

Improving Buck Converter Light-Load Efficiency

The buck converter switching regulator topology has evolved over the years as designers added new improvements to enhance efficiency and improve overall performance. The purpose of this article is to explain the evolutionary steps of progression and help the power supply designer understand the benefits of diode emulation, which is found in many modern buck controllers and switching regulators.

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Figure 1(a) shows an early buck converter using a diode rectifier during the off state of the main power switch. To achieve higher efficiency, designers modified the buck topology by replacing the diode with a synchronous FET (sync FET) as shown in Figure 1(b). While the sync FET improved efficiency over the diode, it introduced circuit behavior that had undesirable side effects under light load conditions. To overcome these adverse light load effects, diode emulation mode was added to enhance the sync FET design. Figure 2(a) illustrates the single transistor buck controller using a diode rectifier. When the switch is conducting, current builds up in the inductor. The amount of current is

a function of the voltage across the inductor and time the switch is closed (ON time). The ratio of the time the switch is closed (ON) to the time it's open (OFF) is used to regulate the output voltage.

When the switch is open (OFF), the current continues to flow in the inductor as shown in Figure 2(b). When the power switch is off, the diode provides the path for the inductor current. This is a practical solution when the buck regulator is used to regulate higher output voltages. But, with the need for lower output voltages and output currents increasing to higher and higher magnitudes, this has become less practical due to the diode losses. Losses were proportional to the voltage

drop of the diode times the magnitude of the current during the portion of the duty cycle in which the current flowed through the diode. To improve efficiency, the standard diode was replaced with a Schottky diode featuring lower forward voltage drop (approximately 0.4 V versus 0.7 V), but this also has its limits.

Synchronous FET advantage

To improve efficiency even further, the diode function was replaced with a FET switch. This FET switch is called a synchronous FET, or sync FET because it is only ON during the OFF time of the main power switch. When the buck converter is switching with nominal output load, the inductor current is always zero or greater as shown in Figure 3.

Under normal load conditions, the inductor current is always positive, flowing from the inductor's input side to the output. The current is composed of a DC portion, but it also has an AC component known as the ripple current. When the sum of the DC and AC components' inductor current remains positive for the entire switching period, the converter is said to be operating in continuous-conduction-mode (CCM). However, if the inductor current under light load conditions becomes negative or zero, the converter is operating in discontinuous-conduction-mode (DCM).

In the single switch buck converter, which uses a diode rectifier, the inductor current could never go negative because the diode allowed current flow in only one direction. Therefore, when the converter was under light load conditions, the current during DCM will appear as shown in Figure 4. Figure 5 illustrates what happens when the buck converter's diode is replaced with a sync FET and is operating under light load conditions – the current goes negative.

Unlike the standard DC/DC buck regulator with a diode rectifier, the sync

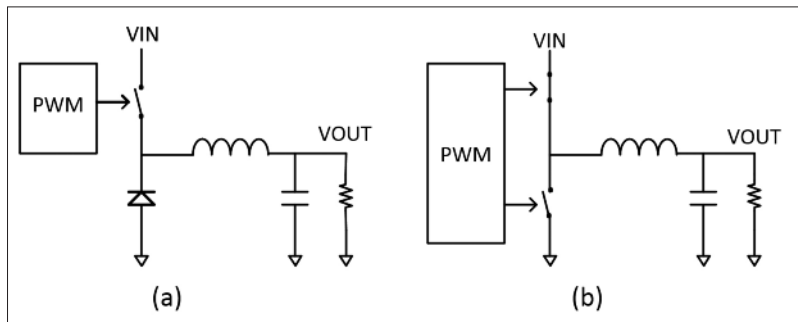


Figure 1: Buck converter with diode rectifier (a), and (b) buck converter with sync FET

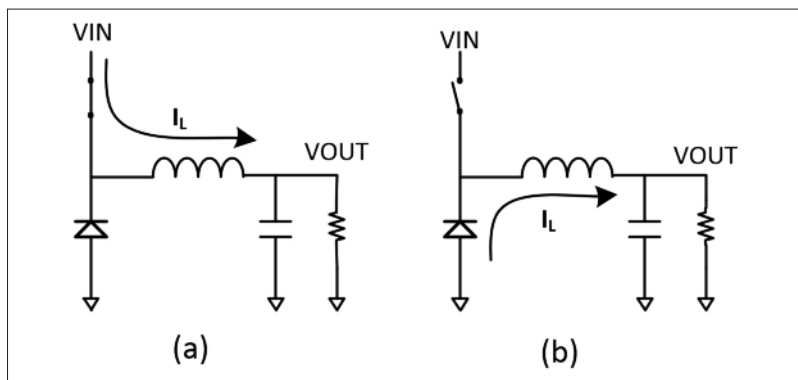


Figure 2: Single transistor buck controller with diode rectifier (a), and (b) controller with switch open flows current to the inductor

