Exclusive Technology Feature

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# Using Forced-Frequency Resonant Zero-Voltage Switching In USB PD Adapters

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Since its introduction in the mid 1990s, USB has not just standardized computer connectivity, with the introduction of the smartphone it has become the power socket of choice for charging. Having hit gigabit speeds with the release of USB 3.0 in 2015 this bus has the potential to completely replace all other types of cables typically associated with PCs and laptops. This includes displays. Until now, however, such devices, as well as external disk drives, printers and scanners, have still required an additional power supply cable.

The development of the USB Power Delivery (USB PD) specification which was released in 2012 with important updates in 2014 (PD 2.0), 2015 (PD 3.0) and 2017, could eliminate this extra cable. Capable of supplying anything from 5 to 20 V and supporting power levels up to 100 W, USB-C cables may be the only thing we need to power our laptops, as well as to connect a wide range of peripherals to them. USB PD also breaks the previous 7.5-W power limit at 5 V, opening up the possibility of charging smartphone batteries even faster.

This article discusses some of the challenges in designing USB PD-based power adapters and how they can be addressed using a switching technique known as forced-frequency resonant zero voltage switching in a DCM-operated flyback topology. A reference design based on a controller developed to implement this technique, the XDPS21071, is presented, its principles of operation and other circuit details are explained, and a prototype and measurements of its efficiency are provided and discussed.

## Both Efficiency And Style Are Required

As smartphones and laptops have become more stylish, so have the power adapters that go with them. A weighty lump of black plastic complete with ac input and dc output cables (in the case of a laptop adapter) no longer matches the sleek lines and matte or gloss finish of the portable devices that catch our eye. Consumers expect their compact, stylish power adapter accessories to fit directly into wall sockets, giving little regard to the miniaturization challenge engineers face in addition to their fulfilling a raft of electrical standards, safety requirements, and efficiency demands.

The quasi-resonant switching converter operating in discontinuous conduction mode (DCM) is the topology of choice in such high-density ac-dc designs. This eases the development challenges and offers a more stable loop control than the alternatives. Despite these advantages, there are still some areas that require optimization.

In low-line situations, the MOSFET almost operates in zero-voltage switching (ZVS) mode. However, in high line situations this is no longer the case, resulting in a fair amount of switching loss. The clamping network also contributes losses, but calculating these is quite tricky.

Using a slow reverse-recovery diode can push a portion of the energy back into the bulk capacitor or the output (Fig. 1). While this results in lower snubber-related losses at high line input, it also leads to higher snubber losses at low line. Using a MOSFET with a higher output capacitance ($C_{OSS}$), together with ZVS, allows leakage current to be recovered. This, together with low $R_{DS(ON)}$ devices, also helps limit conduction and leakage losses.

