all devices rely on some form of power conversion, whether it’s changing the voltage of a DC battery or converting AC mains...
Technical Talks

Renesas

Design Innovations for Next Generation Power Module Solutions

Presented by Jeff Sherman, Senior Manager, Product & Marketing Applications, Power Modules Product Line, Renesas

Many engineers are utilizing power modules due to multiple design advantages – ability to significantly reduce board space, deliver faster time-to-market solutions and successful first-pass rates. In addition, they are easy-to-use and flexible in a very small footprint. In this webinar, you’ll learn how to significantly reduce your board space up to 60% by utilizing the industry’s smallest and thinnest power module solutions, review various performance benefits of the latest generation analog and digital power solutions, and how to simplify your power designs to get to market faster.

Qorvo

Why SiC FETs Excel in Soft Switched Applications

Presented by Dr. Anup Bhatta, Chief Engineer, Power Devices, Qorvo

SiC FETs offer very low Rds(on) values in commonly used through-hole and SMT packages. They offer other valuable features like low Coss, low VF diode drop, low gate charge and low RthJC, to help users maximize the efficiency, power density and system cost of their DC/DC soft-switched designs.

Infineon Technologies

Role of Wide-bandgap in Next Generation Solar and Energy Storage

Presented by Dr. Sam Abdel-Rahman, System Architect Residential Solar & Energy Storage, Infineon

Solar and Energy Storage Systems (ESS) are crucial in the energy supply chain. This presentation will overview the trends of solar and ESS and discuss the importance of residential solar and ESS for renewable decarbon energy generation. It will also discuss the different architectures of home energy systems and how Silicon Carbide (SiC) and Gallium Nitride (GaN) can improve performance in various power conversion stages to meet future application trends.

CoolSiC™ MOSFET for industrial drive applications

Presented by Niclas Thon, System Application Engineer, Infineon

Industrial drives have a long history in power electronics as application. In the recent years, drive manufacturers are putting a stronger focus into enhancing power density and efficiency. With CoolSiC™ MOSFET technology Infineon provides a solution to such requirements. A technical comparison is presented between silicon-based IGBT™ TRENCHSTOP™ technology, optimized for general-purpose drive applications, and CoolSiC™ MOSFET technology. This comparison was conducted under typical drive conditions, including consideration of dV/dt restrictions of <5V/ns, to assess the thermal performance of different power semiconductors in identical motor drives.

STMicroelectronics

Next Steps in Density and Efficiency with ST PowerGaN in 1.2 kW GaN CCM Totem-Pole PFC Implementation

Presented by Gianni Vitale, Application Director, STMicroelectronics

Power density and efficiency for switching converters has made a major step forward with the presence in the market of Gallium nitride (GaN) technology, superior performances of the new WBG technology are now driving the development of consumer chargers towards miniaturization and targeting power conversion stages in server and EV applications. Along with the GaN technology, controllers, gate drivers, passive components and topologies need to be reviewed and adapted to the higher switching frequency operation. The 1.2 kW GaN CCM Totem-Pole PFC reference power stage is here introduced to combine the new 65mOhm E-mode G-HEMT™, the STM32G4 featuring a high-resolution timer for very high switching frequency operation and the STGAP2G galvanic isolated gate driver designed to drive GaN devices to reach 99% efficiency for easy thermal design and compliance to challenging 80 Plus Titanium specification.

Nexperia

MOSFET device analysis at your fingertips with interactive datasheets

Presented by Stein Nesbakk, Marketing Engineer, Nexperia

Allowing engineers to visualize the interaction between parameters such as gate voltage, drain current, RDS(on) and temperature, the collective contribution to the device behavior can now be displayed dynamically in tables or graphs. Nexperia’s interactive datasheets can significantly increase productivity by eliminating the time needed for an engineer to perform manual calculations or set up and debug a circuit simulation. Whether you are a Design Engineer looking to see how a device will perform at elevated temperature, or a Component Engineer trying to compare devices under different test conditions, interactive datasheets are designed to make your life easier.

CLICK HERE TO WATCH ON DEMAND >
How Are EV Batteries Made?

Li-ion batteries’ higher energy density give them dominance in the current ecosystem, but solid-state batteries are on their way to creating disruption

By Abhishek Jadhav, contributing writer for Power Electronics News

As the market forecasts a steady growth in sales of electric vehicles in the next decade, several government initiatives toward climate change also deal with discontinuing fuel-based vehicles. The growth of the EV is powered by electric rechargeable batteries, the basic structure for using clean and renewable energy. EVs use powertrain batteries that supply energy to all the engine components to function as expected.

Producing EV powertrain batteries has proven to be environmentally costly, but unfortunately, only a few automakers are taking the problem seriously. The raw materials used in making these batteries are lithium and its variants. These variants include cobalt nickel, manganese and several other materials. The material dominating the market is cobalt manganese, which many electric auto companies use. But on the other hand, Tesla uses a combination of lithium cobalt and manganese. A few automakers are working on a new powertrain that will be cobalt-free; however, cobalt still represents an essential mineral without which EV powertrains will be difficult to make.

Lithium-ion batteries are widely used in portable consumer electronics like smartphones and laptops. They are also employed in EVs due to their higher energy density than lead-acid or nickel-metal hydride batteries. This advantage enables automotive manufacturers to develop smaller batteries without sacrificing storage capacity. Li-ion batteries also exhibit a high power-to-weight ratio, high energy efficiency, high-temperature performance and low self-discharge. Additionally, the various parts of Li-ion batteries can be recycled, making them an environmentally friendly choice. The next section explores the workings of a basic Li-ion battery.

HOW DOES A LI-ION BATTERY WORK?

Li-ion batteries operate on the principle of electrochemical reactions, whereby the transfer of electrons occurs between two electrodes, one of which is negatively charged while the other is positively charged. The electrodes are immersed in a conductive electrolyte, facilitating the movement of charged ions between them.

Li-ion battery charging

Li-ion cells have intercalation compounds characterized by a crystalline structure with layers that allow the migration or deposition of lithium ions. When charging a Li-ion battery, the ions travel from the positive to the negative electrode as they intercalate and await the next discharge cycle.

The latest generation of batteries exhibits enhanced ion mobility, enabling faster charging without the associated risk of overheating. In response, chipmakers have developed an array of integrated solutions for Li-ion battery management that simplify the design of chargers. These companies now offer silicon that enables engineers to design products capable of taking advantage of the accelerated charging rates during the constant-current phase.

Li-ion battery discharging

During discharging, ions move from the negative electrode to the positive electrode via a liquid electrolyte, while electrons flow from the negative electrode to the positive electrode through an external circuit that delivers power to electronic devices. The combination of ions and electrons at the positive electrode results in lithium deposition. Once all the ions have returned to the positive electrode, the battery is fully discharged and requires recharging.
During the discharging process in EVs, the battery’s stored energy is depleted, and the voltage of the battery decreases as the electric current flows from the battery to the motor. The rate of discharging depends on the power demand of the motor and the battery’s capacity, which determines the amount of energy that can be delivered before the battery requires recharging. Efficient battery discharging is essential for optimizing the range and performance of EVs.

