AN192

Zero-Delay Pulse-Width Modulation Control (ZDP™)

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ABSTRACT

This application note details Zero-Delay Pulse-Width Modulation (PWM) control (ZDP^{TM}). ZDP^{TM} is an MPS proprietary, fixed-frequency power supply control method that improves transient response compared to a common fixed-frequency control method (e.g. voltage mode control or peak current mode control).

INTRODUCTION

MPS's Zero-Delay PWM (ZDP^{TM}) control provides many benefits for power supply designs, including fast transient response and a stable switching frequency (f_{SW}). Some common control topologies (voltage mode control, current mode control, and constant-on-time [COT] control) are described to establish a baseline for comparison with ZDP^{TM}. Then ZDP^{TM} and its benefits are also described in detail.

CONVENTIONAL CONTROL METHODS

Voltage Mode Control

Voltage mode control is one of the simplest control methods. Figure 1 shows voltage mode control.

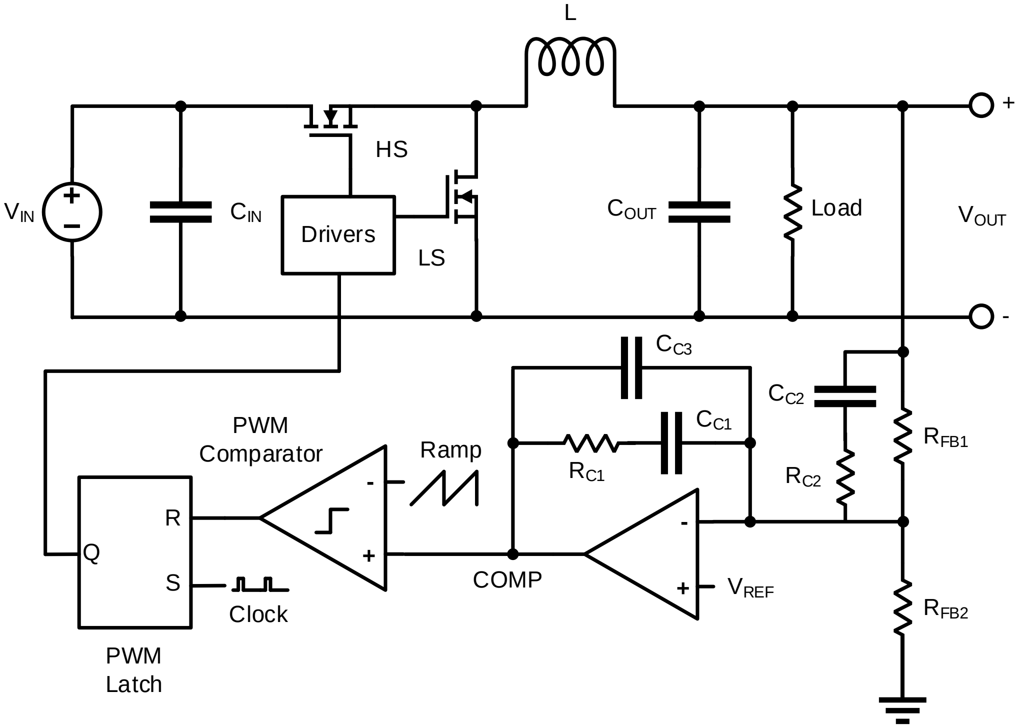

Figure 1: Voltage Mode Control

The difference between the feedback voltage and reference voltage (V_{FB} - V_{REF}) is amplified to generate an error signal (typically the comp voltage). This error signal is compared to a voltage ramp to generate the power stage's duty cycle. Voltage mode control requires either high ESR capacitors or type 3 compensation to stabilize the system. The control gain is also proportional to the input voltage (V_{IN}). This causes the crossover frequency to change as V_{IN} changes. To avoid this, the ramp voltage should be proportional to V_{IN}.

Peak Current Mode Control

Peak current mode control is one of the most common control methods used for automotive power supplies. Figure 2 shows peak current mode control.