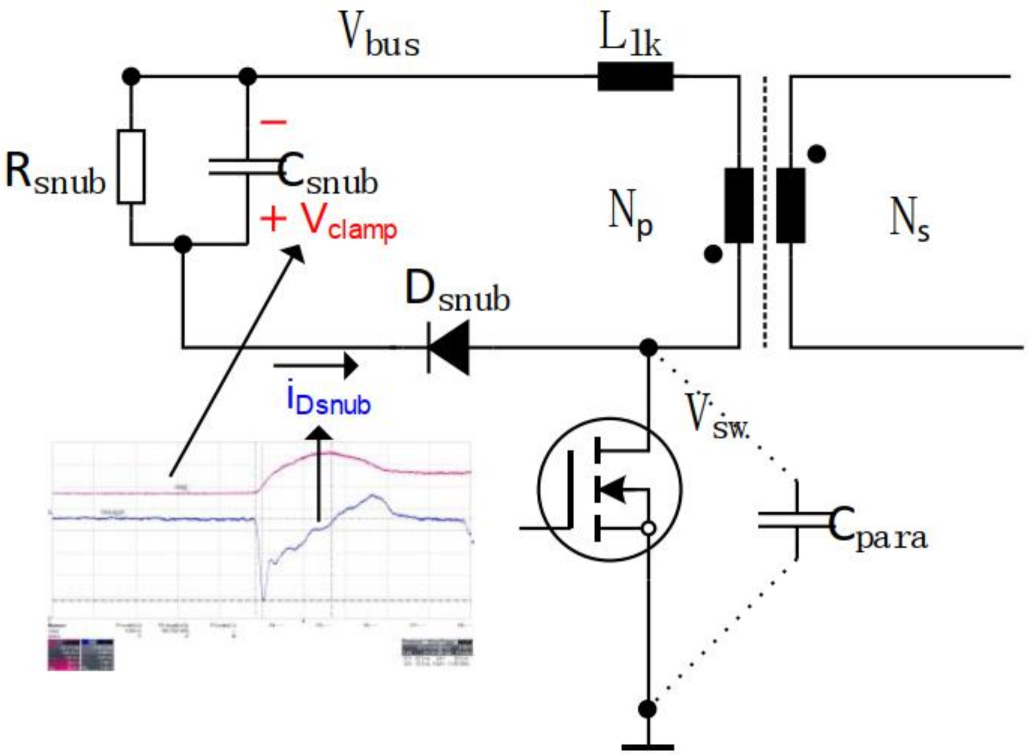



*Fig. 1. A slow reverse-recovery diode can push a portion of the energy back into the bulk capacitor or the output.[1]*

A final difficulty lies in the relationship between load and switching frequency, as this topology drops to its lowest switching frequencies under heavy loads. This is suboptimal in terms of transformer utilization at peak power levels. The variation of frequency change under QR control is also a typical cause of common-mode noise interference in touchscreen applications.

In order to simplify the manufacture of the transformer, manufacturers prefer to work with windings integrated into the printed circuit board (PCB). This requires operation at frequencies above 100 kHz to reduce copper losses. This directs the designer toward a fixed-frequency ZVS design, which is referred to as forced-frequency resonant ZVS (FFRZVS).

By implementing switching at the zero-voltage point in the primary transformer, the turn-on losses of the power switch can be minimized. This reduces heat dissipation in this device and increases efficiency. By operating at high frequencies, the size of the magnetic components can also be minimized, allowing for a high-density, compact solution.

## *Principles Of Operation For FFRZVS*

The circuit approach for FFRZVS differs minimally from a conventional flyback design in that it only incorporates one additional winding added to the primary side. In addition to the primary winding and the auxiliary winding that is used for zero-crossing detection, a zero-voltage winding is included. This allows for a self-controlled ZVS cycle. Together with a capacitor, power switch, and low-side gate driver, this addition can be implemented at a low system cost compared to a high-side approach (Fig. 2).

