Optimizing Automotive Applications with Zero-Delay PWM Control (ZDP™)

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Introduction

The increasingly high power consumption for rails in advanced driver-assistance systems (ADAS) and digital cockpit applications calls for an improved control scheme from traditional control methods (e.g. peak current mode control), with a need for excellent load transient performance and low on-time capabilities. While constant-on-time (COT) control can be utilized as a control scheme, its varied frequency operation makes it unsuitable for EMI-sensitive automotive environments.

This article presents zero-delay pulse-width modulation (PWM) control (ZDP™), which is MPS's proprietary, fixed-frequency power supply control method that provides improved dynamic performance compared to peak current mode control while maintaining fixed-frequency operation.

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

At a high level, the design of ZDP™ integrates typical blocks from traditional COT and peak current mode control schemes (see Figure 1).

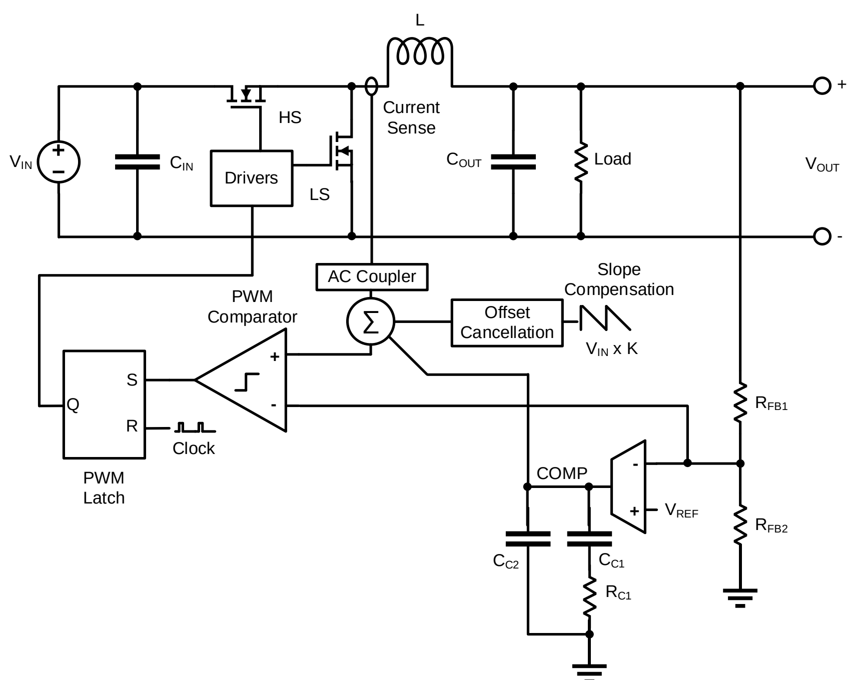

Figure 1: Zero-Delay PWM (ZDP™) Control Scheme

Like in a traditional COT scheme, ZDP™ bypasses the error amplifier (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 high-side MOSFET (HS-FET) and low-side MOSFET (LS-FET) to compensate for output voltage (V_{OUT}) fluctuations without ramping the compensation up and down.

For example, if V_{OUT} drops due to a large load transient, then the duty cycle increases during the next on cycle to provide power to the output capacitors, which recover V_{OUT}. ZDP™ recovers V_{OUT} without adjusting the switching frequency (f_{SW}), as its PWM latch is reset by a fixed-frequency signal.

Based on traditional peak current mode control, ZDP™ provides a slow path through the EA to improve regulation accuracy. The slow path uses the difference between the feedback voltage and reference voltage (V_{FB} - V_{REF}) to create an error signal. The error signal is then combined with an AC coupled current signal and slope compensation ramp.

The sum of the error signal, AC coupled current signal, and slope compensation ramp is compared to V_{FB}, which feeds into a PWM latch block that uses a fixed-frequency clock as the reset signal. ZDP™ loop stability can only be achieved with type 2 compensation. This reduces design cycle time compared to type 3 compensation.

