White Paper

How to Select a PWM Controller for Narrow On-Time Buck Conversion

Introduction

Modern power delivery systems with DSPs, FPGAs and CPUs run on lower supply voltages and consume higher current. In fact, sub-1V voltages are everywhere now. Meanwhile, intermediate bus voltages have stayed the same or increased depending on the application. To make things more challenging for power supply designers, system frequency requirements have steadily increased to support smaller inductor and capacitor (L&C) filtering. Yesteryear's 500kHz is today's 1MHz.

In high voltage applications where a lower output voltage is required, designers have traditionally relied on modules that increase system cost, or two stage DC/DC solutions that increase solution footprint and complexity. This white paper looks at the trends influencing narrow on-time point-of-load (POL) conversion and compares the current mode control architectures typically used, including their strengths and weaknesses. A hybrid valley current mode (VCM) architecture with adaptive slope compensation is examined, including its use in a new 60V synchronous buck controller. The hybrid VCM allows this controller to deliver stable operation over a wide range of Vin and Vout combinations, and low duty cycle enabling a direct step-down conversion from 48V to a 1V point-of-load.

Narrow On-Time POL Conversion

A buck converter is the most widely used power supply topology, and recent trends indicate that next generation switching controllers must be able to provide stable and efficient operation at very small duty cycle. While the current mode control approach offers many advantages compared to voltage mode control, it has its own limitations depending on the application requirement, particularly in terms of duty cycle limits.

Generally, the power delivery systems in telecommunication and industrial applications are based on multistage conversion. There has been a continuous shift in power delivery systems with POL input voltage increasing from 3.3V to 5V to 12V. With this increase in power requirements, the use of 12V rails is now common, while 3.3V is rare.

More recently, the trend is moving toward much higher voltages, such as 24V~42V for industrial applications, and 48V for telecom, as shown in Figure 1. Consistent improvements in technology have made it possible to control narrow pulses. At the same time, new studies show that a higher input voltage enables higher overall efficiency, lowers system cost and contributes to system reliability by reducing distribution path temperature.
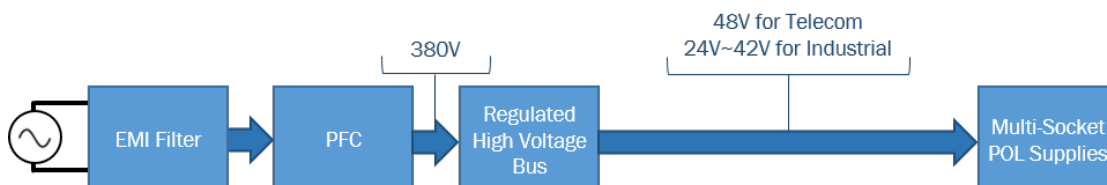

Figure 1: Modern trend in high power telecom or industrial system

Another factor driving the requirement of a narrow PWM pulse is the need for higher switching frequency, which in turn results in higher power density. Operating power supplies at a switching frequency of 1MHz has become a common industry practice. In fact, the switching frequency needs to be above 1.8MHz in automotive infotainment applications to avoid the AM frequency band. A 12V to 1V power conversion at 1MHz would still need to generate 83ns pulse.

Low Duty Cycle Operation

An ideal buck converter can generate any voltage lower than Vin down to zero; however, in practice, there are many limitations in terms of the reference voltage, internal or external losses in the circuit, and most important, the type of modulator being used to generate the control signal.

Given a particular input voltage, there are limitations that prevent the converter from covering the entire range 0% to 100%. Most obvious is the reference voltage:

$$Vout = Vref * (1+R1/R2)$$

This indicates that the output cannot be regulated below the Vref voltage. The second major limiting factor for the minimum Vout is the minimum on-time of the controller. For a given input voltage (Vin), minimum Vout can be expressed as:

$$Vout = Ton\ min* Vin\ *Fs$$

Hence, for a switching frequency (Fs), the on-time of the upper MOSFET will be:

$$Ton= D*(1/Fs)$$

Control Methods

In a typical current mode PWM controller, the size of the PWM pulse is determined by the output of the error amplifier and the inductor current signal as shown in Figure 2. The current loop senses the inductor current signal and compares it to the VCOMP reference to modulate the PWM pulse width. Since the current loop will force the inductor peak or valley current to follow the voltage error amplifier output, the inductor will not appear in the voltage control loop. The double pole LC filter becomes a single capacitive pole structure for the voltage loop. A simple type 2 compensation is enough to stabilize the voltage loop.
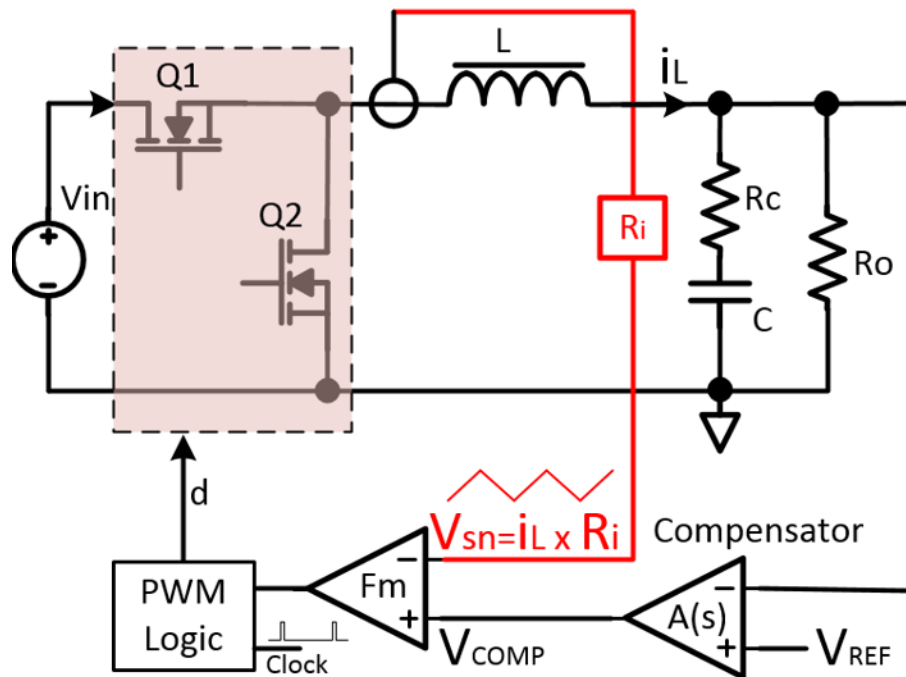
Figure 2: A simple current mode control architecture

Suitable Modulators for Narrow On-Time Operation

Peak current mode control is one of the most commonly used architectures, and while it's well understood and offers reliable control techniques with multiple advantages, it exhibits significant shortcomings when narrow on-time operations are required. In peak current mode, inductor current information is sensed across the upper MOSFET. Figure 3 shows typical current waveforms in both the upper and lower MOSFET in relation to the PWM signal. The turn on event of the upper MOSFET generates a significant amount of ringing due to the different parasitics inside and outside of the MOSFETs in the turn on loop. This ringing can send erroneous signals to control circuitry and falsely terminate the PWM signal. To ignore this initial ringing, peak current mode-switching controllers employ blanking time before sensing the inductor current. Typically, a 150ns to 250ns blanking time is employed. This blanking time requirement in peak current mode controllers will not allow it to regulate a very narrow on-time power conversion. Even a 12V to 1V power conversion would be difficult to regulate at 600kHz frequency, which translates into less than 140ns minimum on-time.