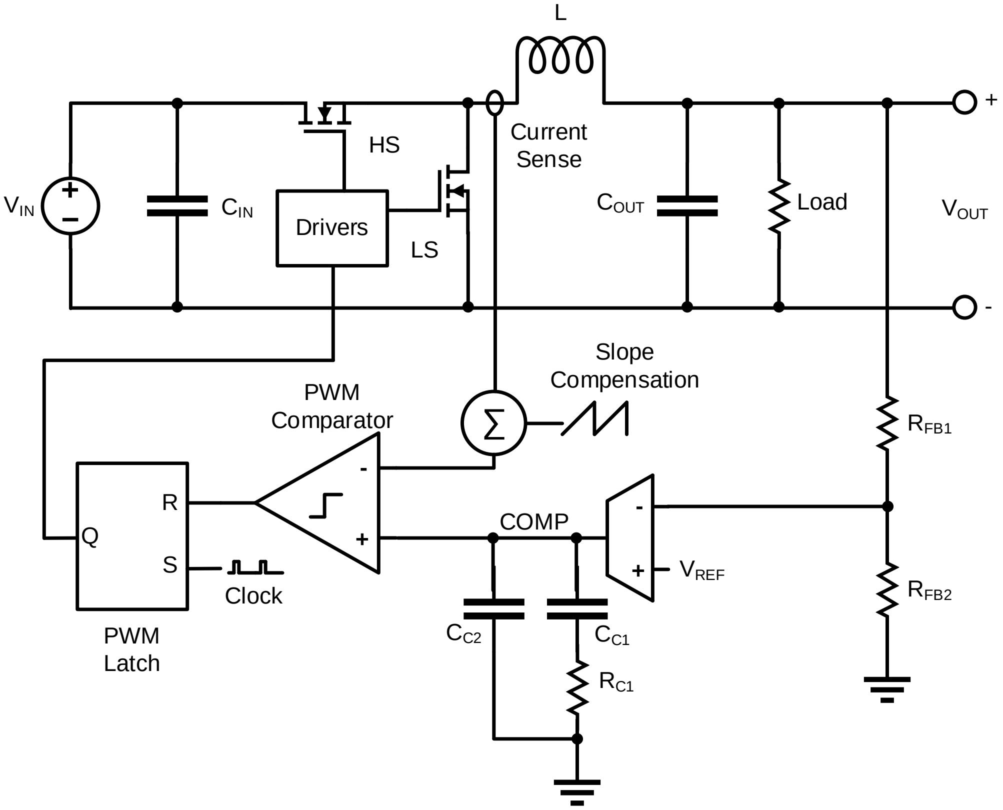

Figure 2: Peak Current Mode Control

Similar to voltage mode control, V_{FB} - V_{REF} is amplified to generate an error signal. Peak current mode control compares this error signal to the inductor current (I_L), which is typically sensed via a mirror MOSFET, sense resistor, or lossless current-sense circuit. Typically, peak current mode topologies include a slope compensation signal to ensure stability duty cycles exceeding 50%. By incorporating the sensed I_L in the loop, the compensation complexity decreases, and only type 2 compensation is required. This also removes the control gain impact V_{IN}, which means the crossover frequency remains relatively constant across the entire V_{IN} range.

The current signal is not stable in a peak current mode topology during switching transitions, and the PWM comparator should be blanked for a short time once the high-side MOSFET (HS-FET) turns on. This leads to a longer minimum on time (t_{ON_MIN}) compared to voltage mode control, traditional COT, or ZDP™.

Peak current mode control is implemented in MPS devices such as the MPQ2167, MPQ4436, MPQ4323, and MPQ4430.

Traditional Constant-On-Time (COT) Control

In high-performance applications, traditional COT control is used to improve transient performance. Figure 3 shows traditional COT control.