Compared to peak current mode control, ZDP™ features valley current sensing in its architecture to detect the inductor current (I_L). Peak current mode control senses I_L on its upward slope when the HS-FET turns on, while valley current sensing detects I_L on its downward slope when the LS-FET turns on. Using valley current sensing with ZDP™, a lower minimum on time (t_{ON_MIN}) can be achieved, as the current-sense block is not limited to the blanking time that constrains peak current sensing. This allows ZDP™ to operate at a lower duty cycle and a higher f_{SW}, which are required to step down the 12V automotive battery voltage to the operating supply level used in systems-on-chip (SoCs).

Simulation Results (1)

The load transient response simulation results of a ZDP™ device provide further insights into its architecture (see Figure 2).

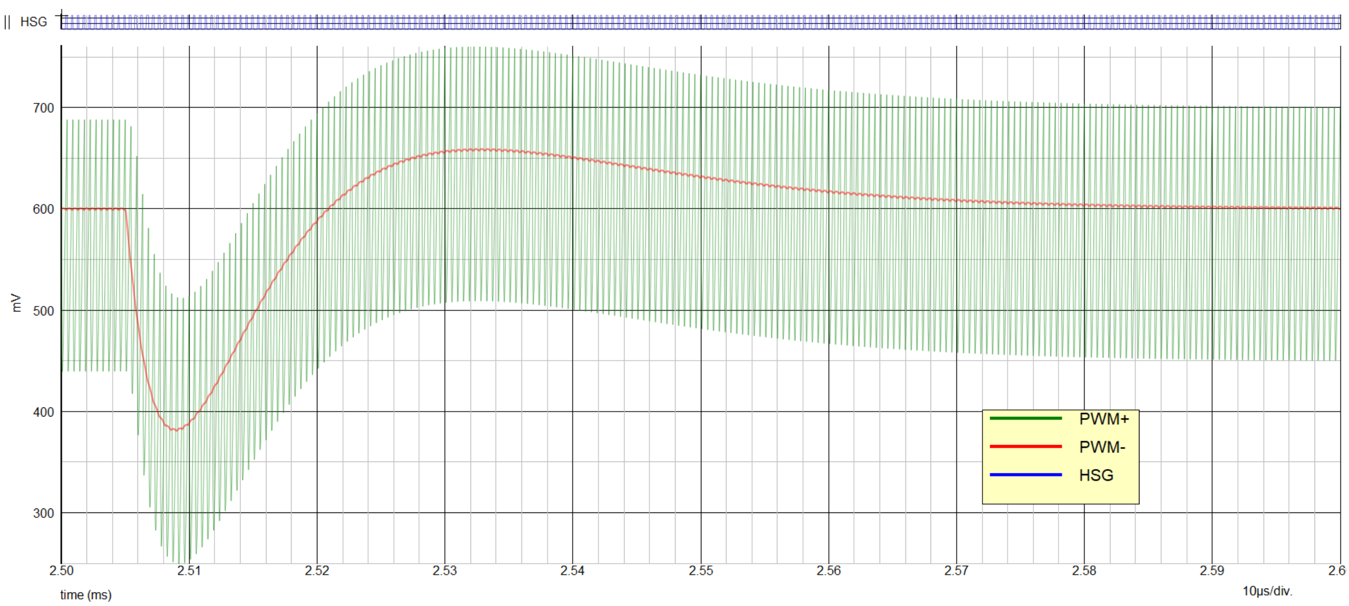

Figure 2: ZDP™ Simulated Load Transient Response

The simulation results show the inputs of the PWM comparator (PWM- and PWM+) and the process to trigger the high-side gate (HSG) on and off. Based on Figure 1, PWM- comes directly from the feedback, and PWM+ is the sum of I_L, the slope compensation, and the EA output. If PWM+ exceeds PWM-, then the HSG turns on (see Figure 3) and is terminated by the fixed-frequency clock that resets the gate driver.