Valley current mode control easily overcomes the blanking time shortfall of the peak current mode control. In valley current mode control, the inductor current signal is sensed during the off-time of the upper MOSFET, avoiding the upper MOSFET ringing. This solves the problem of controlling very narrow on-time PWM pulses; however, valley current mode comes with other disadvantages.
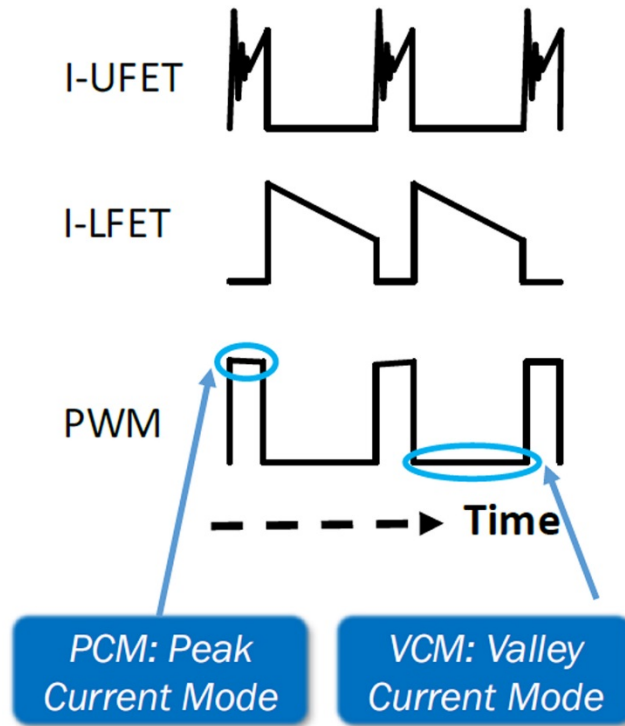
Figure 3: Buck converter waveforms depict signal sense location in current mode control architectures

Two major issues with valley current mode control are sub-harmonic oscillation and poor line regulation. Sub-harmonic oscillation is a common problem with any current mode control. It occurs in peak current mode control as well, but at more than 50% duty cycle. For valley current mode, the reverse is true.

Sub-harmonic oscillations in current mode controllers (both peak mode and valley mode) can be prevented using slope compensation. However, fixed slope compensation cannot handle all duty cycles and inductors. The sub-harmonic oscillation problem reappears if the duty cycle is significantly away from the assumed value used in the slope compensation design.

Emulated peak current mode control is a variant of peak current mode that avoids the blanking time limitation. It overcomes the upper MOSFET ringing by measuring the valley current information across the lower MOSFET. This valley current information is then used to emulate the inductor upslope to obtain the peak current information.

As in peak current mode control, emulated peak current mode also suffers from sub-harmonic oscillation and needs slope compensation. This slope compensation is derived from the emulated peak current signal. Though emulated peak current mode is designed to have the benefit of both peak current mode and valley current mode control methods, its shortcomings are mostly due to a lack of inductance information in the control loop.

Valley current mode with adaptive slope compensation is a way to overcome the shortcomings of traditional valley current mode control. An optimized adaptive slope compensation circuit can prevent the sub-harmonic oscillation for all duty cycles. This adaptive compensation and inherent capability of low duty cycle operation enables a controller with this architecture to operate at very high switching frequency.

A Viable Narrow On-Time Solution

Intersil's ISL8117 buck controller is an example of a valley current mode control with low side MOSFETs Rdson, valley current sense and adaptive slope compensation. As shown in Figure 4, the ISL8117's ramp signal adapts to the applied input voltage to improve the line regulation. A unique implementation of valley current mode and the optimized slope compensation resolves the shortcomings of traditional valley current mode controllers. Its unique control technique allows it to support a very wide range of input and output voltages. In essence, it is a hybrid between voltage and current mode control, displaying advantages of both modulation architectures.