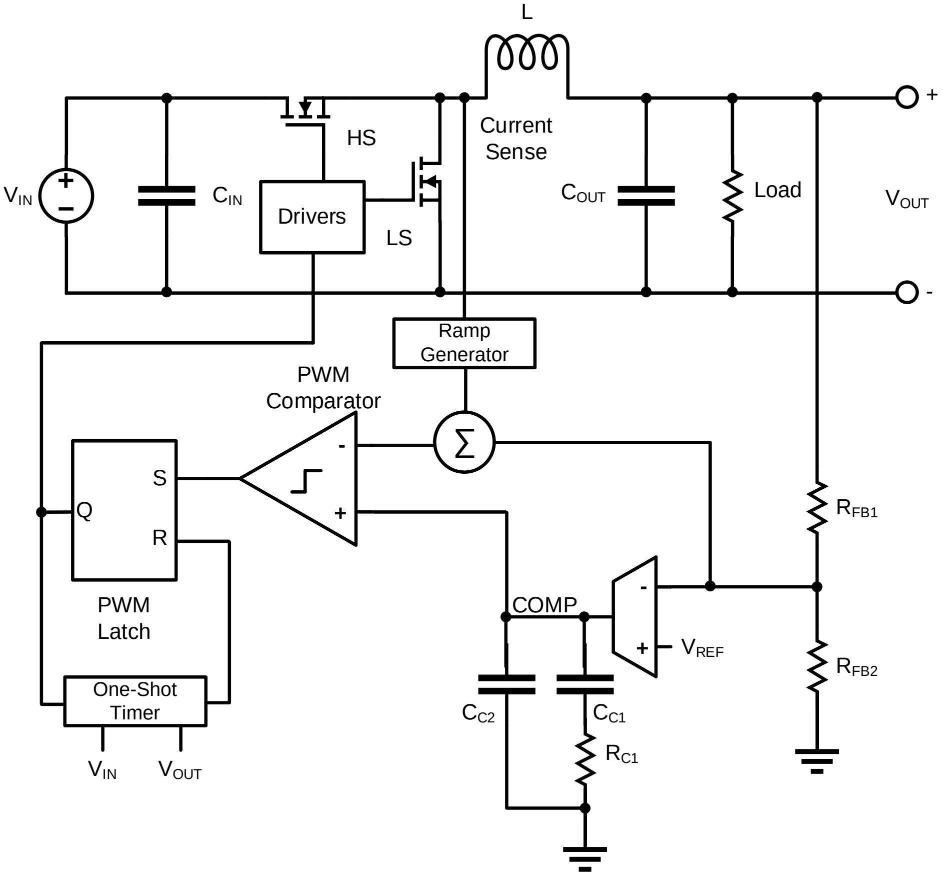

Figure 3: Traditional COT Control

Traditional COT control compares V_{FB} directly to V_{REF} to trigger an on pulse. This is only possible if the feedback signal ripple is in phase with I_L. This may come from the output capacitor ESR, a ramp injection circuit placed across the inductor, or an internally generated synthetic ramp. When V_{FB} drops below V_{REF} or the error signal, an on-time pulse is generated and fed into the gate driver. Consecutive on-time pulses are generated with an internal minimum off time during large transients to recover the output voltage (V_{OUT}) quickly. This provides improved load transient response compared to voltage mode control and current mode control.

An error amplifier (EA) can be used as a slow path to generate the error signal to compare to V_{FB} for improved regulation accuracy. Traditional COT control can be achieved with type 2 compensation. This reduces the component count for systems with COT topologies.

Since consecutive on-time pulses can occur during load transient responses, f_{SW} temporarily increases during operation. This may not be suitable for applications where EMI performance is of greater concern, such as industrial or automotive electronics with strict EMI requirements to reduce crosstalk in the system.

COT control is implemented in MPS devices such as the MPQ2179, MPQ2172, and MPQ3431A.

ZERO-DELAY PWM CONTROL (ZDP^{TM})

Architecture

Zero-Delay PWM (ZDP^{TM}) control achieves the same load transient performance as traditional COT control, but with a fixed-frequency scheme. Figure 4 shows ZDP^{TM}.