Note:

1) V_{IN} = 12V, V_{OUT} = 3.3V, 0A to 4A load step at 5A/µs, f_{SW} = 2.2MHz, L = 1µH, C_{OUT} = 2 x 22µF, and the capacitor voltage derating is simulated and tested on the MPQ4340-AEC1.

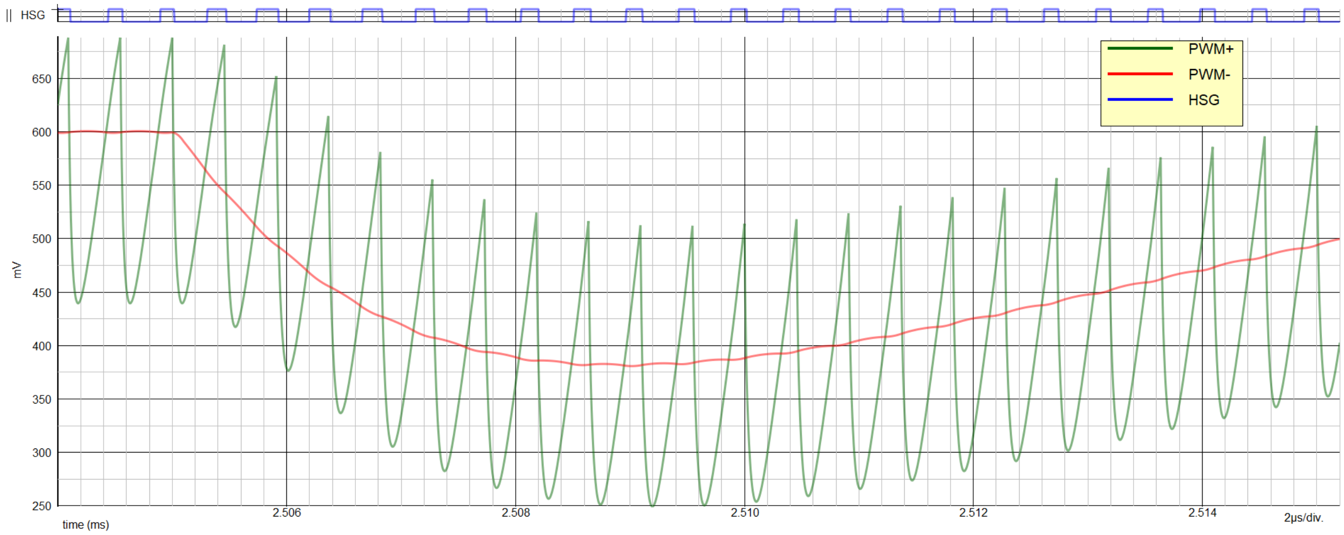

Figure 3: HSG Turns On during ZDP™ Load Transient Response

V_{OUT} initially drops when the load steps up from 0A to 4A, causing PWM- to drop proportionally. PWM+ then exceeds PWM- for a longer time than during steady state. This increases the duty cycle to correct V_{OUT} from the load step. Since PWM+ bypasses the EA, the duty cycle increases immediately after V_{OUT} fluctuates without changing f_{SW} (see Figure 4).

