WHITEPAPER

Enhancing charging performance with Infineon's USB-C PD solutions

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Abstract

Universal Serial Bus Type-C (USB-C) has become a prevalent interface for data transfer and power delivery across a wide range of electronic devices. USB-C distinguishes itself from other USB connectors with a reversible connector and the capability to support significant power levels up to 100 W and more. This feature has transformed charging practices, promoting a unified charging standard for devices from smartphones to laptops.

Since its introduction, the USB-C standard has incorporated the USB Power Delivery (PD) specification, enhancing its capacity to deliver higher power compared to older USB standards. This functionality accelerates charging times and simplifies the overall charging infrastructure by moving towards a more versatile charging solution.

This whitepaper explores the advancements in USB-C power delivery, discussing a range of topics including current market trends, strategies for selecting optimal components, topologies and controllers, their benefits, and considerations for mitigating Electromagnetic Interference (EMI). It aims to provide stakeholders, including developers, manufacturers, and consumers, with a detailed understanding of USB-C PD's capabilities and limitations, facilitating well-informed transitions to more efficient power delivery mechanisms.

1 Introduction

The Total Addressable Market (TAM) for the charger and adapter sector is projected to expand significantly, exhibiting a Compound Annual Growth Rate (CAGR) of 9.2% from 2022 to 2028 [1]. This growth highlights notable shifts in technological adoption and consumer purchasing behavior, illustrating an evolving landscape where the demand for more efficient and powerful charging solutions is on the rise.

A recent study conducted by SAR Insight & Consulting and Infineon indicates a strong market shift toward chargers with higher power outputs, especially in the segment exceeding 75 W. The market for these high-powered chargers is expected to grow from $460 million in 2022 to a substantial $1,974 million by 2028. This trend is driven by consumer preferences for faster charging capabilities and the emergence of devices that require more power, highlighting a pivotal shift in the technological needs of modern electronics.

Conversely, the market for chargers with less than 30 W is observing a decline, anticipated to drop from $755 million in 2022 to $260 million in 2028. This decline can largely be attributed to a strategic shift by original equipment manufacturers (OEMs), who have started removing chargers from the boxes of new phones beginning in 2021. This move, part of broader environmental and cost-saving measures, reflects changing industry standards and consumer expectations.

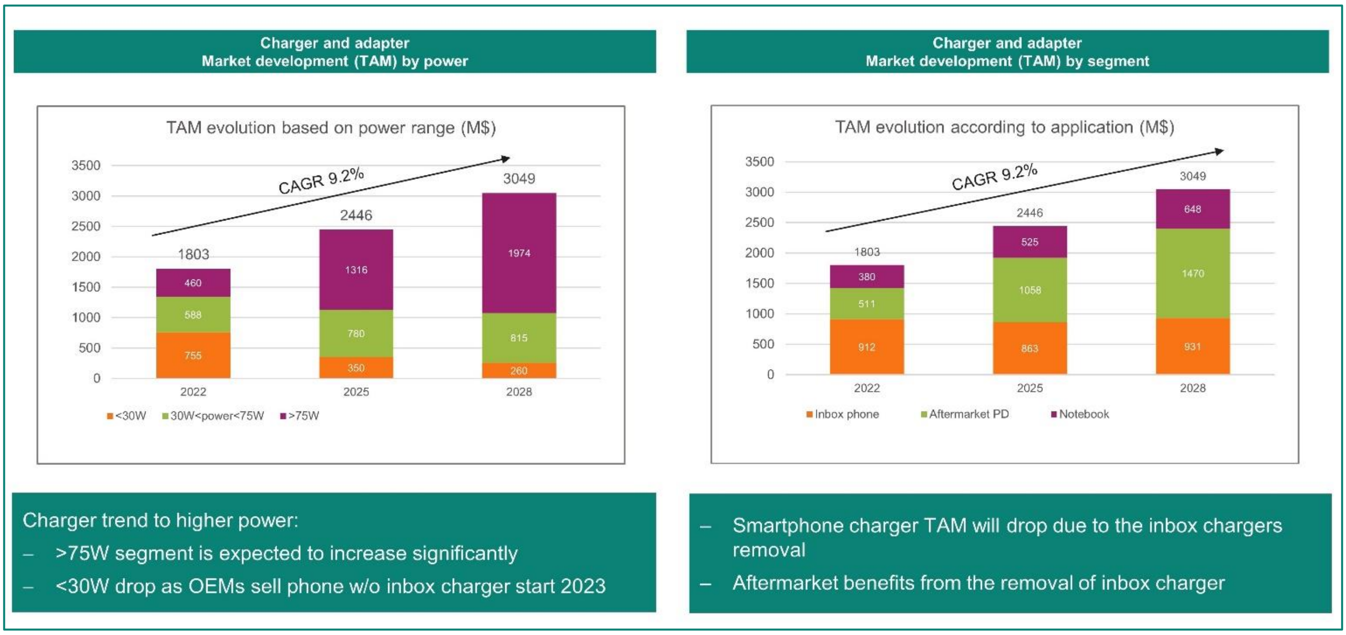

Figure 1 TAM evolution based on power range (left); TAM evolution according to application (right)

The impact of OEMs removing chargers from product packaging is also evident in the market segmentation by application as presented in figure 1 (right). The in-box phone/tablet charger segment shows minimal growth from $912 million in 2022 to $931 million in 2028, a stark contrast to the substantial growth in the aftermarket PD segment. The latter is projected to increase from $511 million in 2022 to $1,470 million by 2028, driven by a rise in demand for replacement and additional chargers. This trend is indicative of a flourishing market opportunity for manufacturers to innovate and cater to the aftermarket demand.

Similarly, the laptop charger segment is ready for growth, anticipated to rise from $380 million in 2022 to $648 million in 2028. The increasing reliance on portable computing and the ongoing advancements in laptop technology necessitate more robust and efficient charging solutions, propelling growth in this market segment.

The charger and adapter market is undergoing significant shifts due to technological advancements and strategic changes by manufacturers. As the industry evolves, companies need to strategically position themselves to capitalize on emerging trends and market opportunities while addressing new consumer and regulatory challenges. Effective adaptation is essential for sustained growth and maintaining a competitive edge in this dynamic market.

2 Component choices and design techniques

USB-C PD is a critical charging solution, requiring a comprehensive understanding of its design principles and technological components. This section addresses USB-C PD design, focusing on selecting topologies suited for high power and density, gallium nitride (GaN) switches to enhance efficiency, and advanced controllers for effective power management.

It also discusses the methods for minimizing EMI, essential for maintaining system integrity and compliance. Each subsection is dedicated to explaining the technical elements necessary for developing robust USB-C PD systems that meet demanding performance criteria.