The ISL8117 can operate from any voltage between 4.5V and 60V, and its output can be adjusted from 0.6V to 54V. It has an adjustable frequency range of 100kHz to 2000kHz and can produce minimum on-time of 40ns (typical). With a minimum on-time of 40ns, the controller can generate 1V output from a 12V bus at 1.5MHz. It is also capable of generating a 1V supply from a 48V source at lower frequency. Figure 5 shows an application with the ISL8117 generating 1.2V from a 48V power source, while Figure 6 shows the transient from a stable 48V to 1.2V conversion. In systems susceptible to a particular switching frequency noise, the ISL8117 can be synchronized to any external frequency source to reduce radiated system noise and beat frequency noise mitigation.
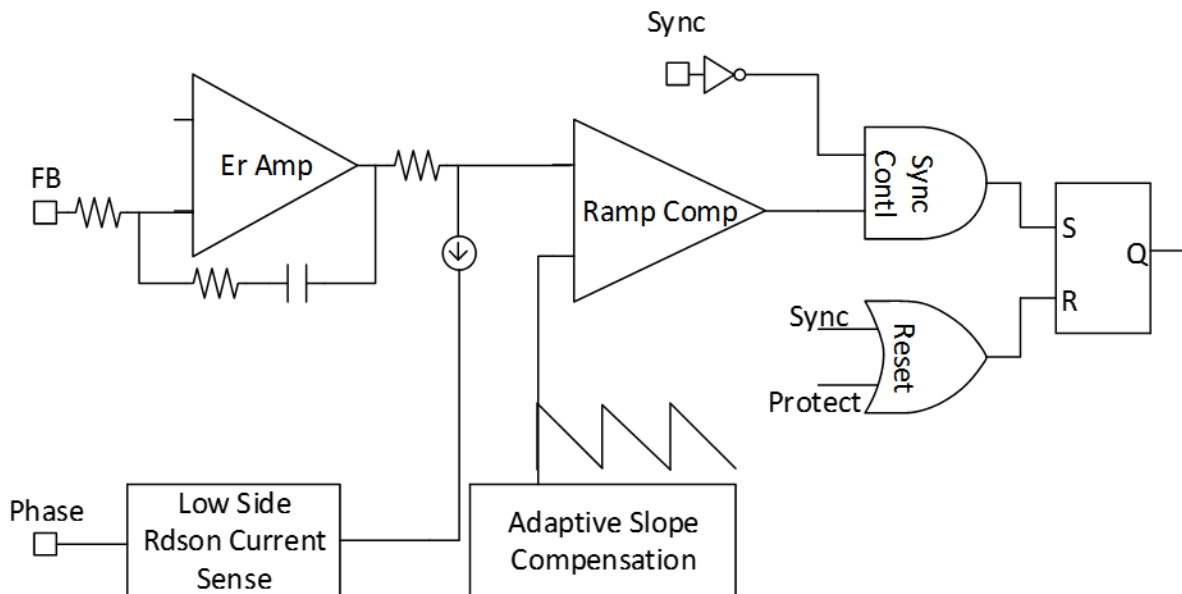
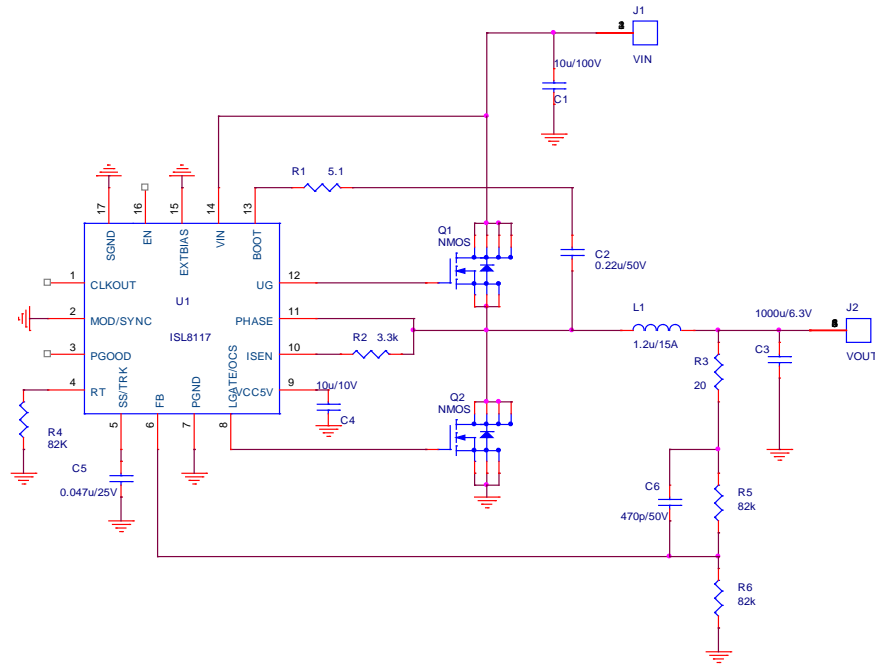