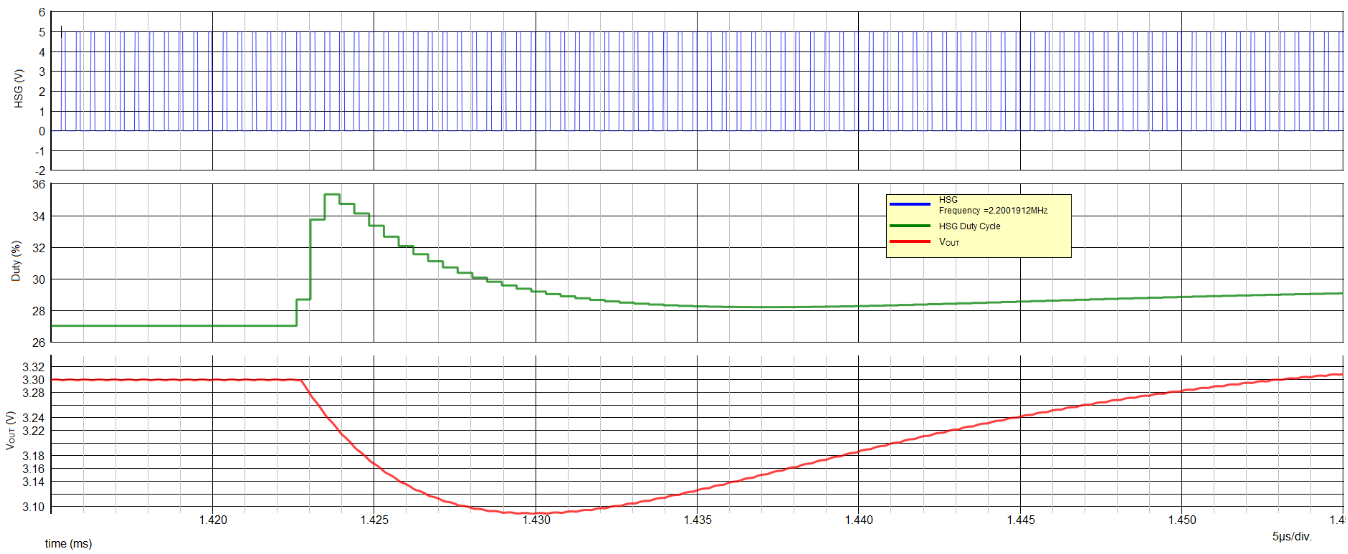

Figure 4: Duty Cycle during ZDP™ Load Transient Response

The green trace in Figure 4 represents the duty cycle (in %). Within a couple of switching cycles, the duty cycle increases from 27% to 35%. This causes V_{OUT} (represented by the red trace in Figure 4) to quickly return to its regulated 3.3V level. The HSG (represented by the blue trace in Figure 4) confirms that f_{SW} remains constant during a load transient, demonstrating ZDP™ fixed-frequency operation.

Hardware Results [2]

Fast load transient response during fixed-frequency operation is achieved with ZDP™ through the hardware results and advantages of MPS devices. For example, the [MPQ4340-AEC1](MPQ4340-AEC1) is a synchronous buck converter that features a ZDP™ control scheme. The converter is designed for off-battery automotive applications, where switching regulators require fixed-frequency operation for stringent EMI environments. Its load transient performance corresponds with Figure 4, where f_{SW} stays constant and the duty cycle changes instantaneously when V_{OUT} droops due to a load step (see Figure 5).