**Li-ion battery expression**

The battery-charging equation is expressed in relation to the battery capacity. It depends on the numerical value of the rated battery capacity in ampere-hours and the time at which this value is declared. The equation is defined as:

\[ I = M \times C_n \]

Where \( I \) is the charge or discharge current in amperes, \( M \) is the multiplication factor of \( C \), \( C \) is the numerical value of rated capacity in ampere-hours and \( n \) is the time in hours at which \( C \) is determined.

**WHAT ARE THE INDUSTRY STANDARDS FOR DEVELOPING EV BATTERIES?**

Currently, the industry standard for developing EV batteries involves utilizing Li-ion technology, which has undergone significant advancements over the past 30 years. While these batteries provide superior energy density compared with other technologies, they require precise control of recharging processes and appropriate packaging. At present, Li-ion technology is considered the optimal choice for achieving a combination of capacity, recharging flexibility and durability.

Despite the considerable buzz around all-solid-state batteries, the development of such batteries has yet to progress sufficiently to establish them as the primary source for producing EV batteries. These batteries aim to replace the liquid electrolyte of traditional Li-ion batteries with a solid-state material, which may take the form of polymers or inorganic powders, such as ceramics.

The liquid electrolyte in Li-ion batteries can penetrate both the cathode and anode. High temperatures can accelerate the chemical degradation of the electrolyte, and organic solvents’ flammability can lead to system malfunctions and fires. Conversely, all-solid-state batteries are non-volatile and are expected to remain stable and safe at high temperatures.

EV makers like Nissan are focusing on the development of solid-state batteries. The company has already started developing a prototype at the Nissan Research Center in Kanagawa Prefecture, and the process is one year in progress. Nissan has also revealed that it will manufacture the first batch of its solid-state batteries, which are free of liquid electrolytes, in 2025, with plans to launch mass production by 2028.

**References**

3. Nissan Motor Corporation. “High-quality battery technology that dramatically boosts the performance of EVs.”
Loss Analysis in Low-Power High-Frequency WPTSes

By Saumitra Jagdale, contributing writer for Power Electronics News

Wireless power transfer systems (WPTSes) for wearable and portable applications are gaining popularity as the demand for wireless mobile phone and smartwatch chargers increases. Due to the considerably low coupling factor (<0.1) between the primary transmitting (Tx) coil and the secondary receiving (Rx) coil in such applications, achieving high efficiency has been very challenging. Moreover, many consumer electronics are now battery-operated, which has greatly increased interest in designing charging platforms for multiple receivers. Recently, for such kinds of applications, there has been a push for operation in the restricted and unlicensed lower ISM band at 6.78 MHz.

Many scientific works on this subject have focused only on the optimization of transmitter and/or receiver modules. Also, WPTS efficiencies are provided as just experimental data without any preliminary investigation of the silicon devices’ impact on both the primary and secondary sides of the system. Therefore, the main goal of the research is to provide an effective model for the analysis and efficiency evaluation of WPTSes, including all the semiconductor device losses for low-power applications relevant to wearable devices. This article will show an analytical model based on the first harmonic solution of a WPTS and its solution along with the simulation results and experimental measurements for a 2-W @ 6.78-MHz WPTS.

WPTS MODELING AND NUMERICAL SOLUTIONS

The WPTS mentioned henceforth refers to the architecture in Figure 1. It can work with a primary constant frequency and a secondary PWM control ensuring duty-cycle and phase-shift modulation. The authors aim to calculate the output current ($I_{out}$) and WPTS efficiency given the output voltage ($V_{out}$) and the fire angles of the MOSFETs $Q_1$, $Q_2$, $Q_3$, and $Q_4$. 

Figure 1: Series-series resonant WPTS
The relations among phase-lag (Φ), the angle between zero-crossing current (i₂t) and falling voltage (v₂t) denoted by α, the angle between the rising voltage (v₂t) and (i₂t) denoted by β and D are given by Equation 1, where \( \Phi = (a - \beta) / 2 \) and \( D = 1 - (a + \beta) / \pi \).

For unidirectional operations, values of practical interest for α and β are the ones ensuring \( 0 < D < 1 \) and \( -\pi / 2 < \Phi < \pi / 2 \). Given \( V_s, \alpha, \beta \) and the capacitances \( C_s1 \) and \( C_s2 \), the WPTS output power and efficiency are influenced by the system's total losses.

Considering the WPTS first harmonic solution:

The instant where \( i_2t \) crosses zero with the positive derivative is the reference for the phase angles. The equations for the WPTS Tx-Rx coupled loops are:

\[
\begin{align*}
V_1(t) &= V_s \cos(\omega t + \phi_1) & i_1(t) &= I_1 \cos(\omega t + \phi_1) \\
V_2(t) &= V_s \cos(\omega t + \phi_2) & i_2(t) &= I_2 \cos(\omega t + \phi_2)
\end{align*}
\]

The instant where \( i_2t \) crosses zero with the positive derivative is the reference for the phase angles.

The equations for the WPTS Tx-Rx coupled loops are:

\[
\begin{align*}
\tilde{V}_1 &= \tilde{Z}_1 I_1 - j\omega M \tilde{I}_2 \\
\tilde{V}_2 &= \tilde{Z}_2 I_2
\end{align*}
\]

Where

\[
\begin{align*}
\tilde{V}_1 &= V_1 e^{j\phi_1}, & \tilde{I}_1 &= I_1 e^{j\phi_1}, & \tilde{V}_2 &= V_2 e^{j\phi_2}, & \tilde{I}_2 &= I_2 e^{j\phi_2}
\end{align*}
\]

\[
\begin{align*}
\tilde{Z}_1 &= R_1 + j\omega L_1 + j\omega C \left( \frac{1}{Z_0} \right) & \tilde{Z}_2 &= R_2 + j\omega L + j\omega C \left( \frac{1}{Z_0} \right)
\end{align*}
\]

Applying Fourier formulas to the Tx and Rx voltages and currents provides:

\[
\begin{align*}
V_1 &= \frac{4}{\pi} V_s \cos(\alpha) & V_2 &= \frac{V_{out}}{\pi} \sqrt{\frac{1}{2} \sin(\alpha) \cos(\beta)} \\
\phi_2 &= \phi_1 - \frac{1}{2} (\alpha - \beta) = -\frac{1}{2} (\pi - \alpha + \beta)
\end{align*}
\]

Merging Equations 3 and 5, we get Equations 6 and 7:

\[
\begin{align*}
\Gamma_{re} &= \frac{\omega M V_1 \cos(\phi_1 + \frac{\pi}{2}) - Z_1 Z_2 I_2 \cos(\phi_2 + \phi_1 + \phi_2)}{-\omega^2 M^2 I_2 \cos(\phi_2) - V_2 Z_2 \cos(\phi_2 + j \phi_2)} = 0 \\
\Gamma_{im} &= \frac{\omega M V_1 \sin(\phi_1 + \frac{\pi}{2}) - Z_1 Z_2 I_2 \sin(\phi_1 + \phi_2)}{-\omega^2 M^2 I_2 \sin(\phi_1) - V_2 Z_2 \sin(\phi_1 + j \phi_2)} = 0
\end{align*}
\]