2.1 Selecting the right topology

Selecting the appropriate topology is a foundational and critical step in designing USB-PD systems. Charger designs feature a variety of topologies, each optimized for particular performance requirements and efficiency levels. Among them, the most commonly used topologies are:

- Quasi-resonant (QR) flyback
- Zero voltage switching (ZVS) flyback
- Active-clamp flyback (ACF)
- Hybrid flyback, or commonly known as an asymmetrical half-bridge flyback converter

2.1.1 Quasi-resonant (QR) flyback

The QR flyback topology is popular due to its cost efficiency and simplicity. It operates using valley switching—where switching actions occur at the minimum voltage points (valley points) in the switching waveform to minimize energy loss. However, consistent zero-voltage switch-on is not possible to be achieved across all input voltages with QR, especially at high inputs, which increases the stress and power-loss in the MOSFET. Additionally, this topology requires the transformer to store all the energy, leading to larger transformer sizes, and limiting power density.

To counter this, increasing the switching frequency may reduce the transformer size but increase losses from parasitic elements, such as leakage inductance and MOSFET capacitance. Newer soft-switching topologies are developed to overcome these limitations.

2.1.2 Zero voltage switching (ZVS) flyback

Infineon's introduction of the secondary-side controlled QR ZVS flyback using the EZ-PD™ Power Adapter Generation (PAG2) chipset marks a significant advancement, optimizing zero-voltage turn-on and minimizing the need for external components. This topology aims to streamline charger design and enhance operational efficiency. Figure 1 and figure 2 showcase the QR ZVS flyback topology with ZVS operation principles. The EZ-PD™ PAG2 controller is discussed in detail in an upcoming section.

As in the case with the flyback circuit's operating principle, after the primary FET is turned off, the synchronous rectification (SR) MOSFET will turn on with a slight delay by a short blanking time. Ideally, when the demagnetizing current reaches zero, the SR MOSFET is turned off, causing the magnetizing inductance L_p and equivalent capacitance C_{eq} to oscillate. The voltage across the primary MOSFET will oscillate between V_{bulk}+$V_{reflect}$ to V_{bulk}-$V_{reflect}$. Just before the primary MOSFET is reactivated, a short ZVS pulse is applied to the SR MOSFET to build a negative magnetic-tank energy depending on the duration of the ZVS pulse. Once the ZVS pulse ends, the energy stored in the magnetizing inductance induces a current in the primary circuit to discharge C_{eq} across the primary FET's drain to source. With a configurable dead-time delay, the primary FET drain voltage is minimized to zero, creating a perfect ZVS condition to switch on the primary FET.

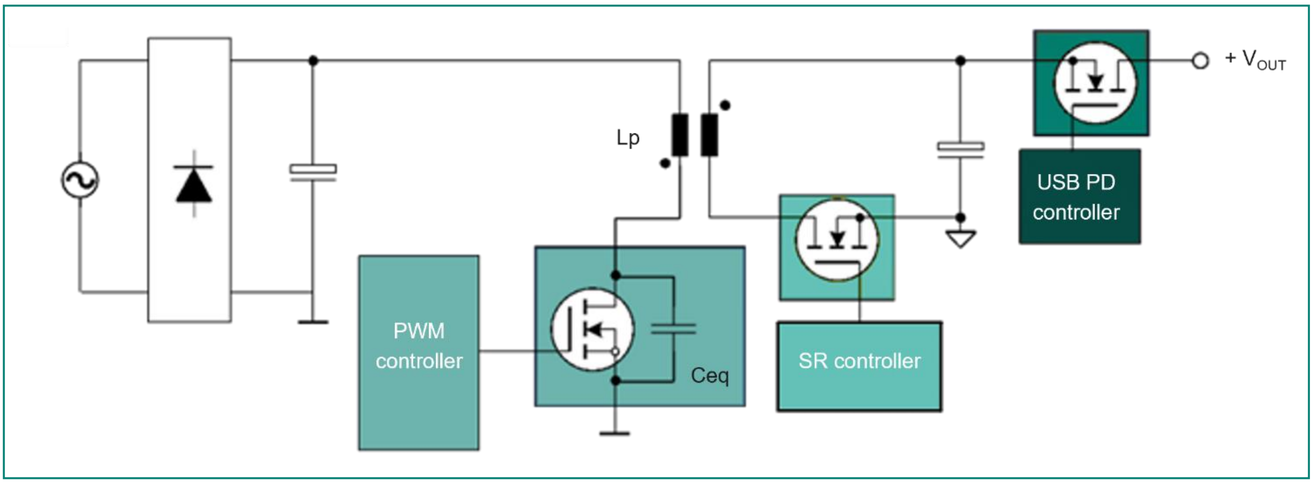

Figure 2 QR ZVS flyback topology

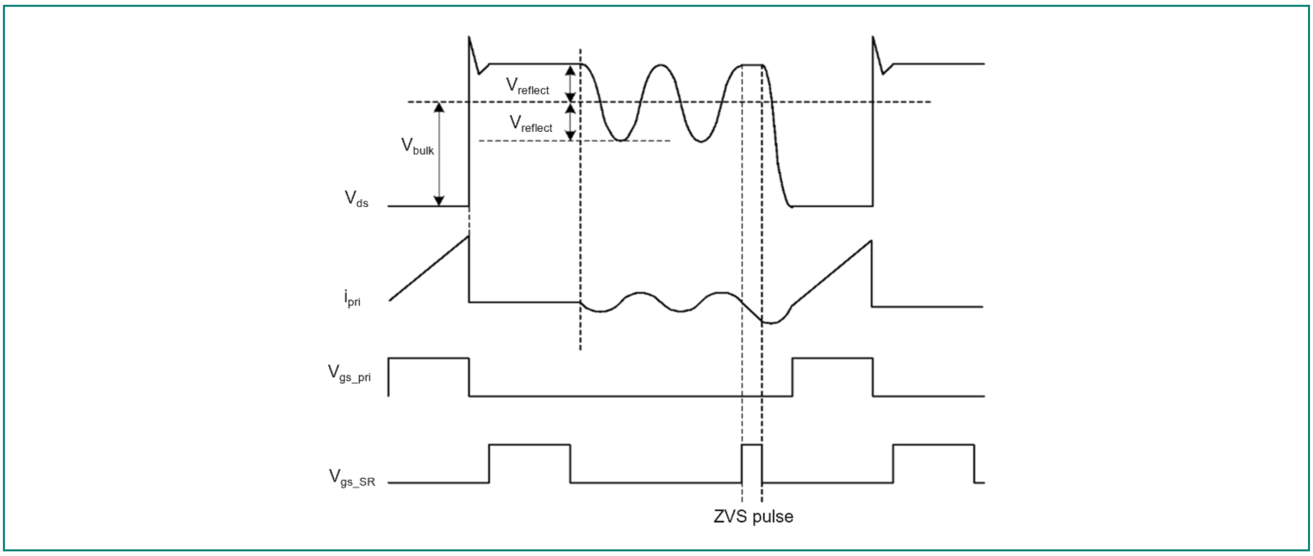

Figure 3 Timing diagrams for the QR ZVS topology

2.1.3 Active-clamp flyback (ACF)

Infineon's EZ-PD™ PAG2 chipsets also support the ACF configuration to further improve system efficiency. ACF improves upon the traditional flyback technique by incorporating an active clamp that recycles the energy from the transformer leakage to the output load via a clamp-capacitor. The ACF also enables ZVS events for the primary FET. This allows for a higher switching frequency and a reduction in the size of the power supply. The operating principle is shown in Figure 3 and Figure 4. The control-timing concept is similar to that of QR-ZVS, but the ZVS generation here is done by the primary high-side FET instead.