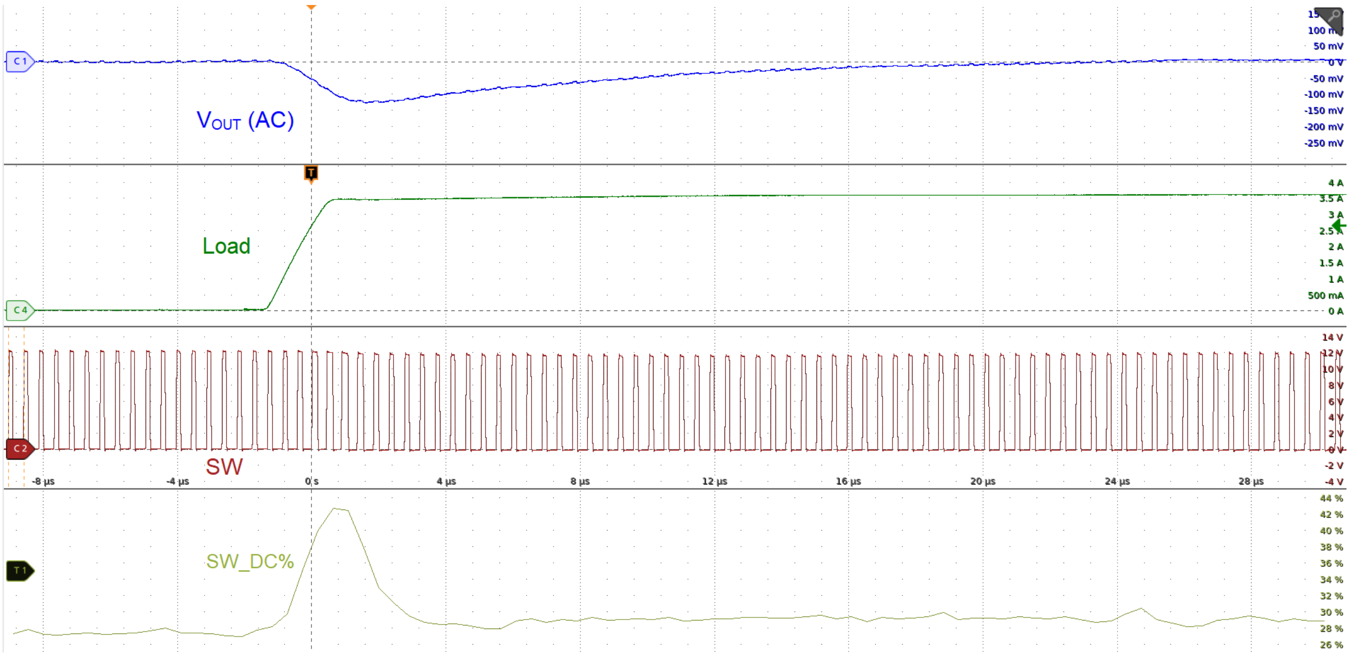

Figure 5: MPQ4340-AEC1 Load Transient Response

When compared to a traditional control scheme (e.g. peak current mode control), ZDP™ excels in load transient performance, making it a significantly more suitable control scheme compared to peak current mode control for quick performance with minimal component costs.

To demonstrate this, we will compare two similar products with different control architectures. Figure 6 shows a 0A to 3.5A load transient comparison between ZDP™ (using the MPQ4340-AEC1) and a traditional automotive peak current mode control device. Both devices are tested using the same inductor, number of output capacitors, and f_{SW}.

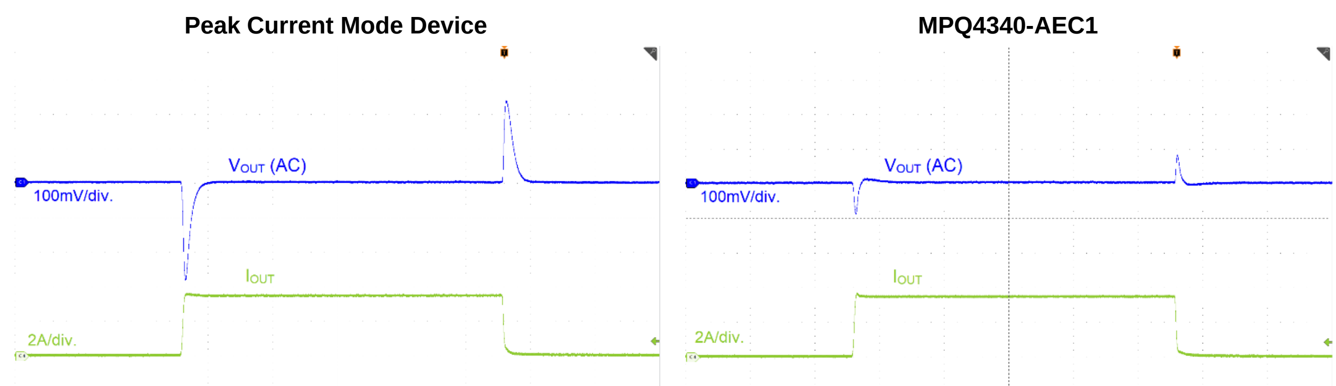

Figure 6: Peak Current Mode Control vs. ZDP™ Load Transient Response

Note:

2) V_{IN} = 12V, V_{OUT} = 3.3V, 0A to 3.5A load step at 2A/µs, f_{SW} = 2.2MHz, L = 1µH, and C_{OUT} = 2 x 22µF. Tested using the MPQ4340GLE-33-AEC1 and a generic automotive peak current mode device.