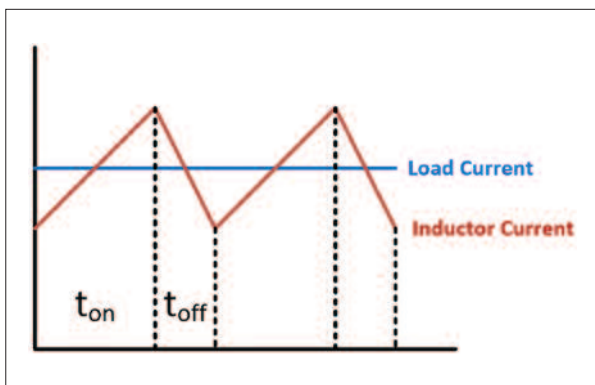


Figure 3: Buck converter switching with inductor current that is always greater than zero current flow

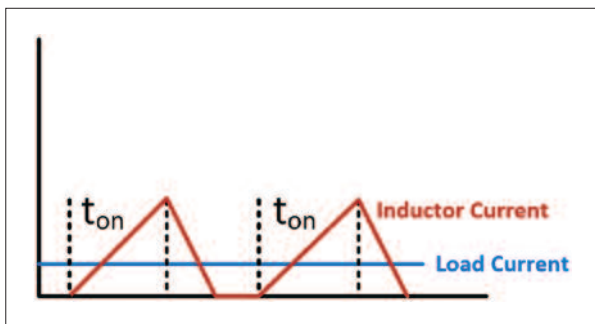


Figure 4: Buck converter in light current load condition operating in DCM

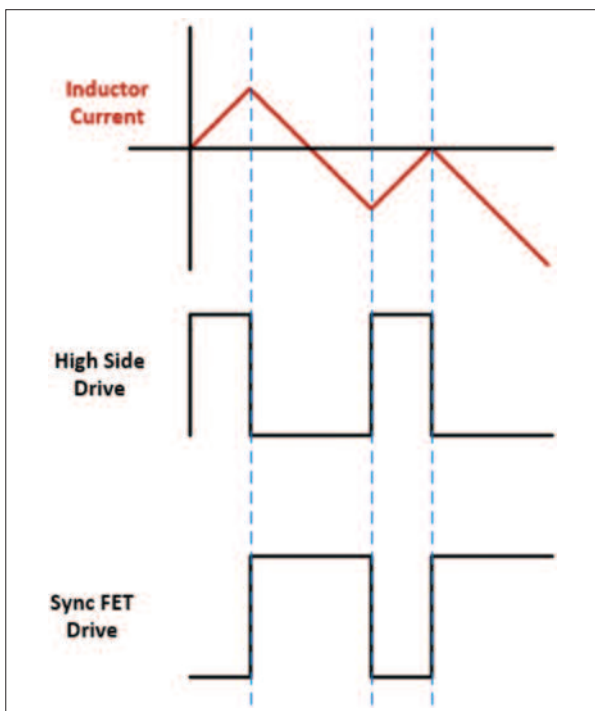


Figure 5: Buck converter's sync FET allows negative current flow

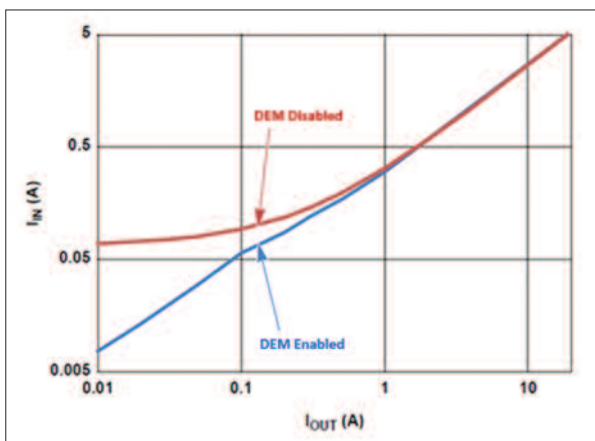


Figure 6: Input current to the ISL8117 is reduced with DEM enabled

FET causes the current in the inductor to flow “backwards” during DCM, stealing energy from the output filter capacitor. This behavior reduces the light-load efficiency because of the unnecessary conduction loss as the low-side MOSFET sinks the inductor current when it would be more efficient to prevent this current from flowing at all.