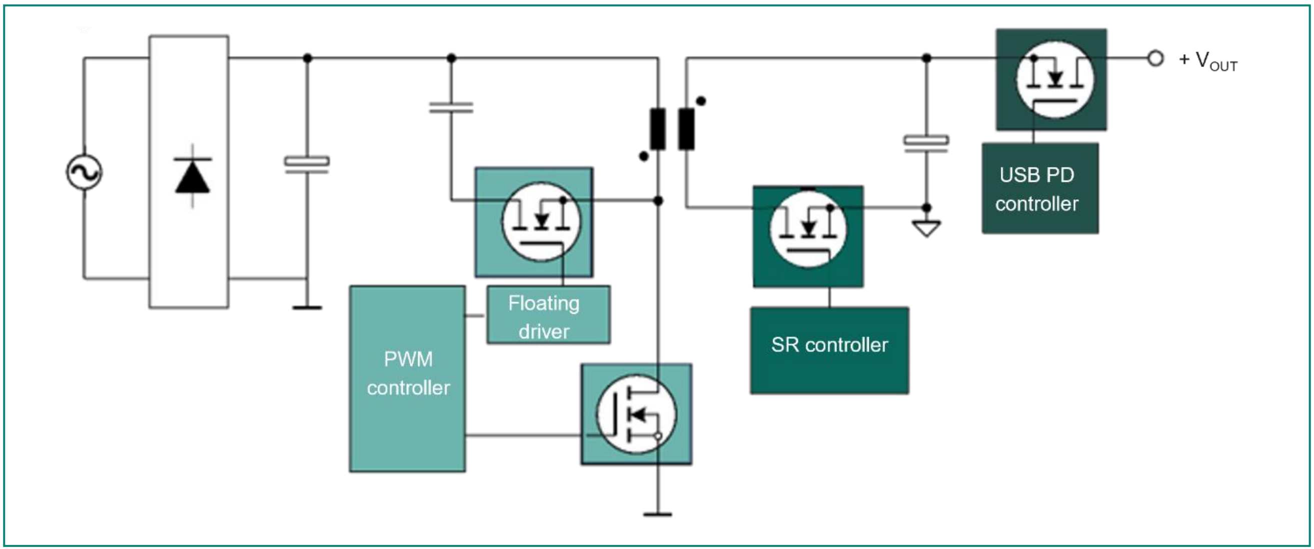

Figure 4 ACF topology

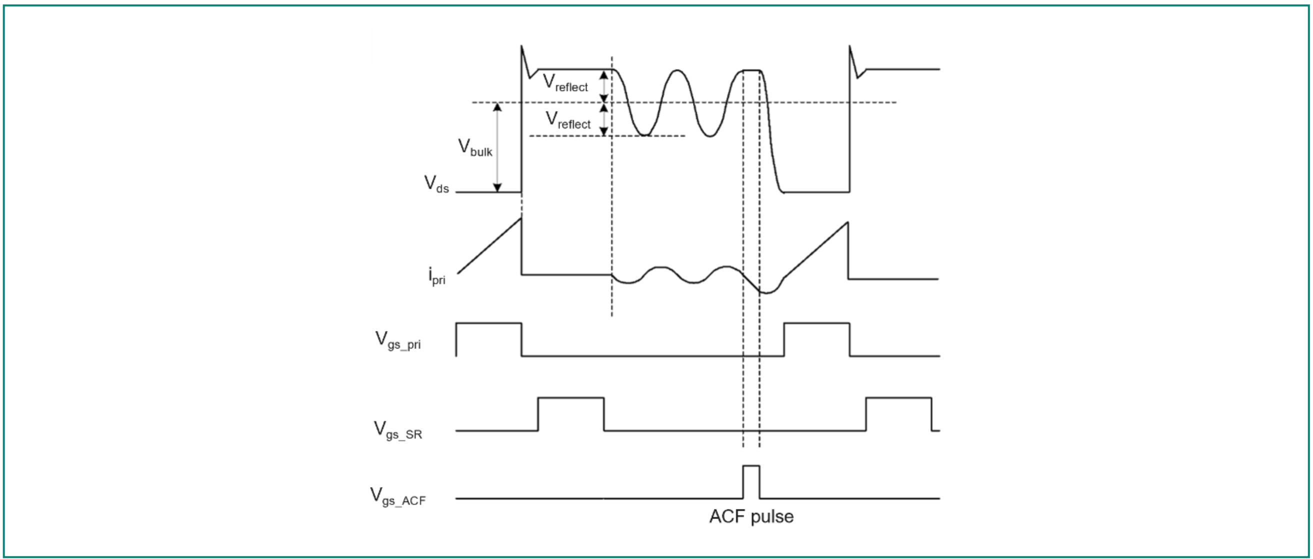

Figure 5 Timing diagrams for the ACF topology

2.1.4 Hybrid flyback

Infineon's XDP™ digital power XDPS22xx family supports the innovative hybrid flyback topology. This topology, also known as the asymmetrical half-bridge flyback converter, merges the features of flyback and forward converters. It addresses the main problems related to high-density adapters operating at moderate switching frequencies. The hybrid topology can ensure ZVS and zero-current switching (ZCS) over line and load. It lays the foundation for the highest conversion efficiency by using the magnetization current to achieve ZVS on the primary-side half-bridge and ZCS on the synchronous rectification switch. The parasitic leakage inductance is an integral part of the converter.

Unlike other topologies, hybrid flyback transformers do not need to store all the energy, thus reducing the charger's size. Hybrid flyback can achieve full ZVS operation on the primary side, and full ZCS operation on the secondary side, and the leakage energy is recycled, thereby achieving high efficiency. The duty-cycle directly influences the output voltage, offering a solution to the limitations of the LLC topology in applications requiring a wide range of output voltage output:

$$V_{out} = D \cdot V_{in} \cdot L_m / N / (L_m + L_r)$$

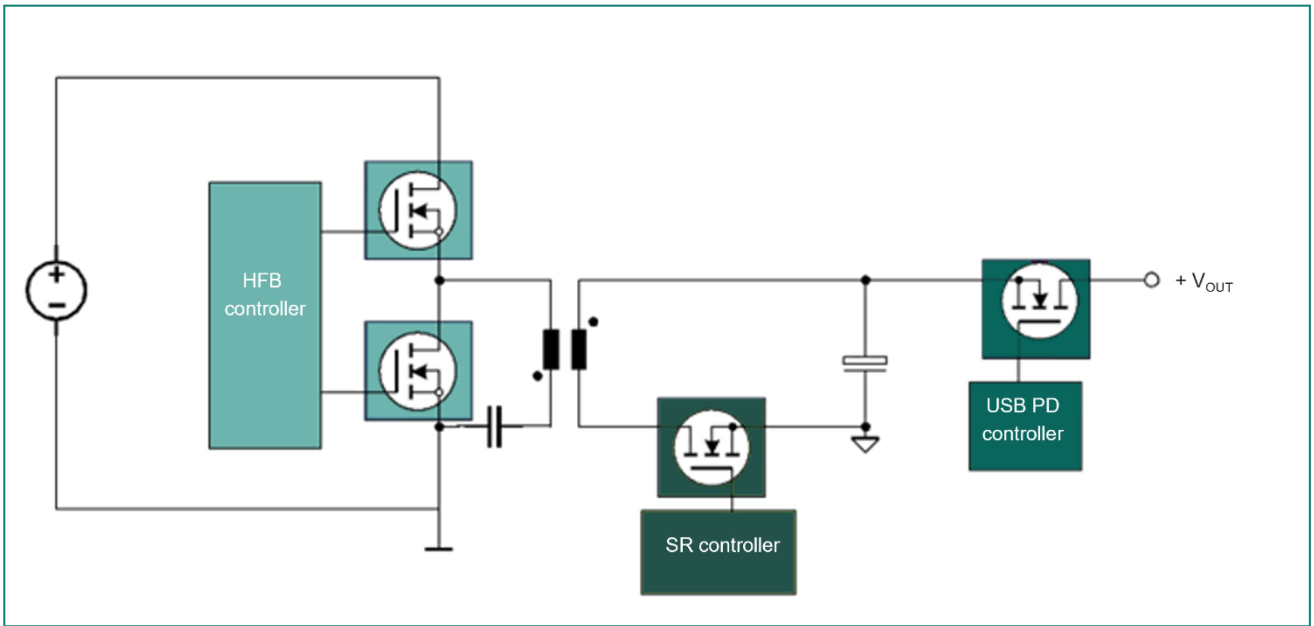

Figure 6 Hybrid flyback topology

2.2 Choosing the right GaN switch

Selecting the optimal GaN switch is crucial for attaining high efficiency and power density required by contemporary electronic devices. GaN power transistors stand out due to their superior electrical properties compared to silicon (Si) MOSFETs, providing substantial benefits in a wide array of applications from mobile chargers to industrial power systems.

2.2.1 Overview of GaN transistors

GaN transistors represent a significant advancement in semiconductor technology, distinguished by their exceptional efficiency and robust power handling. Utilizing the wide-bandgap (WBG) properties of GaN, these transistors surpass traditional silicon devices with a higher voltage-withstand capability and faster switching speeds. Their low on-resistance and intrinsic capacitance facilitate compact, efficient designs that generate less heat, making them ideal for demanding applications like fast-charging systems, power supplies, and renewable energy converters.

Infineon's CoolGaN™ series offers both discrete and integrated GaN solutions, achieving unmatched efficiency and power density and is suitable for power conversion up to 700 V. The transistors feature rapid turn-on/off capabilities, minimal switching losses, and diverse packaging options. This combination allows for easier and quicker design processes, superior performance, reduced costs, and simplified implementation, setting new benchmarks in the industry.

Features and applications of CoolGaN™ Transistors

- **Voltage range and current handling:** Infineon's CoolGaN™ Transistors operate across a range of 60 V to 700 V with current capacities from 4 A to 150 A, catering to diverse power requirements.
- **Ultrafast switching speed and high efficiency:** These transistors feature ultrafast switching capabilities with no reverse-recovery charge, capable of reverse-conduction, and boast low gate and output charges. Such characteristics lead to improved system efficiency and higher power density.
- **Physical and thermal advantages:** Due to their lower on-resistance and lower capacitances relative to their Si counterparts, GaN transistors have reduced losses, shrunk system weight and improved thermal management in compact designs.
- **Driving capability:** Infineon's CoolGaN™ can be driven directly by PWM controllers through simple RC networks.

Infineon's GaN devices are ideal for a variety of high-power applications, including USB-C adapters and chargers, 48 V power distribution and more. Their fast-switching properties and high efficiencies make them suitable for demanding applications that require high power density and efficient heat management.

Technical considerations and design guidelines

- **Synchronous rectification:** GaN transistors excel as SR switches due to their lower charges and faster switching transitions. However, they exhibit a higher third-quadrant mode voltage drop compared to MOSFETs, which can lead to increased conduction losses during turn-on/off. These losses are more pronounced at higher switching frequencies.

- **Optimization for high frequencies:** To minimize dead-time losses, it is critical to optimize the controller circuit to shorten the delay for turn-on and turn-off gate-biasing. The layout of the PCB plays a significant role in the accuracy of drain-source voltage (V_{DS}) sensing and the SR controller's reaction time, impacting the efficiency of the GaN transistor.
- **Design implementation:** Although GaN transistors offer numerous advantages, they require more consideration of the chosen topology, PCB layout, and the specific operational requirements of the application to obtain additional values. Special attention must be given to the potential increase in switching losses during higher-frequency operations, which necessitates an optimized design approach.

GaN-based power devices represent a significant advancement in power semiconductor technology and are particularly well-suited for USB-C PD applications that demand high efficiency and compact form factors. By understanding the characteristics, applications, and design considerations of GaN devices, developers can leverage these advanced components to build superior power systems that meet the needs of today's high-performance electronic devices.

With Infineon's CoolGaN™ products and comprehensive design support, engineers are well-equipped to utilize GaN to its fullest potential, enhancing the performance and efficiency of their power conversion applications.

2.3 Choosing the right controller

In the design of USB-C PD systems, choosing the right controller is necessary to ensure efficient, reliable, and safe power management. Controllers are sophisticated electronic components that manage the power flow between sources and devices, executing critical functions such as voltage regulation, power conversion, and safety protocol enforcement.

They play a very important role in optimizing the performance of power delivery systems by adapting to the varying power demands of connected devices while maintaining compliance with USB-PD standards.

2.3.1 Secondary-side-controlled ZVS flyback converter chipset – EZ-PD™ PAG2

EZ-PD™ PAG2 from Infineon is a sophisticated solution tailored for creating efficient USB-C power adapters and chargers. It is a comprehensive solution designed around a secondary-side-controlled ZVS (QR ZVS and ACF) flyback converter. This advanced chipset comprises two main components: EZ-PD™ PAG2P and EZ-PD™ PAG2S, which work in harmony to deliver efficient power management and conversion across various applications.