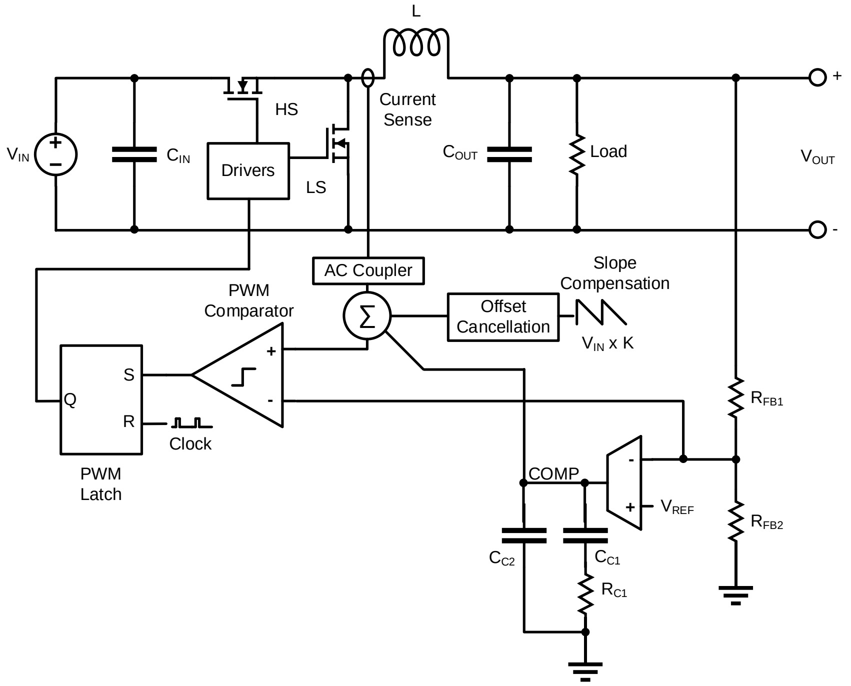

Figure 4: Zero-Delay PWM (ZDP^{TM}) Control

Similar to traditional COT control, ZDP^{TM} bypasses the EA by connecting the feedback node directly to the PWM comparator, creating a fast path to the PWM comparator. This fast path quickly changes the duty cycle that drives the HS-FET and low-side MOSFET (LS-FET) to compensate for V_{OUT} fluctuations without ramping the compensation up and down. For example, when V_{OUT} decreases due to a large load transient, the duty cycle increases during the next on cycle to provide power to the output capacitors to recover V_{OUT}. ZDP^{TM} achieves this without adjusting f_{SW} (see Figure 5).

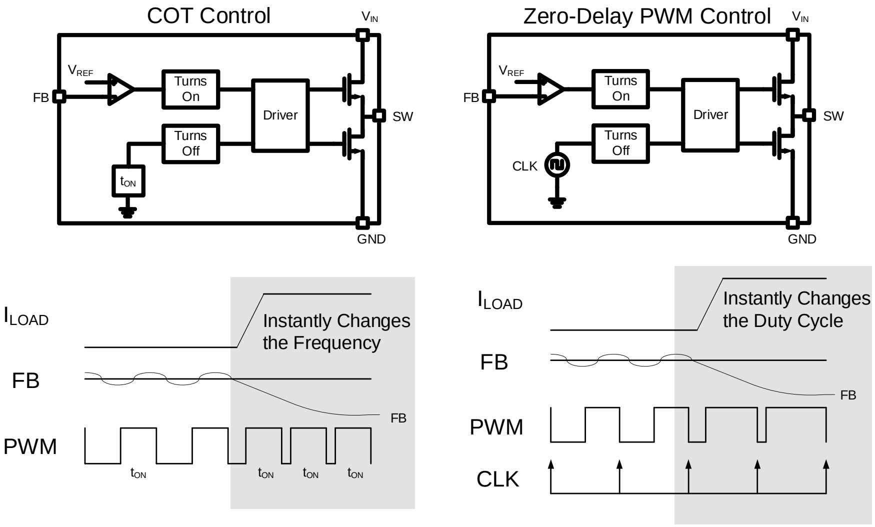

Figure 5: Traditional COT Control vs. ZDP^{TM}

Similar to traditional COT control, a slow path using an EA improves regulation accuracy. The slow path uses (V_{FB} - V_{REF}) to create an error signal. This signal is summed with an AC coupled current signal and a slope compensation ramp. Then the summed signal is compared to V_{FB}, which feeds into a PWM latch block that uses a fixed frequency clock as a reset signal. ZDP^{TM} loop stability can be achieved with type 2 compensation, which saves design cycle time compared to type 3 compensation.