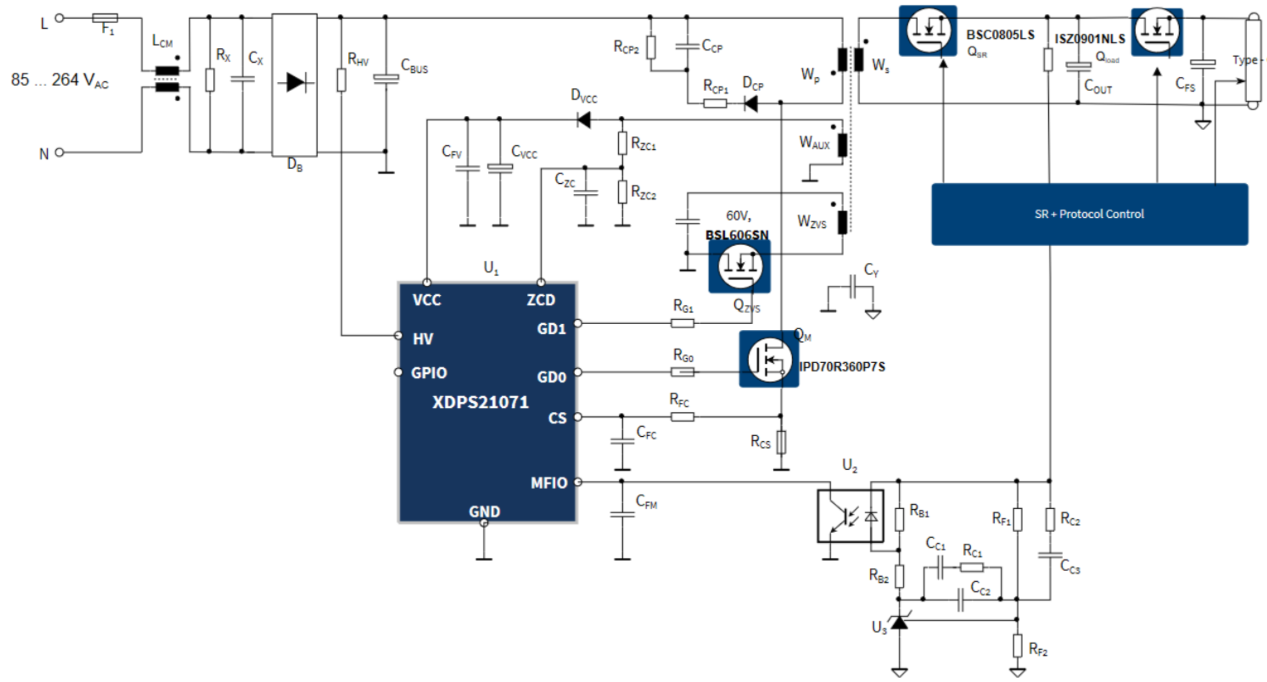



*Fig. 2. Simplified circuit diagram highlighting additional $W_{ZVS}$ winding and components for the FFRZVS flyback design.[2]*

The sequence of operation differs minimally from classical designs, as shown in Fig. 3. After the primary MOSFET ($Q_M$) turns off ($t_0$), the synchronous rectifier (SR) MOSFET is engaged after a short blanking time. Once the magnetizing current drops to zero, this switch turns off ($t_1$) and the primary-side coil together with the equivalent capacitance on that side oscillate around the voltage $V_{bulk}$. It is at this point that the additional coil ($W_{ZVS}$) comes into play ($t_2$). Engaging the ZVS MOSFET associated with the $W_{ZVS}$ winding at the resonant peak of the primary MOSFET where the magnetizing current is zero, results in a negative magnetizing current building up.

Once a peak current is reached, this ZVS MOSFET is switched off again ($t_3$). This causes the current in the magnetizing inductance to reverse direction, discharging the energy in the equivalent capacitance. This results in the drain voltage of the primary MOSFET reaching a minimum at which point it turns on ($t_4$). This results in a significant reduction in the turn-on losses, coming close to that of true ZVS.

Determination of the precise timing relies on the controller’s measurement of the output voltage. It is also important to note that this ZVS approach is only possible during discontinuous conduction mode (DCM) operation.