EZ-PD™ PAG2P: This component serves as the primary HV (high-voltage) startup controller within the chipset. It integrates several critical functionalities:

- **HV start-up function:** Facilitates the initial power-sequence, utilizing an internal high-voltage JFET to charge the VCC capacitor, transitioning control from the high-voltage startup to the auxiliary winding of the flyback transformer post the initial phase.
- **PET receiver and gate drivers:** Includes a pulse edge transformer (PET) receiver that helps maintain isolation and robust communication between the primary and secondary sides. It also integrates both low-side NFET and high-side logical level gate drivers for robust switch management.
- **Comprehensive protection:** Features fault protection, x-cap discharge, and a VCC boost converter, which collectively help in minimizing the bill of materials while enhancing system performance and reliability.

EZ-PD™ PAG2S: This secondary-side controller is crucial for executing precise power-delivery and regulation as well as USB PD communication. It supports various topologies and operational modes:

- **ACF:** The EZ-PD™ PAG2S-AC configuration utilizes this mode to enable efficient energy-recycling and ZVS operation, significantly enhancing the overall system efficiency.
- **QR-ZVS:** In the EZ-PD™ PAG2S-QZ configuration, a synchronous rectification control scheme is employed that optimizes ZVS without the need for additional winding or switches, making it highly efficient for quasi-resonant operations.

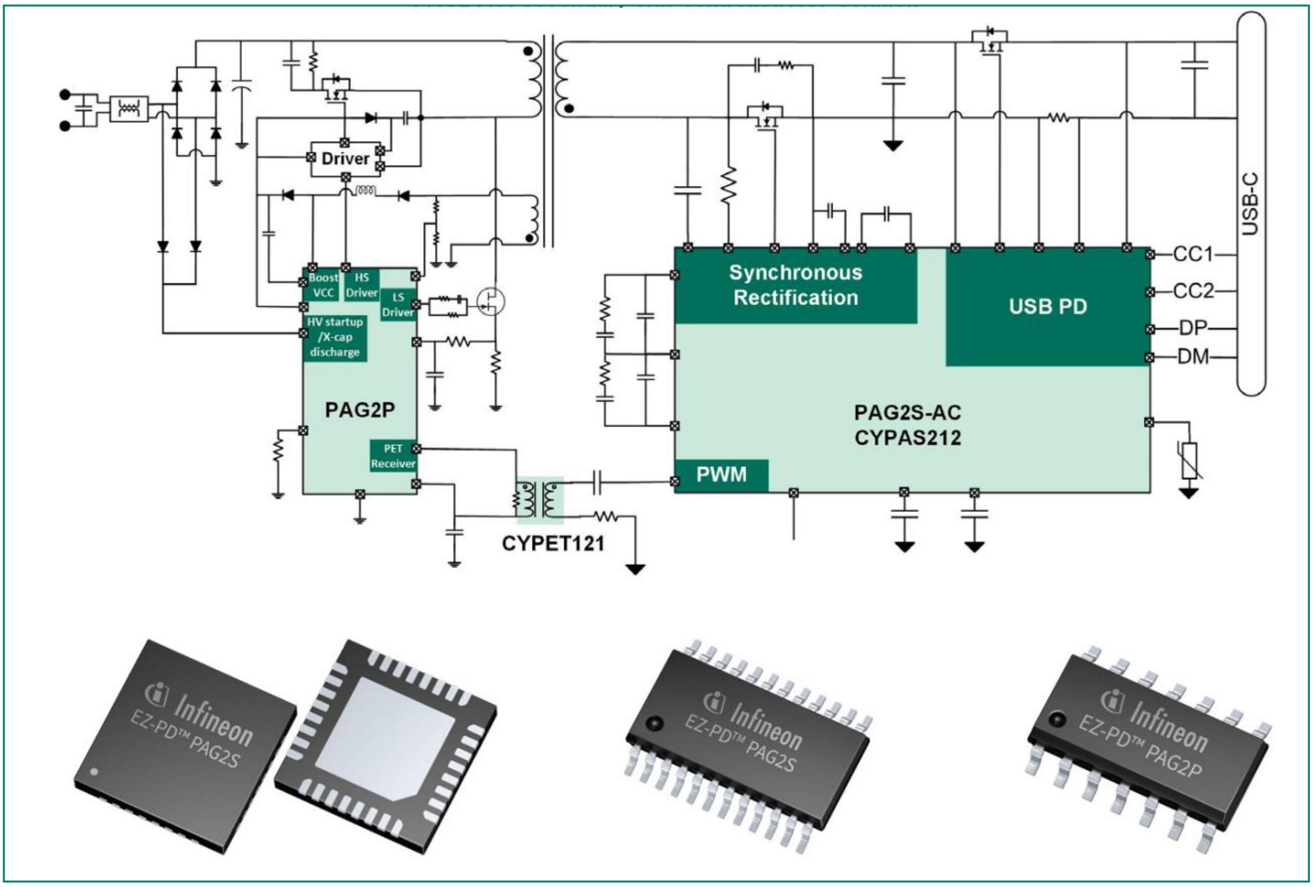

Figure 7 **EZ-PD™ PAG2-AC: secondary-side controlled ACF solution**

Technical benefits and system integration

The EZ-PD™ PAG2 series not only supports active-clamp and quasi-resonant topologies but also improves regulation accuracy and synchronous rectification. Thus, it reduces standby-mode power-consumption compared to traditional primary-side-controlled PWM controllers. Its programmability extends across multiple parameters:

- **Digital valley table:** Allows for optimizing switching moments to minimize energy loss.
- **Adjustable ZVS/ACF pulse-width and frequency:** Tailors the operation to specific needs, enhancing efficiency and response.
- **Configurable SR turn-on/off delays:** Improves the responsiveness and effectiveness of synchronous rectification.

2.3.2 PFC and hybrid flyback combo ICs - XDP™ digital power XDPS22xx

Infineon supports hybrid-flyback design with various controllers:

- XDP™ digital power XDPS2201: Controller for DC-DC hybrid-flyback stage
- XDP™ digital power XDPS2221: Controller for combo-control of QRM-PFC plus DC-DC hybrid-flyback stage
- XDP™ digital power XDPS2222: Controller for combo-control of QRM-PFC plus DC-DC hybrid-flyback stage supporting extra wide output-voltage range

When targeting high-power adapter and charger designs, the PFC plus hybrid flyback combo IC XDP™ XDPS2222 represents a significant advancement in power-controller technology, particularly for applications that demand high-efficiency power conversion with integrated Power Factor Correction (PFC) and a versatile DC-DC hybrid-flyback operation. XDP™ XDPS2222 is engineered to address the complex requirements of USB-PD chargers and adapters, supporting a broad output-voltage spectrum of up to 48 V.

Architectural overview of PFC plus hybrid flyback combo IC XDP™ XDPS2222

The XDP™ XDPS2222 PWM controller is a highly integrated device that uniquely combines a multimode AC-DC PFC controller with a DC-DC hybrid-flyback controller in a single package. This integration facilitates the reduction of external component counts and optimizes overall system performance through the harmonized operation of the PFC and hybrid-flyback stages.