Diode emulation mode advantage

Many modern controllers include circuitry that avoids the DCM conduction loss by making the low-side sync FET emulate the current-blocking behavior of a diode. This smart-diode operation is called diode emulation mode (DEM) and functions to turn the sync FET off when the circuitry senses that the inductor current is starting to flow in the wrong direction. This circuitry monitors the voltage across the RDS(ON) of the low-side sync FET and turns off the FET when adverse conditions occur.

For example, the ISL8117 high voltage buck controller (V_{IN} 60 V to 4.5 V, V_{OUT} 54 V to 0.6 V, with an operating frequency of 100 kHz to 2 MHz) offers a mode option in which DEM circuitry can be enabled to enhance light load efficiency. When enabled, the DEM circuitry examines the voltage across the sync FET and activates DEM if it signals that the inductor current is going negative for eight consecutive PWM cycles while the LGATE pin is high (the SYNC FET is ON). Using detection over eight cycles prevents noise from activating DEM. If the ISL8117 enters DEM mode, the switching frequency of the controller will also decrease. Both of these actions increase efficiency by not allowing negative current flow and by reducing unnecessary gate-driver switching losses. The extent of the frequency reduction is proportional to the reduction of load current.

Figure 6 illustrates the reduced input current to the ISL8117 buck regulator circuit when DEM is enabled and when it's not enabled. The data for Figure 6 was taken using the ISL8117 evaluation board with V_{IN} at 48 V and V_{OUT} at 12 V configured to support a full-scale 20 A load. The DEM circuitry is used to enhance light-load efficiency.

Conclusion

If your buck regulator application requires excellent light-load efficiency, you'll want to consider the selection of a controller or regulator that offers DEM. Avoiding DCM conduction loss and reducing unnecessary gate-driver switching losses will help your next power supply design meet its performance specification targets.

Synchronous Buck Controller Converts Directly from 48 to 1 V

Intersil introduced its first 60V synchronous buck controller able to bypass the intermediate step-down conversion stage traditionally employed in industrial applications. The ISL8117 synchronous step-down PWM controller's low duty cycle (40 ns minimum on time) and adjustable frequency up to 2 MHz enables the direct step-down conversion from 48 V to a 1V point-of-load. In such 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 decrease efficiency.

The controller employs valley current mode control with low side MOSFETs on-resistance, valley current sense and adaptive slope compensation. Its 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 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 4.5 V and 60 V, and its output can be adjusted from 0.6 V to 54 V. It has an adjustable frequency range of 100 kHz to 2000 kHz and can produce minimum on-time of 40 ns (typical). With a minimum on-time of 40 ns, the controller can generate 1 V output from a 12 V bus at 1.5 MHz. It is also capable of generating a 1 V supply from a 48 V source at

lower frequency. 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.

Engineers can design a complete DC/DC buck converter with 10 components, including external power MOSFETs and passives, and achieve up to 98 % conversion efficiency with 1.5 % output voltage accuracy. The DEM/Skipping Mode at light load lowers standby power consumption with consistent output ripple over different load levels. The ISL8117 high voltage controller can be combined with Intersil 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.

The ISL8117 is available in 4mm x 4mm QFN and 6.4mm x 5mm HTSSOP packages. Both packages use an EPAD to improve thermal dissipation and noise immunity. Pricing for the QFN package is \$1.80 and the HTSSOP is \$1.95 in 1k quantities. Two evaluation boards are priced at \$80 – the ISL8117EVAL1Z low power (V_{in} 4.5V-60V and 3.3V_{out}/6A), and the ISL8117EVAL2Z high power (V_{in} 18 V-60 V and 12 V_{out}/20 A). Two demonstration reference design boards priced at \$60 allow designers to produce low power (factory automation or robotic) and high power (telecom) applications.

www.intersil.com/products/isl8117