Neglecting rectifier switching losses, the authors calculated the average output current \( I_{out} \) of the rectifier as:

\[
I_{out} = I_{net,av} = \frac{1}{\pi} \int_{-\beta}^{\alpha} I_2 \sin(\theta) d\theta = \frac{1}{2} I_2 \left[ \cos(\alpha) + \cos(\beta) \right]
\]

Considering that a part of \( I_{out} \) is lost because of the MOSFET switching losses:

\[
I_{out,net} = I_{out} - I_{sw,rec}
\]

The switching current \( I_{sw,rec} \) can be considered as sought by an equivalent dissipative current source connected in parallel to the rectifier output. Such current effectively allows analysis of the impact of rectifier switching losses on the output power and efficiency of the WPTS. Accordingly, the equivalent current \( I_{sw,rec} \) is given by:

\[
I_{sw,rec} = \left( P_{on-off,rec} + P_{gate,rec} + P_{body,rec} \right) / V_{out}
\]

From Equations 8, 9 and 10, the net output current \( I_{out,net} \), accounting for the effect of the rectifier MOSFET losses, is determined. \( I_{out,net} \) results correlate to the current \( I_2 \) through a nonlinear equation, which is also dependent on the sign of fire angles \( \alpha \) and \( \beta \). Given \( \alpha \) and \( \beta \), the rectifier \( I_2 \) versus \( V_{out} \) curve, which also represents the output characteristic of the WPTS, can be determined for different rectifier MOSFETs to identify the device, ensuring the best power and efficiency performance.
The inverter switching losses $P_{sw,inv}$ were modeled by means of an equivalent current source in parallel to the inverter input, whose current is given by:

\[
I_{sw,inv} = \left( P_{on-off,inv} + P_{gate,inv} + P_{body,inv} \right) / V_s
\]

The Tx and Rx conduction losses are given by:

\[
P_{Tx} = \left( R_{i_1} + R_{L_1} \right) I_{1,rms}^2 \quad P_{Rx} = \left( R_{x_2} + R_{L_2} \right) I_{2,rms}^2
\]

The overall WPTS efficiency is evaluated as:

\[
\eta = \frac{V_{out} I_{out,net}}{V_{in} I_{in,net} + P_{con,inv} + P_{sw,inv} + P_{tx} + P_{rx} + P_{con,rec} + P_{sw,rec}}
\]

**EXPERIMENTAL VERIFICATION OF WPTSES**

The WPTS adopted for the validation of the proposed model is characterized by the following operating parameters: $f_s = 6.78$ MHz, $L_1 = 7.5$ μH, $L_2 = 0.93$ μH, $C_1s = 1 + (\omega_s^2 \times L_1) = 73.5$ pF, $C_{2s} = 1 + (\omega_s^2 \times L_2) = 583$ pF, $Q_{L_1} = 150$, $Q_{L_2} = 40$, $Q_{C_1} = Q_{C_2} = 1,000$. The WPTS is physically realized with the Tx coil (nine turns, 70 × 70-mm$^2$ diameter) and the Rx coil (eight turns, 15 × 15-mm$^2$ diameter).

The Rx coil was placed centered with respect to the Tx coil at 6 mm of distance from each other, yielding a coupling factor of $K = 0.076$ (calculated by means of Ansys's high-frequency structural simulator). Rohm's RUF015N02 MOSFETs were adopted for the inverter and rectifier stages. Texas Instruments’ LM5113-5A gate drivers were used for rectifier and inverter MOSFETs, providing gate voltages of $V_{gs} = 5$ V and deadtimes of $t_{dt} = 2$ ns. Xilinx’s Spartan-6 FPGAs were adopted for the overall control implementation.

The nonlinear model and the numerical algorithm proposed previously were coded in Matlab. The simulated maps compared with the experimental ones show that the model predictions are correct over the entire investigation range. Three operating conditions that were selected are: $D = 1$, $\phi = \pi = 0$; $D = 0.68$, $\phi = \pi = 0.19$; and $D = 0.52$, $\phi = \pi = -0.29$.

**References**


Ideal Power Inc. has developed an innovative solution to address the challenges of power conversion with its cutting-edge bidirectional bipolar junction transistor (B-TRAN). This four-quadrant power switch offers exceptional performance by delivering ultra-low forward-voltage drop and minimizing switching losses.

Compared with conventional power switches like SCRs, IGBTs and MOSFETs, B-TRAN offers significant performance improvements. In fact, during silicon testing, the B-TRAN demonstrated only 0.6-V $V_{CE(on)}$ at 30-A load current, with a driving power of only 8.4 W (1.2 V × 7 A), resulting in a total power loss of 26.4 W, which is considerably lower than that of IGBTs. These results showcase the incredible potential of B-TRAN as a game-changer in power-conversion technology.

B-TRAN can be considered the ultimate development of power-semiconductor topologies. It is considered the logical endpoint of the evolution of power-semiconductor topologies due to its unique combination of performance, reliability and efficiency.

In Figure 1, we have a variety of electronic devices made of silicon. The first one is called "open," which is made of pure silicon and is not useful for conducting electricity, but it’s great for insulating. Next, we have a resistor made of doped silicon that can resist the flow of current due to impurities.
added, either N-type or P-type. A diode is formed by adding a heavily doped layer of N material on one surface of a P-type resistor, allowing current to flow in one direction only. The MOSFET combines the resistor and diode functions and has a switch to select between modes. An IGBT is similar to a MOSFET, but with an additional doping layer to change its behavior.

Lastly, B-TRAN is a bidirectional bipolar junction transistor equipped with a control on both sides for enhanced performance and inherent bidirectionality. “By incorporating all the features into one die using both sides of the wafer, a bidirectional switch can be made without using pairs of IGBTs and diodes like traditional bidirectional circuits,” Brdar said.

**B-TRAN PERFORMANCE**

![Figure 2: (a) B-TRAN symbol; (b) real B-TRAN; and (c) B-TRAN specifications](image)

Figure 2 displays the circuit symbol and device along with its bidirectional operating characteristics. The device, with its two control inputs, can block voltage in both polarities and conduct current in both directions. This makes it suitable for bidirectional applications like voltage source inverters or battery chargers, as well as unidirectional applications.

“Coming up with a version of technology that is really a bidirectional switch targeted for applications that require faster switching speeds, for example, using silicon carbide can be an option,” Brdar said.

However, to create a bidirectional switch, two MOSFETs or two IGBTs plus two diodes must be connected in a common-emitter configuration, which significantly increases the part count for bidirectional power converters.

**B-TRAN DRIVER & DPT**

![Figure 3: (a) Test circuit; (b) driver board with B-TRAN system and power board](image)

A double-pulse testing (DPT) system, specifically designed for testing the switching performance of B-TRAN, is used. The system is comprised of three main sections: power supply and control, driver and the device under test. The B-TRAN test system block diagram is shown in Figure 3(a). The top emitter and base terminals are referred to as E1 and B1, while the bottom terminals are E2 and B2. Figure 3(b) shows the B-TRAN driver, consisting of one B-TRAN and a power board developed for the test.

![Figure 4: (a) Current flow from E1 to E2; (b) current flow from E2 to E1](image)
To test bidirectional switching, Figure 4 illustrates the circuit schematics for the specific current direction. Low-\(R_{\text{DS(on)}}\) cascade MOSFETs are used to drive B-TRAN as a normally off switch like an IGBT. These devices can block high voltage in their off state and conduct high current with low loss in their on state.