Key features and functionalities

- **Integrated gate drivers:** XDP™ XDPS2222 supports both GaN and Si switches, providing flexibility in choosing power components based on performance and cost objectives. Integrated gate drivers enhance the efficiency and reliability of the switching operations.
- **High-voltage start-up cell:** Features a 600 V high-voltage start-up cell for fast VCC charging, essential for quick power-up sequences and maintaining efficiency under variable load conditions.
- **Burst-mode operation control:** This feature is crucial for achieving the lowest no-load standby power, a critical factor in enhancing energy efficiency across operational conditions.
- **Adaptive PFC and hybrid-flyback control:** The controller adapts the PFC bus voltage according to operating conditions, which is vital for optimizing efficiency during average and light-load operations. The hybrid-flyback control, utilizing ZVS operation of high-side and low-side switches, further improves efficiency.

System optimization and performance enhancement

XDP™ XDPS2222 excels in environments that require:

- **Variable output-voltage range:** Supports system designs that need a wide output-voltage range, crucial for applications ranging from small personal devices to larger electronic components.

- **Configurable protection modes:** Ensures robust system protection with customizable parameters that guard against overcurrent, overvoltage, and under-voltage conditions.

Application scenarios and integration

- **USB-PD chargers/adapters:** XDP™ XDPS2222 is ideally suited for chargers that require efficient power conversion over a wide voltage range. Its capability to integrate PFC and hybrid-flyback functionalities makes it a compact and efficient solution for modern USB-PD applications.

- **Energy-efficient system designs:** By leveraging novel ZVS hybrid-flyback topology and adaptive control features, XDPS2222 allows designers to create highly efficient and compact power adapters without sacrificing performance.

Technical benefits

- **Reduced external parts:** By integrating multiple control functions into a single controller, XDPS2222 significantly reduces the bill of materials, simplifying the design and manufacturing process.

- **Enhanced system efficiency:** The controller's advanced features enable ultrahigh system efficiency, which is crucial for reducing thermal stress and improving the longevity of the end product.

2.3.3 Single- and multi-port PD plus DC-DC controllers – EZ-PD™ CCG7SC/CCG7DC

The multiport controller EZ-PD™ CCG7xC family that includes EZ-PD™ CCG7SC and EZ-PD™ CCG7DC, stands as a flagship solution within Infineon’s portfolio for managing complex USB-C PD requirements in charging applications. The products come with an on-chip 32-bit Arm® Cortex®-M0 processor and are designed to cater to the robust demands of multiport chargers and adapters, providing a blend of high output power, advanced USB PD compliance, and integrated buck-boost functionality.

Architecture and key features

- **EZ-PD™ CCG7SC (single-port controller):** This controller integrates a USB-C PD controller with a buck-boost converter, making it suitable for single-port applications. It supports up to 100 W of power output per port, adhering to the USB Type-C and PD 3.1 specifications. The inclusion of a highly integrated buck-boost controller aids in maintaining optimal power levels across various device requirements.

- **EZ-PD™ CCG7DC (multi-port controller):** Extending the capabilities of EZ-PD™ CCG7SC, EZ-PD™ CCG7D is tailored for multi-port configurations, enabling up to 100 W per port. This model is particularly beneficial in environments where simultaneous charging of multiple devices is required, such as desktop charging stations, multi-power wall chargers, public charging kiosks and more.

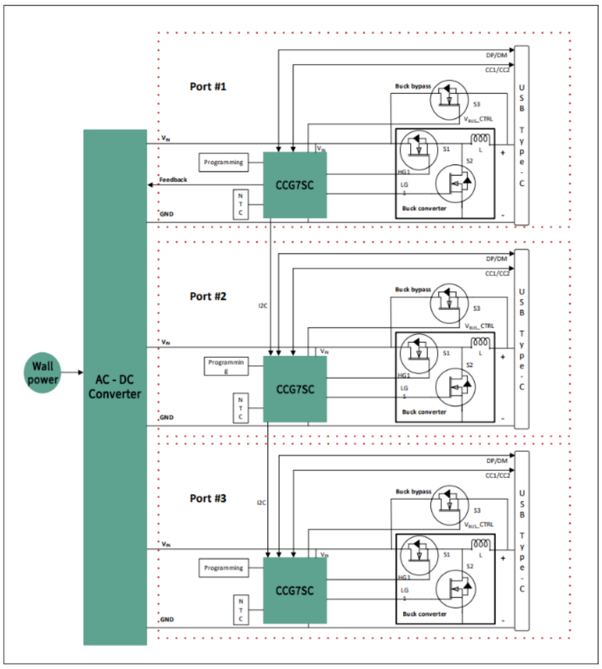

Figure 8 **A high-level block diagram of a charger and adapter solution using EZ-PD™ CCG7SC**

Integration and system optimization

Both models in the EZ-PD™ CCG7xC series are built to reduce the BOM and provide a compact footprint for charging and power delivery applications. They incorporate several advanced features that enhance system design:

- **Configurable Software Development Kit (SDK):** Accompanied by a comprehensive SDK , both controllers allow customized implementation of features such as dynamic power-sharing, output-power-throttling based on battery voltage and temperature, and sophisticated diagnostic capabilities via a black-box function.

- **Safety and reliability:** The controllers include comprehensive fault protection mechanisms such as overvoltage, under-voltage, and over-temperature protections, ensuring reliable operation under rigorous conditions.

- **Firmware upgradability:** Both models support authenticated field firmware updates, allowing ongoing enhancements and compliance with evolving standards without needing hardware changes.

Technical specifications and benefits

- **Programmable power supply (PPS):** Supports detailed power management and communication with connected devices, ensuring optimal charging efficiency and device compatibility.

- **Advanced charging protocols:** Beyond standard USB PD, the controllers support various fast-charging protocols, including Qualcomm QC 2.0/3.0/4.0/5.0, Apple 2.4 A charging, and Samsung AFC, providing versatility across different device ecosystems.
- **Granular power management:** Features like granular output-power-throttling and dynamic load-sharing optimize the energy distribution based on real-time system and battery conditions, enhancing the overall efficiency and longevity of the battery.

2.4 Planar transformer design and EMI reduction techniques

Planar transformers are a variant of traditional wire-wound transformers, distinguished by their construction and the materials used. Instead of using round wires, planar transformers employ flat conductors or etched circuits, which are often integrated directly into a PCB. This design allows for a more compact, lower-profile transformer that fits well in power-dense electronic devices.

The core of a planar transformer is typically made from ferrite and aligns closely with the layers of the PCB, enabling efficient magnetic coupling and heat dissipation. The windings, made from copper foil or tracks etched onto the PCB, are arranged in planar coils that stack above or beside each other.

Planar transformers are gaining significant attention in the charger/adapter market due to their compatibility with the growing demand for portable, high-density power solutions. Their slim, low-profile design is particularly well-suited for compact devices, aligning seamlessly with the industry's push towards enhancing portability without compromising on power capacity.