ZDP^{TM} also implements valley current sensing. Unlike with peak current mode control, valley current sensing with ZDP^{TM} does not require a blanking time since the current can be sensed as the LS-FET turns on. By eliminating the blanking time, a lower t_{ON_MIN} can be achieved. This allows the device to operate at a lower duty cycle, due to a larger V_{IN}:V_{OUT} ratio, and a higher f_{SW}.

ZDP^{TM} is implemented in MPS devices such as the MPQ4340, MPQ4371, and MPQ2286.

Simulation Results (1)

Figure 6 shows the MPQ4340 load transient simulation results.

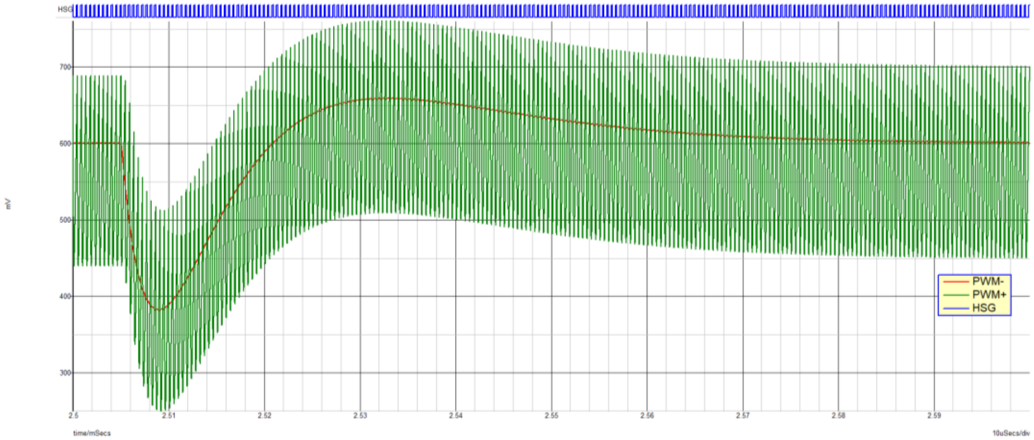

Figure 6: MPQ4340 Load Transient Response

Where PWM- is the feedback signal; PWM+ is the sum of the comp signal, the AC coupled current sense, and the slope compensation; and HSG is the high-side gate start-up signal.

V_{OUT} recovers quickly after the undershoot and slight low-frequency overshoot caused by the output load changes from 0A to 4A. This V_{OUT} recovery is proportional to PWM-.

The HSG turns on once PWM+ exceeds PWM- (see Figure 7).

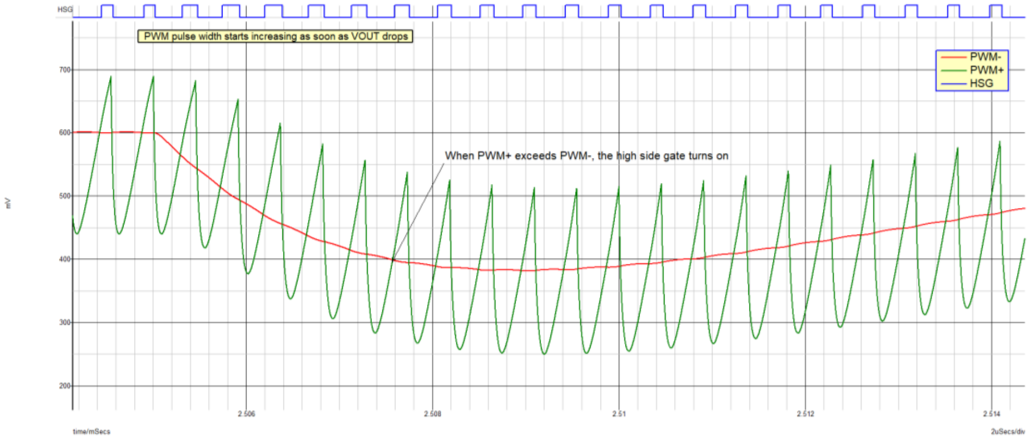

Figure 7: HSG Turns On during MPQ4340 Load Transient Response

Once V_{OUT} drops, the HSG pulse width increases to deliver more energy to the output and correct V_{OUT} after the load step.