“Our conduction losses are less than half of the conventional semiconductors,” Brdar said. “We actually enable applications like a solid-state circuit breaker, where conduction losses really drive the design.” Inductor L1 and fast-recovery diode D1 are connected across the inductor as part of the DPT.

**B-TRAN CHARACTERIZATION**

Initial measurements of B-TRAN dies and packaged devices are conducted using a Keithley high-power test system. Breakdown voltage and leakage current are measured by ramping up the voltage across the device while monitoring the current. A breakdown voltage of 1,280 V is measured, and leakage currents are measured to be 25 µA at 1,000 V and 45 µA at 1,200 V, which confirms the basic steady-state performance parameters. The emitter-emitter saturation voltage and current gain (\(\beta\)) are measured to be 0.6–0.8 V and 7 A, respectively.

Output characteristics for three values of \(V_{\text{BE}}\) are shown in Figure 5, indicating an almost linear relationship between the forward-voltage drop, \(V_{\text{BE(on)}}\), and the output current \(I_{\text{E1}}\) for each \(V_{\text{BE}}\). When more current is injected into the base by increasing \(V_{\text{BE}}\), the forward-voltage drop is significantly reduced. This feature allows the modulation of \(R_{\text{DS(on)}}\) by changing the base-emitter voltage. The same output characteristics are obtained in the opposite direction.

Figure 6 shows the DPT waveforms at 800 V/14 A. The bidirectional switching test is conducted using the same connection setup as shown in Figure 4, except that the diode (D1) and \(V_{\text{DC}}\) polarities are reversed to show the current flow from E2 to E1 terminals.

Figure 7 shows the waveforms with a turn-on rise time of 50 ns and a turn-off fall time of 165 ns. The control signal, emitter-emitter voltage, and emitter current are labeled as 1, 3, and 2, respectively.

**B-TRAN APPLICATIONS**

B-TRAN serves as a bidirectional switch capable of performing direct AC/AC conversion. This makes it suitable for applications requiring bidirectional power transfer between the AC mains and the load, including EVs, renewable-energy generation, energy storage, solid-state circuit breakers and motor drives.

“If you can improve the range of the vehicle, which is something you can do with B-TRAN, and you can get another 8% to 10% range out of the batteries but do it without the high cost of going to silicon carbide, it wins on both counts,” Brdar said.
Figure 8 illustrates a typical EV power system, with red ovals indicating potential uses for B-TRAN.

B-TRAN can also be used in multiple other places, such as motor drives, UPS systems for data centers, elevators, EV chargers, renewable-energy applications like solar and wind, and power conversion for smart grids.

“We’ve seen a lot of interest from different industries and different companies who want to use our technology for various applications,” Brdar said. “One of the big things we want to do is really make sure that the product is accessible to as many applications as possible.”

B-TRAN introduces a new power-semiconductor topology that is simple yet innovative. It combines the benefits of MOSFETs’ fast, low-loss switching; IGBTs’ high-current density; and BJTs’ low forward-voltage drop. “We ended up replacing a set of four devices with one, and it has about half the losses of conventional approach and about a quarter of losses if you think about it in a bidirectional situation,” Brdar said.

Moreover, B-TRAN’s unique bidirectionality enables its use in AC-link converter topologies, offering significant advantages in terms of efficiency and system economics for a broad range of power-converter applications, including PV inverters, wind converters, variable-frequency motor drives and electrified vehicle traction drives.

B-TRAN exhibits symmetrical bidirectional performance, providing a breakdown voltage exceeding 1,200 V and an on-state voltage drop of 0.6 V at high currents of up to 30 A. Compared with existing power-semiconductor devices for bidirectional applications, B-TRAN has considerably lower conduction and switching losses. A specialized TO-264 package with double-sided cooling capability has been developed for B-TRAN, and a bidirectional driver has been optimized to switch and control current conduction in both directions.

“What we’re using is double-sided cooling since it is a double-sided device,” Brdar said. “And since you generate more efficiently, you are actually generating less heat to begin with, and as you know, heat is the killer for electronics. So if you’re generating less heat to begin with and you’re using double-sided cooling, which provides very uniform cooling, you can end up with a device that can run very efficiently and cool.”

SiC Devices for EV Chargers

By George Hariman, systems architect at Rohm Semiconductor Americas

The widespread adoption of electric vehicles has depended largely on successfully augmenting their practical range beyond the bounds of city driving. This has been achieved by steadily increasing the capacity of the battery pack along with the efficiency of the associated power electronics. In parallel, consumers have demanded ever shorter charging cycles and more convenient charging methods within a broad network of physical locations. These two trends are in direct competition and have ultimately spurred the advancement of EV charging stations themselves.

As shown in Figure 1, battery capacities have more than doubled in the last five years, and charging station power capacity has nearly tripled. This has been made possible by technological leaps in chemistry and construction on the battery side and by circuit topology and components on the charger side.
The prototypical EV charging station contains a myriad of building blocks, as depicted in Figure 2. At the top left, three-phase AC power is introduced and rectified using efficient active devices that also control for power-factor correction. The output current and voltage are monitored and fed into the EV battery in the range of 400 V to 1,000 V. A parallel and isolated low-voltage domain is used to control all of the high-voltage power electronics. This includes an AC-to-DC converter, a microcontroller and a variety of interfaces.

To meet the demands of these highly capable and efficient EV charging designs, Rohm offers a broad product portfolio of active and passive electronic devices specifically tailored to EV charging applications. In particular, silicon carbide MOSFETs and diodes, along with supporting gate drivers, have yielded a strong competitive advantage in terms of price and performance.

**SIC MOSFETS: DRIVING EV TRENDS**

SiC is a wide-bandgap semiconductor that has taken center stage in the world of power electronics for its high voltage tolerance, high power density, low on-state resistance and excellent thermal conductivity. These characteristics are all perfectly suited for many of the tasks performed within an EV charging station.

Rohm’s fourth generation of SiC MOSFETs is based on a proprietary trench structure that reduces the on-resistance of the active area while maintaining high voltage operation, as shown in Figure 3. The result is the industry’s lowest-loss device that offers fast switching, high reliability and painless implementation.

In addition to reduced conduction losses in the active area of the device, parasitic capacitance is significantly improved. This helps reduce the power lost during high-speed charging and discharging of these parasitics and avoid self-turn-on. The result is a dramatic improvement in heat generation and up to 40% reduction in heatsink size requirements, as shown in Figure 4.
Another important characteristic of the fourth-generation trench design is a markedly higher threshold voltage. In a typical bridge circuit, as shown in Figure 5, there is often the danger of one MOSFET turning itself on too fast, which causes the other device to be accidentally turned on as well due to parasitic $C_{gd}$ coupling. This can significantly increase losses to the switching process because of transient feed-through current. To mitigate this effect, the MOSFETs are often biased in the off state with a dedicated negative voltage supply. This additional supply increases costs, complicates the design and introduces a new potential failure mode.