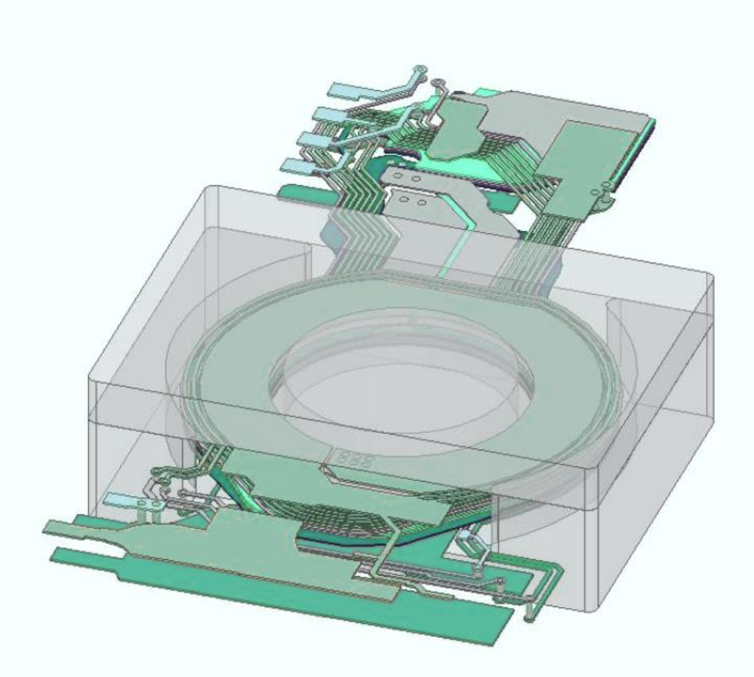

Figure 9 A planar transformer

Advantages of planar transformers

There are a number of advantages of the planar transformer, such as:

1. **A slim design is achievable:** Thanks to the compact and flat configuration of the planar core, the overall profile of the device is significantly reduced.
2. **Automation eliminates manual labor in the production of planar transformers:** Due to the small and flat window defined by the planar core, it is very common to use PCB-winding instead of wire-winding to build the transformer. PCB-winding is manufactured through standard PCB-fabrication, which is fully automatic. This helps keep the product consistent in terms of magnetic and capacitive coupling, which will, in turn, ensure the consistency of system performance in mass production.
3. **Better magnetic coupling and lower leakage-inductance:** Improved magnetic coupling and reduced leakage-inductance are significant benefits of using PCB winding designs in planar transformers. This design approach enhances magnetic coupling, leading to decreased leakage inductance. Leakage inductance is a primary factor contributing to voltage overshoot in various topologies, notably in widely utilized flyback converters. By minimizing leakage-inductance, designers can either enhance the design margin for the selected power FET or opt for lower V_{DS}-rated power FETs as a cost-saving measure. Additionally, reduced leakage inductance contributes to efficiency gains in commonly used flyback converters with passive snubber circuits.
4. **EMI-reduction through noise-cancellation**: With multilayer PCB-winding in use, it is possible to create a unique 3D PCB design to minimize the displacement current flowing from the primary to the secondary and lower the common-mode noise across the transformer. One design example is shown in the Figure 10 below.

An identical PCB pattern is designed right between the adjacent layers of Pri and Sec, which have the same shape and polarity. By doing so, the voltage-potential of adjacent layers is purposely designed to be up/down together with the same polarity and amplitude, and the displacement current between primary and secondary can be dramatically reduced for lower EMI.

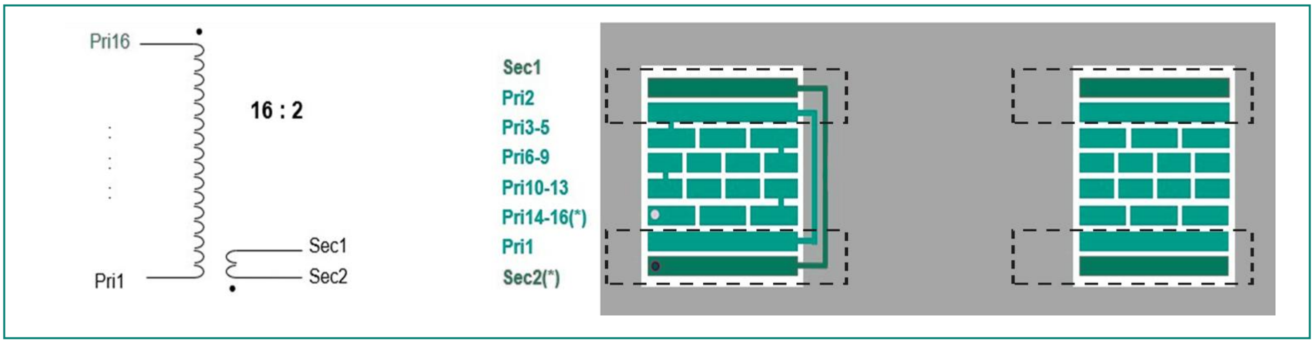

Figure 10 **Cross-sectional view of a planar transformer**

Challenges and solutions in implementing planar transformers

There are a few challenges in implementing planar transformers. Some of them include:

- **Very limited core-window area for winding design and also limited winding turn numbers are allowed:** In order to deliver the rated power with the limited winding turns, a high switching frequency is required, such as 200 kHz or above. Consequently, relevant components to support high switching frequency are necessary to build the system, including power switches, magnetic core material, PWM controllers, etc. GaN transistors is the right component with fast switching and is a good fit for the requirement here.
- **High capacitive-coupling between windings will form parasitic capacitors in the SMPS circuit:** In conventional hard-switching topologies, such parasitic capacitances lead to high switching losses in power FETs and cause the efficiency to drop as well as a thermal issue in the device. The solution to address this issue is to implement soft-switching control to recycle the capacitive energy for efficiency improvement.

Infineon provides full support with GaN transistors and high-frequency ZVS PWM controllers to make the perfect combination with a planar transformer to enable high-density slim design.

3 Infineon's latest reference designs

3.1 Ultrahigh-density 65 W solution based on EZ-PD™ PAG2

REF_65W_HFACF_PAG2_PA is a compact 65 W USB-C PD power adapter solution by Infineon, leveraging the innovative ACF topology, designed for higher frequency operations, which significantly enhances the efficiency and performance of the system. This ACF topology features ZVS of the FETs, which minimizes switching losses and improves overall efficiency by allowing for complete energy recovery from transformer leakage inductance—a major advantage over traditional QR flyback RCD clamps.

This solution employs the non-complementary (NCP) mode, which reduces circulating currents under light loads, thereby minimizing losses and improving system efficiency.

Figure 11 REF_65W_HFACF_PAG2_PA - compact 65 W USB-C PD power adapter

Central to this solution are the EZ-PD™ PAG2P and PAG2S controllers, which manage the primary-side startup and secondary-side USB PD power adapter control, respectively. These controllers are integral to optimizing the performance of the power solution, ensuring that it meets the rigorous demands of modern consumer electronics. EZ-PD™ technology not only supports the dynamic control needed for high-efficiency power conversion but also facilitates the implementation of multiple fast-charging protocols, making the solution versatile across different device requirements.