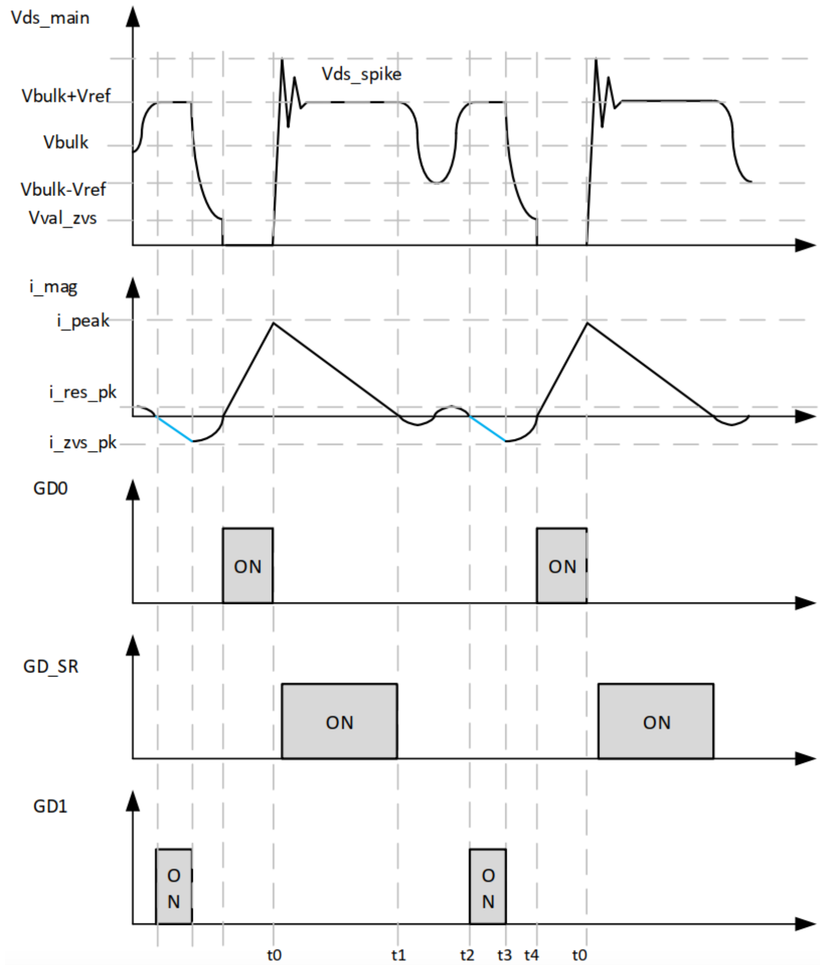


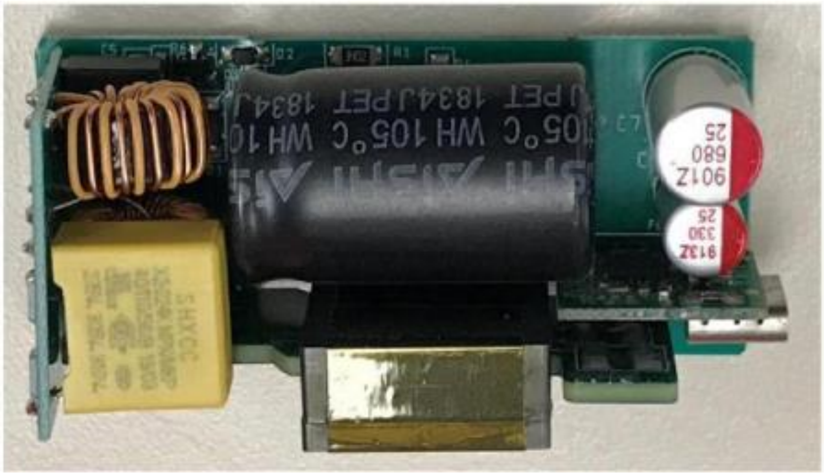

*Fig. 3. Timing diagram showing the principles of operation for FFRZVS.*[2]

## *FFRZVS Controller For USB PD Adapter*

Power adapters for USB PD are universal devices, expected to operate over line voltages from 90 to 260 Vac, providing an output voltage of 5 to 20 Vdc and a peak power of 20 Vdc and 2.25 A. The Infineon XDPS21071 forced frequency resonant flyback controller is designed to target such high-density adapter applications, making use of its DCM flyback topology. Thanks to its multi-mode capability, it can also operate in a burst mode (BM) that optimizes efficiency under light load conditions.

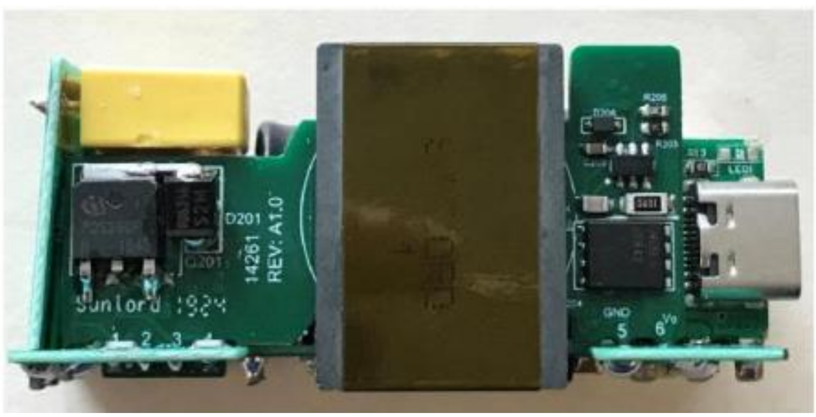
In the XDPS21071, high-voltage circuitry provides voltage monitoring as well as brown-in and brown-out protection. Leading-edge blanking is integrated into the current-sense circuitry, ensuring that spikes caused by the switch-on of the main MOSFET don't distort the current limitation control. The mixed-signal controller also features a nano-DSP that handles mode switching and timing control. This is highly configurable thanks to a nonvolatile memory and it is easily accessed using the development software package .dp Vision.