The higher threshold voltage of Rohm’s fourth-generation SiC MOSFETs facilitates reliable operation without the added complexity of a negative gate bias. Even at elevated junction temperatures, the trench design does not exhibit self-turn-on tendencies during fast-switching events.

The reliability of EV chargers is paramount considering the high voltages and currents involved. A critical reliability metric for MOSFETs in this application space is the short-circuit withstand time (SCWT). Rohm’s unique device structure in its fourth-generation SiC MOSFETs allowed for a lower saturation on-resistance. As a result, the device can survive short-circuit conditions for much longer than a traditional structure would. As shown in Figure 6, the Rohm device can remain in short-circuit for 5.54 µs before failure. This is a significant improvement over the two competitive products used for comparison.

The combination of low on-resistance, minimal parasitic capacitance and high short-circuit endurance makes these SiC MOSFETs extremely efficient and reliable. When combined with the simplicity of single-supply gate bias, these devices are a perfect fit for many of the high-voltage, high-power switching applications seen within EV charging stations.

**SIC DIODES: THE NEXT GENERATION OF AUTOMOTIVE INNOVATION**

High-speed, high-voltage diodes are a critical component in EV charging systems, particularly in LLC resonant inverters. Rohm’s third generation of Schottky barrier diodes (SBDs) employs its proprietary SiC construction to achieve high reverse breakdown voltage with minimal parasitic capacitive charge. This enables very fast reverse-recovery times that are insensitive to operating temperature. Figure 7 demonstrates the improvement in reverse recovery when comparing SiC diodes with their traditional counterparts.

Rohm’s SiC SBDs also offer excellent forward-voltage drop for reduced power consumption, extremely low reverse current and high tolerance to current pulses. Figure 8 presents a comparison of these SiC devices to three competitive diodes.
For high-voltage converters, the combination of SiC MOSFETs and SiC SBDs can be used to reduce total component count and improve overall efficiency. As shown in the schematic below, the number of front-end switches is cut in half, as is the number of secondary diodes.

INCORPORATING GATE DRIVERS INTO AUTOMOTIVE DESIGNS

When designing switching converters for EV charging stations, great care must be applied to the design of the driver circuits. To aid in this effort and minimize design complexity, Rohm provides a wide array of fully insulated and half-insulated driver ICs specifically designed for SiC MOSFETs and other high-power switching devices. A fully insulated example, the BM6105AFW-LB, is shown in Figure 10. This driver uses inductive coupling to completely isolate the low-voltage control signals from the high-voltage gate signals. This is especially useful for the high-side switches that are typically designed with floating-voltage domains.
Figure 12: Comparison of integrated isolation to optocoupler

For applications requiring only half-insulation, the BM60212FV-C can be used, as shown in Figure 11. The high-side devices are inductively isolated, while the low-side devices are driven directly from the control-voltage reference. This reduces design complexity and cost while providing a safe and effective means of switching control.

When comparing Rohm’s inductively coupled gate drivers to the more commonplace optical isolation, significant performance benefits can be gained. As shown in Figure 12, the turn-on and turn-off times of the inductive drivers are more than twice as fast, even at elevated operating temperatures.

Accurate Characterization of Low-Voltage, Small-Form-Factor GaN FETs

By Ryo Takeda, solution architect at Keysight Technologies; Takamasa Arai, application engineer at Keysight Technologies; Ron Simpson, proprietor of GRAD Engineering LLC; and Mike Hawes, power solution consultant at Keysight Technologies

Applications for 100-V (and lower) GaN FETs are numerous, from reducing distortion in Class D audio amplifiers to improving efficiency in synchronous rectifiers and motor drives. They are also popular in 48-V automotive and server applications, as well as USB-C, LiDAR and LED lighting. However, the small size and minimal packaging parasitics create multiple challenges to dynamically characterize these power devices. This article reviews the challenges that GaN semiconductor manufacturers face to characterize these devices, as well as some new technologies that help address these challenges.
In recent years, wide-bandgap (WBG) devices have made significant progress in replacing silicon-based power MOSFETs and IGBTs in many power-related applications. Their fundamental characteristics enable significant improvements in key areas for power applications. When comparing GaN with silicon, it is well known that GaN’s higher bandgap, higher electron mobility and larger electric-field potential enable important attributes, such as lower losses (i.e., higher efficiency), faster switching and a significantly reduced size (i.e., higher power density). However, WBG devices have a much shorter history of use in a variety of power applications compared with silicon, especially “high uptime” applications like automotive.

JEDEC formed the JC-70 Committee in 2017 to develop needed new reliability, characterization, test methods and datasheet enhancements to appropriately characterize GaN and SiC WBG power devices. The existing Si-based standards were not sufficient to enable designers to determine the most appropriate WBG devices for their application. For example, on-resistance (R_{on,sec}), the main parameter characterizing conduction losses, is a dynamic phenomenon in GaN, based on the charge being trapped in the transistor structure (current collapse). JEP-173 was JC-70’s first publication (issued in January 2019) to provide a standard for “dynamic on-resistance test method guidelines for GaN HEMT-based power-conversion devices.”

EXAMPLES OF LOW-VOLTAGE GaN FET APPLICATIONS

One application of the initial Class D audio amplifiers was sound systems for automobiles. The amplifier’s lower power dissipation and superior efficiency (>90%), compared with Class A amplifiers, enabled “limited power” automobiles the ability to have multiple speakers and more sound (>100 W). However, the tradeoff for less power consumption was higher total harmonic distortion (THD), created by slower-switching power Si MOSFETs. GaN FETs with significantly faster switching speeds (up to 10×) and no reverse-recovery charge provide a superior linear response and significantly reduced THD.

In addition to automotive applications, you’ve probably noticed the recent boom in portable speakers. As well as advances in battery technology, this application is enabled by efficient, compact Class D audio amplifiers designed with GaN FETs. Good audio quality is provided because of the lower-distortion attributes of GaN, while the ability to run for extended times on batteries is possible because of GaN’s high efficiency. There are many other portable consumer devices that can leverage the same attributes as portable speakers.

Automotive systems are moving toward higher-voltage operation (e.g., 48 V) as more electrical power needs develop for autonomous driving, including radar, cameras, ultrasonic sensors and LiDAR. These functions require uninterrupted, highly reliable power. As the 48-V bus emerges as one of the new higher-voltage power systems, efficiency is again the key with a limited power source (i.e., car battery). GaN technology enables better power density than silicon, minimizing additional weight, size and thermal management. GaN’s higher-frequency switching and increased efficiency also reduce necessary passive component size (e.g., inductors), further minimizing the size of the power-converter design. DC/DC converters (12–48 V) made from these GaN FETs enable the standard 12-V power bus to supply power for these emerging automotive system requirements.

The motor drive (e.g., stepper motors, drones, etc.) is yet another large application for 100-V (and lower) GaN devices. Low losses often remove the need for heatsinks. GaN enables higher-frequency PWM signals and significantly reduces switching losses. Higher-frequency switching reduces/eliminates switch-node oscillations, which often require snubber circuits in Si-based designs.

The are many evolving applications primed to take advantage of GaN’s superior performance compared with silicon. But the challenges to characterize these devices follow the themes described above: small size (power density) and higher efficiency.