Features and advantages

- **High efficiency:** Achieves greater than 94 percent peak efficiency, reducing heat generation and extending battery life in consumer devices.
- **Advanced control:** Supports multiple charging protocols, including USB PD 3.1, enabling compatibility with a wide range of consumer electronics.

– **Enhanced safety:** Integrates comprehensive protection features such as overvoltage, undervoltage, overcurrent, and short-circuit protection, ensuring reliability and safety in operation.

The design also emphasizes safety and reliability, incorporating features that protect against common electrical hazards, thus ensuring the charger's suitability for high-volume consumer applications. With its robust design and advanced technological features, the 65 W solution sets a new standard for charger efficiency and versatility, making it an exemplary choice for manufacturers looking to enhance their products with superior power solutions.

3.2 Ultrahigh density 140 W design based on hybrid flyback control

The REF_140W_HFB_PAG2S is an ultrahigh-density 140 W design, utilizing a hybrid flyback control (HFB) strategy, which is a significant advancement from traditional power conversion methods, allowing for higher power densities and efficiency. This design incorporates XDP™ digital power XDPS2221, a controller that combines PFC and hybrid flyback technologies to optimize the conversion process across a wide range of operating conditions.

Figure 12 REF_140W_HFB_PAG2S - 140 W ultra-high power density USB-C EPR adapter

The hybrid flyback method employed here is distinct as it combines the benefits of both flyback and resonant converter topologies. The PFC feature ensures that the power supply operates with high efficiency at varying load conditions by adjusting the input current to be in phase with the input voltage, thereby minimizing reactive power and improving the power factor. This is particularly important in applications where energy efficiency and minimal power wastage are critical.

Moreover, the use of the XDPS2221 IC allows for seamless integration of these features into a single, compact solution. This IC not only manages the PFC and HFB operations effectively but also includes integrated gate-drivers, which reduce external component requirements and simplify the overall system design. The hybrid approach allows for ZVS in the flyback topology, which further enhances efficiency by reducing switching losses.

On the secondary side, EZ-PD™ PAG2S (CYPAS213) is used. It engages the internal error amplifier (EA) to take the feedback from the secondary side and pass it on to the primary controller over an isolation barrier like an optocoupler for output regulation. Furthermore, EZ-PD™ PAG2S integrates three key features:

- Secondary-side rectification
- Charging protocol control up to 28 V
- Fault protection like overvoltage protection (OVP), under voltage protection (UVP), overcurrent protection (OCP), short-circuit protection (SCP), and system over-temperature protection (OTP)

The solution supports extended power range (EPR) for USB PD, making it suitable for devices that require fast charging capabilities. This is crucial in today's market, where the demand for quick and efficient charging solutions is growing.

Key benefits

- **Enhanced efficiency:** By integrating PFC with hybrid flyback control, the solution achieves optimal efficiency across a wide range of input voltages and load conditions.

- **Compact design:** The integration of multiple functions within a single IC helps reduce the overall footprint of the power supply, crucial for applications where space is at a premium.

- **Versatility:** Supports various fast-charging standards and can handle higher power outputs, making it suitable for a broad spectrum of consumer electronics, from smartphones to portable gaming devices.

This ultrahigh-density 140 W solution exemplifies how advanced control methodologies and integration can lead to significant improvements in power supply design, offering manufacturers a competitive edge in developing next-generation electronic devices.

3.3 Ultrahigh-density 240 W design based on hybrid flyback control

The REF_XDPS2222_240W1 is an ultrahigh-density 240 W design, engineered to handle even more demanding applications by leveraging the enhanced capabilities of the HFB methodology, specifically tailored for high power requirements. This design utilizes the XDP™ XDPS2222 IC, which is an advancement over its predecessors, designed to efficiently manage higher power outputs essential for more robust applications.

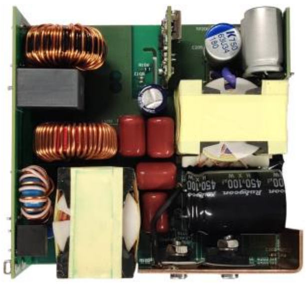

Figure 13 REF_XDPS2222_240W1 – 240 W USB PD form factor reference design

This solution integrates advanced power PFC with a high-performance hybrid flyback system, enabling it to deliver up to 240 W. The use of the XDPS2222 IC allows for significant improvements in efficiency and power density. The hybrid flyback design incorporates ZVS, which is crucial for reducing switching losses at higher power levels, thus maintaining high efficiency across a broad spectrum of operating conditions.

The PFC feature ensures that the power supply conforms to international efficiency standards by adjusting the phase of the input current to align with the input voltage, thereby optimizing the power factor. This is particularly important for reducing energy consumption and meeting regulatory requirements for electronic devices.

This 240 W solution also supports USB-C PD EPR, making it highly suitable for devices such as gaming laptops, high-performance tablets, and other power-intensive portable electronics. The versatility offered by this design is crucial for keeping pace with the increasing demands of modern electronic devices that require more power and faster charging in a compact form factor.

Features and advantages

- **Superior efficiency:** The integration of PFC with hybrid flyback control ensures optimal efficiency at higher power-levels, critical for reducing heat generation and improving overall device performance.
- **High power-output:** Capable of delivering up to 240 W, this solution meets the needs of the most power-intensive devices, supporting a wide range of applications from consumer electronics to industrial equipment.
- **Advanced charging capabilities:** Supports USB PD EPR, providing fast charging capabilities that are becoming standard in the industry for high-end electronic devices.

The ultrahigh-density 240 W design represents a significant step forward in power supply technology, offering an optimal balance between power, efficiency, and size. This makes it an ideal choice for manufacturers aiming to enhance the power capabilities of their next-generation devices without compromising on efficiency or form factor.

4 Summary

The USB-C interface, known for its reversible connector and capability to support up to 240 W, plays a pivotal role in setting a new standard for device charging, from smartphones to laptops. This whitepaper provided a comprehensive overview of the advancements in USB-C PD solutions, highlighting their transformative impact on the charging and power delivery mechanisms across various electronic devices. The paper explained the technical components and considerations necessary for implementing these high-power solutions, including the selection of appropriate topologies, GaN switches, controllers, and methods for reducing EMI.

Furthermore, it explored the market dynamics driven by the growing consumer demand for faster and more efficient charging solutions, evidenced by significant projected growths in high-powered charger segments. The shift towards USB-C PD was also influenced by environmental considerations and cost-saving strategies, such as the removal of chargers from device packages, which further drove the market for aftermarket charging solutions.

Infineon's advancements in GaN technology and innovative charging topologies were discussed, providing insights into their potential to enhance system efficiency, reduce size, and support the high power-demands of modern electronic devices. The paper concluded that the ongoing evolution in USB-C PD technology not only met current market needs but also set the stage for future innovations in power delivery solutions. This progress is crucial for manufacturers, developers, and consumers who are transitioning towards more efficient and standardized charging ecosystems.

References

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