Figure 8 shows how the duty cycle changes once the load increases, while still maintain a constant f_{SW} (see Figure 8).

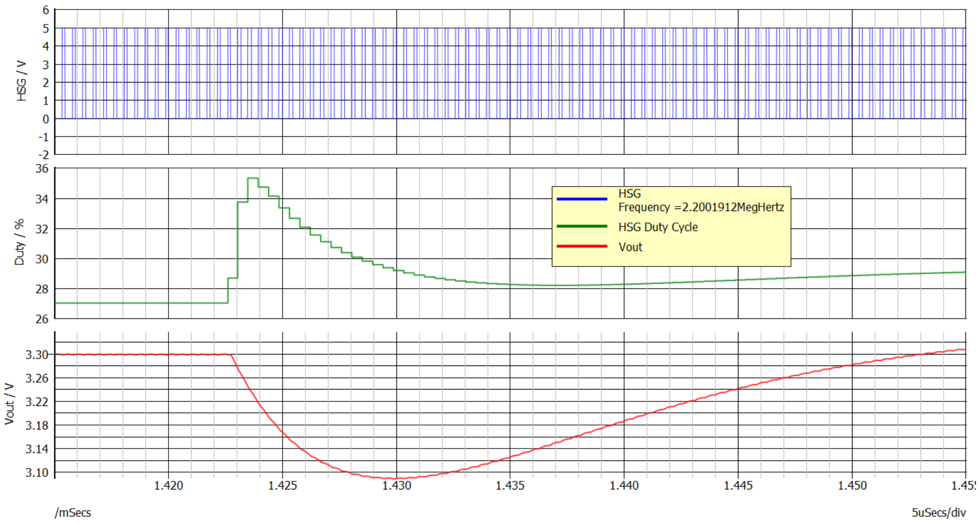

Figure 8: Duty Cycle during MPQ4340 Load Transient Response

The green curve in Figure 8 represents the duty cycle (in %) of the HSG curve shown in Figure 6 and Figure 7 on page 7. The duty cycle increases from 27% to 35% in a few switching cycles to reduce the V_{OUT} droop (caused by the increased load), and to allow V_{OUT} to recover quickly. The blue curve in Figure 8 represents the HSG at a constant f_{SW} (2.2MHz) throughout load transient operation.

Simulated bode plots are generated to observe the stability of the control scheme (see Figure 9).

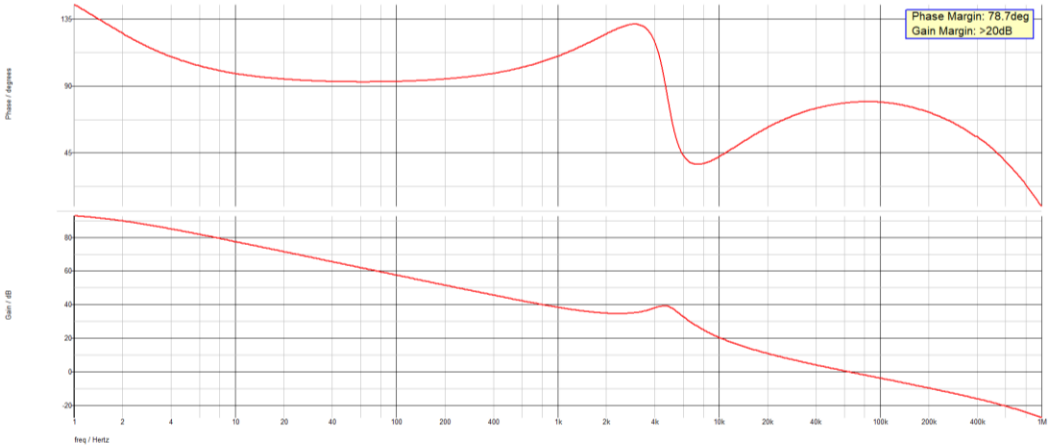

Figure 9: MPQ4340 Bode Plot

The phase margin and gain margin exceed most design targets. The crossover frequency is about 63kHz. Due to the fast path, the large signal transient response is better than what would be expected with a 63kHz crossover frequency. As typically seen with traditional COT control, the bode plot does not accurately reflect the improved load transient response when compared to bode plot of a traditional peak current mode control device.