CHALLENGES CHARACTERIZING LOW-VOLTAGE, SMALL-FORM-FACTOR GaN POWER DEVICES

The first major challenge is the package size. Many of the 100-V (and less) GaN FET packages are ball-grid arrays (BGA) ranging from a few millimeters in the X and Y dimensions to sub-millimeters in the X and Y dimensions. These packages have form from a 2 × 2 matrix of solder balls to a 5 × 15 matrix of solder balls. Figure 1 shows an example of an EPC2045, 100-V, 16-A GaN e-HEMT device with a specified R_{on,sec} of 7 mΩ.

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Because the parasitics of the GaN HEMT and BGA package are so low (e.g., typically <1 nH), this GaN FET can switch at very high frequencies (e.g., 1 MHz). To enable the high-frequency switching energy to be accurately characterized, the DPT fixture must also have low parasitics, especially in the power loop and gate loop. These loops should be designed with low-single-digit nanohenry inductance (e.g., 3 nH or less) in mind to minimize the effect of the DPT fixture. Ideally, the fixture parasitics are less than the device/package parasitics, which is extremely difficult to accomplish for these small GaN FETs.

Additionally, creating a repeatable and reliable DUT connection method to enable a statistically valid sample size (e.g., >10) of GaN FETs to be tested is very challenging. The ideal situation is to solder each device on the fixture’s PCA. However, repeated soldering and unsoldering can easily damage a PCA. The mechanical tolerances needed to repeatably contact a solder ball require sub-millimeter placement accuracy in both X and Y dimensions (see Figure 1: dimensions c, d and e).

As mentioned above, the other major challenge is repeatably characterizing the GaN FET’s efficiency. There are three main dynamic parameters that influence efficiency:

- **Conduction loss (i.e., \( R_{DS(on)} \)):** As mentioned above, \( R_{DS(on)} \) is a dynamic measurement for GaN HEMT devices. JEP-173 provides guidelines for measuring and extracting this parameter. What is needed to determine this parameter repeatably and reliably is a very low parasitic DPT fixture providing clean \( V_{in} \) and \( I_{d} \) switching waveforms. In addition, a fast-clamp circuit is needed to settle quickly, enabling a measurement of the clamped \( V_{ds} \) and \( I_{d} \) 50 to 500 ns after the switching event. These techniques will provide the best \( R_{DS(on)} \) measurement to compare against stress voltages and timeframes to characterize the current collapse in the GaN FET structure.
  - Switching loss (i.e., \( \tau_{on}, \tau_{off}, E_{on}, E_{off} \)): These parameters are specified in the IEC 60747-8 standard and are typically specified in power FET datasheets. The ability to measure and extract these parameters repeatably and reliably is highly dependent on the design of the fixture and the minimization of parasitics. Test conditions typically include \( V_{ds}, I_{d}, V_{gs} \) and sometimes the \( L_{load} \) but almost always the gate resistor (\( R_{g} \)). \( R_{g} \) is one of the main controls of the gate-drive speed and ultimately how hard the device is turned on. Most ideally, \( R_{g} \) is a small value, allowing for a fast-switching transition. However, if the DPT fixture design is not optimized and has unwanted parasitics, then a larger \( R_{g} \) is needed to slow down the switching waveforms to minimize ringing.
  - Drive loss (i.e., \( Q_{g} \)): Drive loss is typically the smallest of the losses. Repeatable and reliable measurement and calculation of gate charge (\( Q_{g} \)) requires clean switching waveforms, specifically \( V_{gs} \) and \( I_{g} \). Minimal gate-loop parasitics are critical for clean waveforms.
small GaN FETs are critical. A customized board for this device was developed to determine if Keysight’s solderless contact technology would provide repeatable results for this challenging device (see Figure 3).

After a couple of design iterations to the device holder, including spring tension on the top plate and alignment holes for the baseplate part registration, we were successful in testing multiple sets of parts with this design.

To further minimize loop areas for the gate loop and power loop, a multi-layer PCB was leveraged, enabling trace routing within different layers to minimize the loop areas. The gate drivers and replaceable $R_g$ daughter boards were placed on the back side of the PCB, further reducing loop areas.

Finally, a simplification of Keysight’s patent-pending current-sensor technology allowed the shunt to be placed closer to the DUT, reducing power-loop area while further minimizing the insertion inductance of the sensor. Together, these modifications to Keysight’s existing customized GaN solution enabled industry-leading results for devices like the EPC2045A.

**CONDUCTION-LOSS RESULTS**

The test system setup to measure dynamic $R_{DS(on)}$ is shown in the next table (left). To measure the repeatability of the system, 10 tests were performed using the same EPC2045A GaN FET, reseating the device in between each test. The second table (right) shows the results. A max./min. measurement variation of less than 10 mΩ is very good for a solderless DUT connection technology. Keysight has ideas for further improvement of this critical parameter.

**SWITCHING-LOSS RESULTS**

The test system setup to measure dynamic switching losses, along with some of the standard switching-time parameters, is shown in the table below. To thoroughly understand the sources of variation, two groups of 10 measurements were made. The first group looped the DPT 10 times, without reseating the part. This enabled an understanding of the variability of the instrumentation measurements and extraction algorithms. In the second group of tests, the GaN FET was reseated in between each test, as was done with the $R_{DS(on)}$ measurements. Statistics were performed for both the turn-on and turn-off waveforms (see Figures 5 and 6).
Even when removing parts, max./min. variations in the sensitive time measurements were only ~500 ps to ~2.5 ns, and the max./min. switching-loss variations were less than 1 µJ. These are excellent results, considering the size of the part, a solderless connection and the difficulty in minimizing parasitics. Not surprisingly, the power-loop inductance \( L_{PL} \) of the customized GaN board is less than 2 nH (see Figure 7).

The final parameter affecting losses for the power device is \( Q_g \). The test system setup to measure and extract \( Q_g \) is shown in the table below (left), along with a table reflecting the result of a single measurement of typical \( Q_g \) parameters. Excellent results were obtained, in large part to the close-to-ideal raw \( Q_g \) waveforms and extracted gate-charge graph (see Figure 8).

Lower-voltage GaN FETs (i.e., 100 V) are reducing size, minimizing cooling requirements and improving efficiency for many traditional Si-based power MOSFET applications. As discussed, there are many challenges to repeatably and reliably characterize the dynamic performance of these devices. Careful and thoughtful mechanical and electrical design of a customized GaN fixture and test board can overcome many of these challenges, enabling the confident use of these new WBG devices in your power-converter designs.
Precision Power Solutions for High-Voltage Electroporation

Standard, configurable or custom approach provides ultimate flexibility.

By Todd Huston, director of strategic marketing for electrosurgery at Advanced Energy

Pulsed electric field, or electroporation, is an exciting development within the electrosurgery and life-science fields that enables many new treatments. As a result, the adoption of this technique is growing. Research and development into pulsed field ablation (PFA) is of particular interest, as the ultra-short pulses increase therapeutic effects while minimizing thermal issues.

However, effective system designers must be able to deliver high-voltage (HV) electrical energy accurately. As researchers continue to hone approaches, these systems need to meet varied parameters without compromising precise control.

In this article, Advanced Energy looks at the developments and challenges in this sector and what they mean for power system design. The article will also consider some of the key building blocks for such a system.