Figure 4: Internal control block diagram of ISL8117

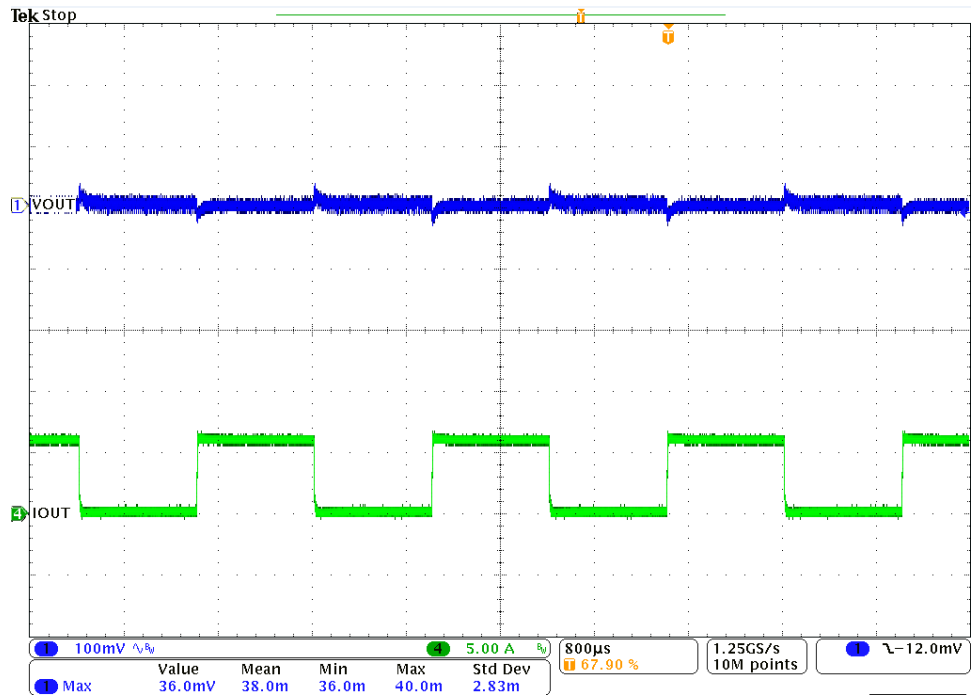Figure 5: Typical application schematic to generate 1.2V from a 48V power supply source

Figure 6: Transient response of 0A to 6A, 6A to 0A from a stable 48V to 1.2V converter

The ISL8117 uses low side sensing and implements a programmable current limit without a sense resister, allowing for reduced power dissipation, component count and system cost. The IC also addresses POL requirements by offering fault protection features such as over-current, over-voltage and over-temperature. The easy-to-use ISL8117 comes in both 16-pin QFN and HTSSOP packages and most of its feature pins have default values. A default value-based buck converter can be designed with only 10 external components, including MOSFETs and other passives. This innovative design translates to efficiency in excess of 94% for a 48V to 5V down conversion.

Summary

The ISL8117 high voltage controller makes it easy for designers to remove the intermediate conversion bus to achieve better power efficiency and reliability in a smaller footprint, while also reducing system costs. It offers a cost-effective and reliable alternative for applications where Vout to Vin ratio is low. The controller uses valley current mode modulation with adaptive slope compensation to enable stable operation over a wide range of Vin and Vout combinations, with no external compensation required. System designers can also use the ISL8117's adjustable frequency up to 2MHz to optimize power supply cost, size and efficiency.

The ISL8117 controller reduces solution footprint and simplifies design without compromising performance. Default design values for commonly used functions and the ISL8117's wide Vin and Vout reduce the number of external components compared to competing solutions. With the ISL8117, engineers can design a complete DC/DC buck conversion solution with only 10 components, including MOSFETs and passives, and achieve up to 98% conversion efficiency with 1.5% output voltage accuracy.

The controller's low pin count and layout friendly pin architecture also minimizes the number of overlapping traces, further improving power supply performance. The ISL8117 can be combined with low dropout linear regulators such as the ISL80136, ISL80138, ISL80101A, and integrated FET switching regulators (ISL8023/24 or ISL8016) to support the bulk power rails in a typical process control industrial application.

Next Steps

- Learn more about the ISL8117

- Download the datasheet

- Order free samples

- Generate a board-level design

- Get the demo board

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