An adapter based on this design has been constructed (Fig. 4). Together with the controller it makes use of a CoolMOS P7 switch (the IPD70R360P7S) for the main MOSFET. This offers an excellent figure-of-merit (FOM), a low 360-mΩ $R_{DS(ON)}$, and the ability to handle the worst-case 560-V peaks expected on the primary side. The ZVS MOSFET uses a small-signal n-channel device, such as a BSL606SN, which is available in a tiny PG-TSOP6-6 package.



(a)

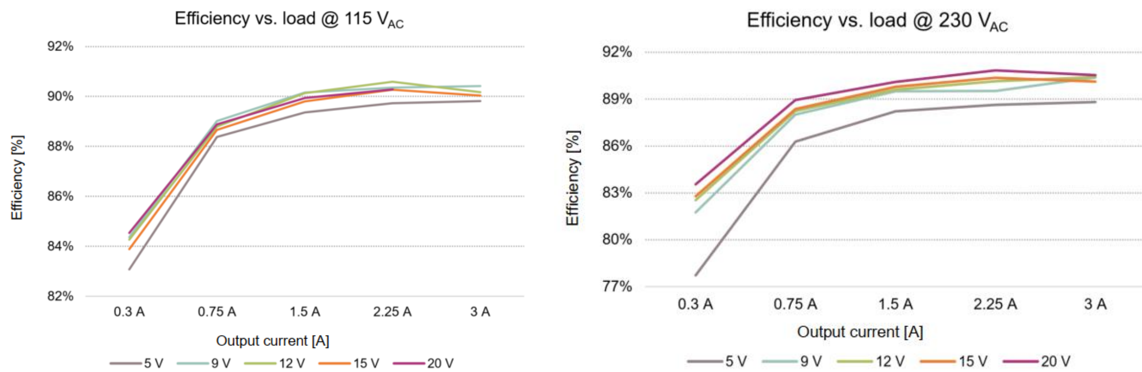
(b)




(c)

*Fig. 4. The implementation of a USB PD reference design based on the XDPS21071 controller with top (a), bottom (b) and side (c) views shown.*[2]

Efficiencies above 90% have been attained with this reference design, which also achieves a power density of 15 W/in$^3$ including the case and both common-mode and differential-mode choke (Fig. 5). Component temperatures stay below 100°C, with the prime generators of heat being the primary and SR MOSFETs together with the core of the transformer.




*(a)* *(b)*

*Fig. 5. Peak system efficiencies above 90% have been attained with the reference design pictured in Fig. 4.[2]*

The integrated frequency jittering, which is also configurable, helps improve the EMI signature at heavy loads where the switching frequency is at its maximum value. Conducted emissions fulfill EN 55022 (CISPR 22) class B test standards. Making use of the multi-mode capability this 45-W design also fully meets standby power requirements, drawing less than 30 mW at all ac input voltages.

## *Summary*

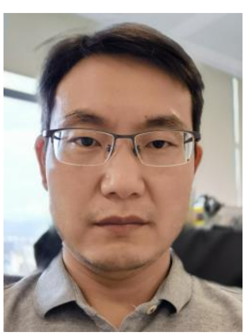
The inclusion of multi-mode support along with a broad range of configurable parameters makes the XDPS21071 highly suited to the demands of high-density and compact USB PD adapters. This, coupled with the novel FFRZVS topology, ensures that both low standby power and high efficiency levels can be attained, along with excellent conducted emission levels. The design can also be easily augmented to support power output levels up to 65 W.

### References

1. "A multi-mode, forced-frequency-resonant, high-performance flyback controller IC," white paper by Jimmy Wang, Infineon Technologies, 01-2020. See page 4.

2. "Design guide for adaptor with XDPS21071," application note DG_1910_PL21_1911_085816. See pages 5, 6, 8, 9 and 10.

### About The Author



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*For further reading on adapter design, see the How2Power Design Guide, locate the Power Supply Function category and select "AC-DC power supplies."*