Electroporation is a technique whereby HV (electrical field, typically thousands of volts per centimeter) is applied to cells to increase the permeability of the cell membrane. There are two types of electroporation: reversible and irreversible.

Reversible electroporation describes non-permanent pore formation in which a low-intensity electric field that does not exceed the target tissue’s threshold is applied. This permits chemicals, drugs or DNA to enter the cell. Primary applications include gene electrotransfer and electrochemotherapy.

Irreversible electroporation (IRE) is the creation of permanent pores when the electrical field exceeds the target tissue’s threshold. These permanent pores lead to cellular homeostasis disruption, culminating in cell death. Primary applications of IRE include cardiac ablation and tumor ablation.

From a technical perspective, the difference between the two electroporation types is simply a function of the electrical field strength and the duration for which the field is applied.
As a technique for delivering electroporation, PFA is a non-thermal energy modality that has been utilized for solid organ tumor ablation for some time. More recently, investigators have demonstrated a unique safety profile and ablative efficacy related to its ability to selectively target cardiomyocytes while sparing collateral damage to the connective tissue structure. This has driven significant research into different pulse trains to determine the most effective approach for various use cases.

Established PFA approaches apply between 80 and 120 unipolar pulses, with a pulse duration of 50 to 100 ms and an electric field that exceeds 1,000 V/cm. While it can be effective, this typical IRE protocol may evoke muscle contraction during the procedure, leading to pain for the patient and causing displacement of the electrode needles.

Recently, a new type of IRE technique called high-frequency IRE (H-FIRE) has emerged. H-FIRE uses a set of bipolar pulse bursts consisting of individual pulses with durations from 0.5 to 10 ms, grouped into a burst of up to 100 ms.

As a specific example, there are multiple documented studies for the application of IRE to liver tumors, with the earliest dating back to 2011. The tumors ranged in size from 2 mm to 100 mm, although there was a high degree of commonality between the electrical parameters of the IRE treatment. The applied voltage was always in the range of 1.5–3 kV/cm, with a duration of 70–100 µs, and the best results were obtained using plate electrodes to deliver 80 pulses of 100 ms at 0.3 Hz, with an electrical field magnitude of 2.5 kV/cm across the tumor.

THE PFA CHALLENGE FOR POWER DESIGNERS
The primary challenge of power solution design for PFA systems is the need to deliver high-energy HV pulses reliably and repeatably. For life-science applications, typically a power system in the 2- to 300-W region is all that is required. For surgical applications like PFA, individual pulses can be up to 20 kW, with an average power for the system in the kilowatt region.

The voltage required is typically in the 1-kV to 3-kV range, with some applications requiring up to 5 kV with currents up to 65 A. Pulse widths are typically in the range of 100 ns to 100 µs, with burst-mode frequencies up to 5 MHz. The associated slew rates for the pulse are both significant and challenging.

The power supply requires features like overcurrent protection and voltage/current monitoring, as well as compliance with relevant medical safety standards and EMI/EMC regulations.

ARCHITECTURE OF A PFA SOLUTION
Typically, a power solution for a PFA application consists of multiple stages, converting from the AC mains input to the HV pulsed DC output required for treatment. A block diagram of a typical design is shown, although this is a simplified view, as the AC/DC front end will usually have multiple outputs to power peripheral devices like displays and the HMI.

The first stage is the AC input and power-factor correction (PFC), shown in orange. This addresses critical compliance parameters, including primary-secondary isolation, leakage current, EMI filtering and PFC. The input can be any AC mains voltage (or even a DC voltage), and the output will typically be an isolated DC voltage of about 380 V.

One technology suitable for front-end PFC is Advanced Energy’s Artesyn AIF04ZPFC series of full-brick PFC modules, which accept a universal 85- to 264-VAC input and present a unity power factor. The modules, which can also be configured to accept a DC input within the range of 120 to 370 VDC, are rated at 1,600 W, have a high conversion efficiency of 95% and provide a nominal non-isolated output voltage of 380 VDC. Featuring an industry-standard 2.4 × 4.6-inch full-brick form factor and a height of only 0.5 inches, the modules have a power density of 290 W/in.³. An enable
function is provided and AIF04ZPFC modules can be operated in parallel for systems requiring greater power levels. A power-fail warning signal is provided, as is an enable output to control downstream devices like the DC/DC converter.

The next stage is a DC/DC converter that produces a tightly regulated voltage from the approximately 380-V output of the PFC stage. This block (shown in blue) also adds further isolation and control while reducing the output ripple and noise. The full specification of the output is largely determined by the requirements of the following HV stage.

The final stage (shown in green) is the HV pulsed DC output that is connected to the patient. This is often a discrete, board-mounted solution, such as Advanced Energy’s UltraVolt high-power 1/8C to 6C series. These regulated DC/DC converters are designed for HV capacitor-charging applications that demand fast rise times with controlled voltage overshoot. Devices in the high-power C series operate from a 24-V input, driven by the output from the blue DC/DC converter stage.

There are several devices available, all with unipolar outputs ranging from 125 to 6 kV at power levels of 60 W, 125 W or 250 W. The highly accurate outputs have ripple values of <1.0% and a temperature coefficient of 50 ppm/°C.

A range of factory-configured options is available, including a choice of 5-V or 10-V operation for control and monitoring, and the header can be replaced by a D-sub connector. A factory-mounted heatsink and threaded standoffs for PCB mounting are also available.

System control and feedback can be further enhanced by the addition of a Fiber Bragg Grating Analyzer (FBGA) for accurate temperature monitoring. The latest FBGAs have no moving parts and employ high-efficiency optical designs that provide excellent wavelength repeatability, resolution, long-term stability, ultra-low power consumption, sub-millisecond response time and lifetime calibration.

FLEXIBLE SOLUTIONS

With so many potential configurations for PFA systems, flexibility is key to ensuring that the needs of the end application are met. Configurable AC/DC power supplies are ideal, as they provide the medical isolation and leakage currents required, and they can incorporate multiple output modules to power peripherals and the HV power module. This is especially beneficial during experimental phases, as the configuration can be changed with nothing more than a screwdriver.

A good example comes from a major medical device company that recently worked with Advanced Energy to deliver a novel PFA solution that used a non-thermal energy source and proprietary HV electric fields to overcome the challenges of traditional temperature-based ablation modalities. This solution required an HV DC/DC power supply to charge a capacitor with a tightly regulated output of up to 2,000 V. While an UltraVOLT high-power C series module easily met the technical requirements, prototyping revealed a need for both a control connector that could be secured with screws and built-in cooling for the unit. To address these requirements, a DB15 D-sub connector and a finned heatsink option were added to the module, and a new sample was delivered and rapidly approved.

Additionally, the customer required a low-power, adjustable voltage DC/DC converter. In this case, Advanced Energy engineers recommended a standard UltraVOLT AA series 1/16AA24-P20 (62-V/20-W) solution to provide a well-regulated, adjustable 0- to 62-V power supply with low ripple and good stability.

CONCLUSION

Electroporation is an emerging therapy segment. Because of advances in precision pulsed HV technology, we are seeing a rapid increase in terms of manufacturing inquiries on precision power control solutions. Depending on the application, these solutions can be developed from standard modules or configurable power supplies. However, in certain situations, a modified-standard product or even full customization is required.