Note:

1) V_{IN} = 12V, V_{OUT} = 3.3V, 0A to 4A load step at 50A/µs, f_{SW} = 2.2MHz, L = 1µH, C_{OUT} = 2 x 22µF, capacitor voltage derating is simulated, tested on the MPQ4340.

Benefits

Compared to other fixed-frequency control methods (e.g. voltage mode control and peak current mode control), the Zero-Delay PWM (ZDP^{TM}) control fast path greatly improves transient response. Figure 10 shows a 0A to 3.5A load transient comparison between ZDP^{TM} (the MPQ4340) and peak current mode control (the MPQ4430). The MPQ4340 and MPQ4430 have the same inductor, capacitors, and f_{SW}.

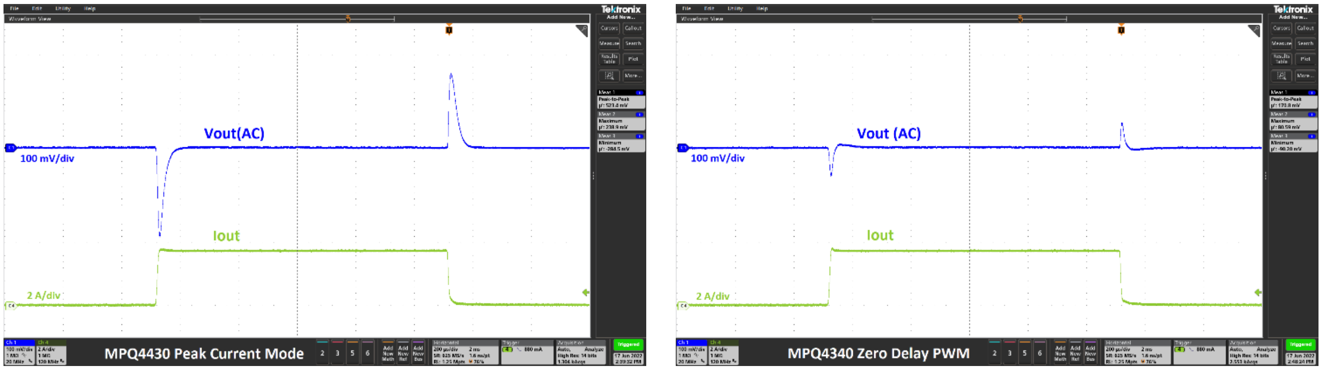

Figure 10: Load Transient with ZDP^{TM} vs. Peak Current Mode Control

The waveforms show a 523mV$_{PK-PK}$ load transient for the MPQ4430 and a 170mV$_{PK-PK}$ load transient for the MPQ4340. The MPQ4340's transient response is significantly better than the MPQ4430's transient response. This allows the user to use fewer output capacitors while improving the transient performance.

The valley current allows for a very short t_{ON_MIN}. While t_{ON_MIN} in devices that use peak current mode control can be between 60ns and 100ns, the MPQ4340's longest t_{ON_MIN} is only 35ns. This allows the MPQ4340 to convert extended automotive battery voltages (up to 18V) directly to 1.8V while switching above the AM band and with frequency-spread spectrum (FSS).

The fixed frequency allows ZDP^{TM} to provide excellent frequency stability. Devices with ZDP^{TM} (e.g. the MPQ4340) can also be synchronized to an external clock or used with FSS. ZDP^{TM} can be used in applications with strict EMC requirements, such as Automotive applications.

CONCLUSION

Zero-Delay PWM (ZDP^{TM}) control improves load transient performance compared to traditional peak current mode control, while also maintaining a fixed frequency during load transient. The fixed frequency differentiates ZDP^{TM} from traditional COT control, which has a fluctuating f_{SW}. ZDP^{TM} also has a shorter t_{ON_MIN}, which allows the device to be used in applications where a high f_{SW} and low duty cycle is desired. These benefits have been proven with simulations and hardware testing on MPS products with ZDP^{TM}.

REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	1/9/2023	Initial Release	-