The load transient response results in Figure 6 underline the significant improvement achieved using ZDP™ architecture compared to peak current mode control architecture. For the same load step, the peak current mode device's V_{OUT} fluctuation was $523mV_{PK-PK}$, while the MPQ4340-AEC1 was $170mV_{PK-PK}$.

The ZDP™ transient advantage also reduces the overall power solution cost since fewer output capacitors can be used compared to traditional control architecture.

The MPQ4340-AEC1 utilizes the benefits of ZDP™ architecture to achieve a low t_{ON_MIN}, down to 20ns (typical) and a maximum of 35ns. By contrast, the peak current mode device has a typical t_{ON_MIN} of 80ns. A lower t_{ON_MIN} allows the ZDP™ device to step down its automotive battery supply voltage (up to 18V under nominal operating conditions) to voltage levels suitable to supply SoCs (as low as 1.8V) while maintaining a high f_{SW} above the AM band, such as 2.2MHz.

The EMI results of the MPQ4340-AEC1 with ZDP™ demonstrate its compatibility for strict EMC environments that automotive applications frequently encounter. These results also illustrate that ZDP™ can use frequency spread spectrum (FSS) to further enable the solution to pass EMI requirements with standard input and output filters (see Figure 7).

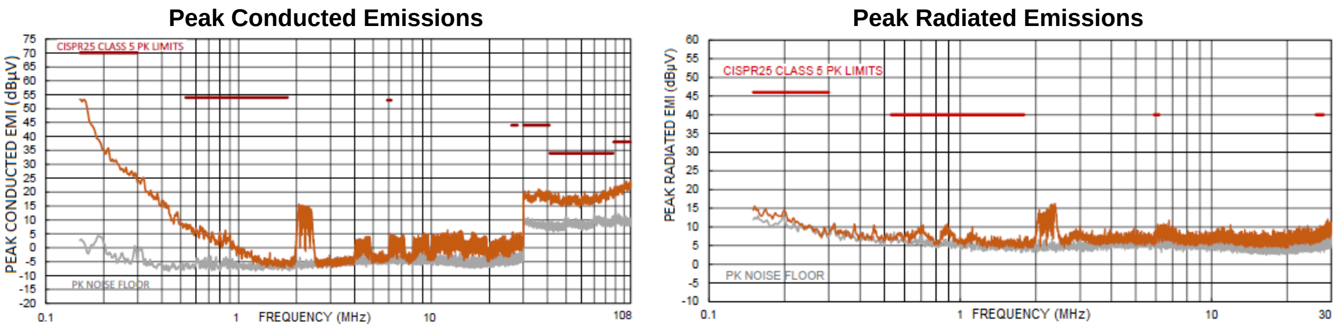

Figure 7: MPQ4340-AEC1 EMI Results (3)

Note:

3) The EMC test results are based on the typical application circuit with EMI filters (refer to the MPQ4340-AEC1 datasheet for more details).

Conclusion

Zero-delay PWM control (ZDP™) optimizes the requirements of switching regulators in modern automotive applications. Products with ZDP™ can meet the fast transient specifications that are required for SoCs in ADAS and digital cockpit applications while still minimizing costs. By using fixed-frequency operation, ZDP™ is well-suited for EMI-sensitive automotive environments. Furthermore, the valley current sensing feature of ZDP™ allows for large V_{IN}-to-V_{OUT} ratios with high f_{SW} due to a low t_{ON_MIN}.

MPS offers a robust portfolio of automotive-qualified products using ZDP™, such as the MPQ4340-AEC1 and MPQ4371-AEC1.