Figure 5 summarizes the various types of power technologies that can be chosen for PFA applications. Naturally, in addition to addressing the technical specifications of a given application, all of these technologies are compliant with the relevant medical standards to minimize the testing and certification needed by the final system.

By choosing the best power technology for a given application, medical equipment designers can deliver advanced ablation systems that ensure more precise targeting of tumors, improve the efficacy of treatments and, ultimately, deliver improved outcomes for doctors and patients.
Gen 4 SiC FETs Provide Lowest On-Resistance in TOLL Package

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

Qorvo’s Gen 4 silicon carbide field-effect transistor (SiC FET) is a type of power transistor that can handle high voltages and currents. Compared with traditional silicon-based transistors, SiC FETs offer several advantages, including lower losses, higher efficiency and better thermal performance. These advantages make SiC FETs ideal for use in several power electronics applications.

Qorvo’s Gen 4 SiC FET features the latest SiC technology, which enables it to deliver the highest levels of performance. The device is optimized for high-voltage power converters and can handle up to 1,200 V (1.7-kV devices are available in Qorvo’s Gen 3 SiC portfolio, too). It also features a low on-resistance ($R_{DS(on)}$), reducing the amount of power lost as heat and reducing the need for external heatsinks.

Another key feature of Qorvo’s Gen 4 SiC FET is its ruggedness. It also has a low gate charge, reducing the energy required to switch the device on and off, simplifying the gate driver design and improving efficiency.

**BENEFITS OF SURFACE-MOUNT TOLL PACKAGE**

The surface-mount TO-leadless (TOLL) package, suitable for space-constrained applications, offers advantages in size, performance and ease of assembly compared with traditional TO packages. The main benefits offered by the TOLL package are as follows:

- **Reduced size:** The TOLL package is surface-mountable and leadless, which reduces its size and footprint compared with traditional TO packages.
- **High performance:** The TOLL package is designed for high-performance power devices, offering excellent thermal conductivity, low parasitic capacitance and inductance, high power density and better switching performance than traditional TO packages.
- **Ease of assembly:** The TOLL package is surface-mountable, allowing easy and efficient assembly in automated manufacturing systems.

**QORVO’S NEW 750-V GEN 4 SiC FETS**

Qorvo (UnitedSiC) has recently announced a 750-V/5.4-mΩ SiC FET offered in a novel surface-mount TOLL package, extending the company’s performance leadership and broadening its portfolio of groundbreaking Gen 4 SiC FETs. This product is the first in a line of 750-V SiC FETs, with $R_{DS(on)}$ ranging from 5.4 mΩ to 60 mΩ, that will be offered in the TOLL packaging. These components are perfect for use in applications with limited space, such as solid-state relays and circuit breakers that can handle 100 A of current and AC/DC power supplies ranging from several hundred watts to multiple kilowatts.

Through acquiring UnitedSiC in October 2021, Qorvo has built a high-performance portfolio of SiC-based FET products, enabling the company to deliver power solutions covering applications like power conversion, motion control and circuit protection.

**CHALLENGING APPLICATIONS**

The new devices meet the needs for size, efficiency and cost of server power supplies, where power density has increased above 100 W/in.$^3$ because of power-hungry processors, and more power in the same size ($>3$ kW, per AC/DC PSU) is required. Similarly, solid-state circuit breakers require solutions able to meet the requirements of space-constrained applications, in which active cooling is an option and the ability to withstand high currents and high voltages is mandatory.
Qorvo’s new TOLL-package devices meet the mentioned requirements due to their:

- Reduced package footprint area
- Thinner package, allowing thicker heatsinks
- Low power losses
- Surface-mount-technology package, enabling automated assembly onto PCB daughter cards for lower cost
- Low resistance per package, avoiding the need to parallel multiple FETs
- High-current withstand capability and longer short-circuit withstand time
- Noise immunity with adequate response time

The advantages of the TOLL’s reduced footprint and height, compared with a conventional D2-PAK package, are shown in Figure 1.

The new SiC FETs take advantage of Qorvo’s exclusive cascode circuit arrangement, in which a SiC JFET is co-packaged with a silicon MOSFET, to create a device that fully leverages the efficiency benefits promised by wide-bandgap switch technology and the easier gate drive of silicon MOSFETs. SiC JFETs provide the same $R_{\text{DS(on)}}$ as SiC MOSFETs but require a much smaller chip area and are normally on devices. Combining a SiC JFET with a normally off silicon MOSFET, the cascode configuration retains the benefits of JFETs, allowing at the same time the compatibility with standard SiC MOSFETs. Cascode is a normally off configuration, transparent to the customer and featuring a standard three-terminal device with gate, source and drain.

The new FETs achieve an industry-leading 0.1°C/W thermal resistance from junction to the case despite the large size reduction. Enabled by advanced production procedures, such as sintered die attach, the new 750-V/5.4-mΩ UF4SC75005L8S has a continuous current rating of 120 A up to case temperatures of 144°C and a pulsed current rating of 588 A up to 0.5 ms. This results in an “I^2t” rating roughly 8× better than a silicon MOSFET in the same packaging, enhancing robustness and immunity to transient overloads while simplifying the design process. The combination of the extremely low $R_{\text{DS(on)}}$, high $T_{\text{j(max)}}=175$°C and outstanding transient thermal behavior provides this. Additionally, the maximum overcurrent of the SiC FETs is 2.8× higher than the lowest-$R_{\text{DS(on)}}$ silicon MOSFET in the same package ($I_{\text{t(max)}}=0.5$–1 ms). Figure 2, which shows the maximal pulse current versus pulse width of silicon and SiC FETs packaged in TOLL, exemplifies this.

These new ultra-low-$R_{\text{DS(on)}}$ TOLL parts are great choices for protection applications that are frequently thermally challenging in small, enclosed places with no active cooling available because of their low conduction loss, compact size, high-surge ruggedness and outstanding turn-off capabilities. They can minimize heatsinking and avoid the need to parallel several FETs.
Infineon launches EU projects for power electronics and artificial intelligence

Infineon Technologies is launching two major EU projects in Villach (Austria) to address the climate crisis. Gallium nitride energy-saving chips that can be quickly integrated are the focus of the “ALL2GaN” project.

NI Announces Software-Defined Battery Lab Solution

NI has made the Software-Defined Battery Lab solution available. The new service, intended for electric vehicle battery validation labs, represents a significant development in NI’s extensive testing capabilities, which span the complete, sustainable battery lifecycle from research and development to validation, production, second-life, and remanufacturing.

onsemi and Sineng Electric develop applications for sustainable energy

onsemi has announced that Sineng Electric will integrate onsemi EliteSiC silicon carbide (SiC) MOSFETs and IGBT-based high-density power integrated modules (PIMs) into its utility-scale sustainable energy solutions, including solar inverter and industry-first 200kW energy storage system (ESS).

Energous doubles energizing capabilities with 2W PowerBridge transmitter

Energous Corporation has announced the launch of a new 2 Watt conducted power transmitter, which addresses the growing power demands from the rapidly expanding IoT ecosystem across supply chain, logistics, retail, industrial and agricultural industries.
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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