

Agency requirements for stand-by power consumption of offline and POL converters for consumer applications

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Introduction

Trying to meet ENERGY STAR® requirements to maintain energy efficiency is a constant design challenge. As the number of consumer devices in homes increases and when taking energy from the grid, designers want to improve light-load efficiency without increasing cost or complexity. Reducing the product's power consumption by one watt can save megawatts from the grid, especially with high-volume consumer applications such as the set-top box. The semiconductor industry has developed new offline AC/DC and point-of-load (POL) DC/DC solutions that greatly improve efficiency at lower stand-by power levels. This article highlights new techniques used by new flyback and secondary-side controllers, and compares two complete POL architectures with and without the light-load efficiency feature. Also covered is the energy-saving advantage gained when selecting a POL solution with light-load efficiency features.

ENERGY STAR requirements for set-top boxes

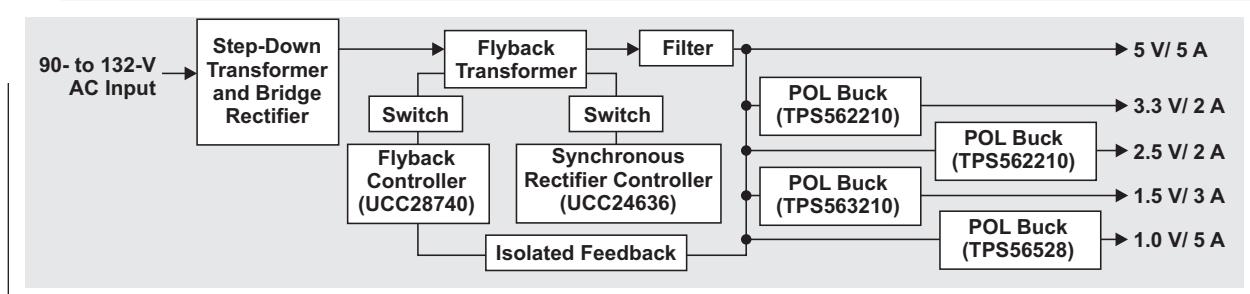
The final ENERGY STAR version 4.1 specification for set-top boxes was announced on April 4, 2014 and took effect on December 19, 2014. Version 4.1 accommodates new technology such as deep sleep functionality, multi-room configurations, displayless gateways, high-efficiency video processing, and ultra-high definition video.^[1] If all set-top boxes sold in the United States (US) were ENERGY STAR compliant, the savings would be more than \$1.8 billion per year, and more than 24-billion pounds of greenhouse gas emissions per year would be prevented. Investigating every avenue to reduce power consumption in a power-management design will improve the ability to meet the evolving ENERGY STAR requirements.

Power-management architecture

A power architecture for the US market was chosen for a design example that consists of an offline power supply that accepts a 90- to 132-VAC input from the mains. Since 5 V is the highest voltage required in most low-power set-top boxes, a 5-V intermediate bus was chosen over a 12-V bus to improve overall efficiency. The 5-V intermediate bus provides around 5 A, or 25 W, and the total power capability required depends on the additional functionalities integrated into the box, such as a removable media player, additional tuners, or an integrated digital video recorder. From the 5-V bus, typical POL voltages are 3.3 V, 2.5 V, 1.5 V, and 1.0 V, which are common in many POL architectures. The output currents of each POL voltage are usually less than 3 A, but requirements for the low-voltage rails have increased over time due to the added functionality of the main processor, which can require up to 5-A peak.

For this demonstration, an isolated AC/DC power supply (Figure 1) was constructed using a constant-current, constant-voltage flyback controller (UCC28740) along with a synchronous rectifier controller (UCC24636). The POL section on the secondary-side uses 2-A (TPS562210), 3-A (TPS563210), and 5-A (TPS56528) step-down buck converters to generate the four voltages from the 5-V bus. Each POL converter uses an advanced Eco-mode™ for high light-load efficiency. A reference design is available for download featuring both sections of the power supply and includes a schematic, bill of materials, test report and design files.^[2]

Figure 1. Isolated AC/DC power supply with Eco-mode™ technology



AC/DC Conversion

The flyback converter can be used for set-top box AC/DC applications because it provides an inexpensive, isolated output and uses few external components. Operation of the flyback converter in discontinuous conduction mode (DCM) is especially attractive because it eliminates reverse recovery losses in the output rectifier to improve the efficiency. The simplified schematic in Figure 2 uses a flyback controller that uses DCM with valley switching to further reduce switching losses. The controller has a maximum frequency of 100 kHz to provide a high-density design and it also maintains control of the peak primary current in the transformer. The controller has a minimum switching frequency of 170 Hz to minimize the no-load power consumption to less than 60 mW when using a standard shunt regulator and optocoupler. Lower standby power can be achieved when using an optocoupler with a high-current transfer ratio and a lower-power regulator instead of a low-voltage shunt regulator.

To achieve higher full-load and light-load efficiency, a traditional diode solution used by the flyback topology can be replaced with a synchronous rectifier controller (UCC24636) and a power MOSFET. This near-ideal diode-rectifier solution reduces power dissipation of the rectifier

and minimizes body-diode conduction time of the power MOSFET. A synchronous rectifier controller also reduces primary-side losses, simply due to the efficiency gains of the total power solution.

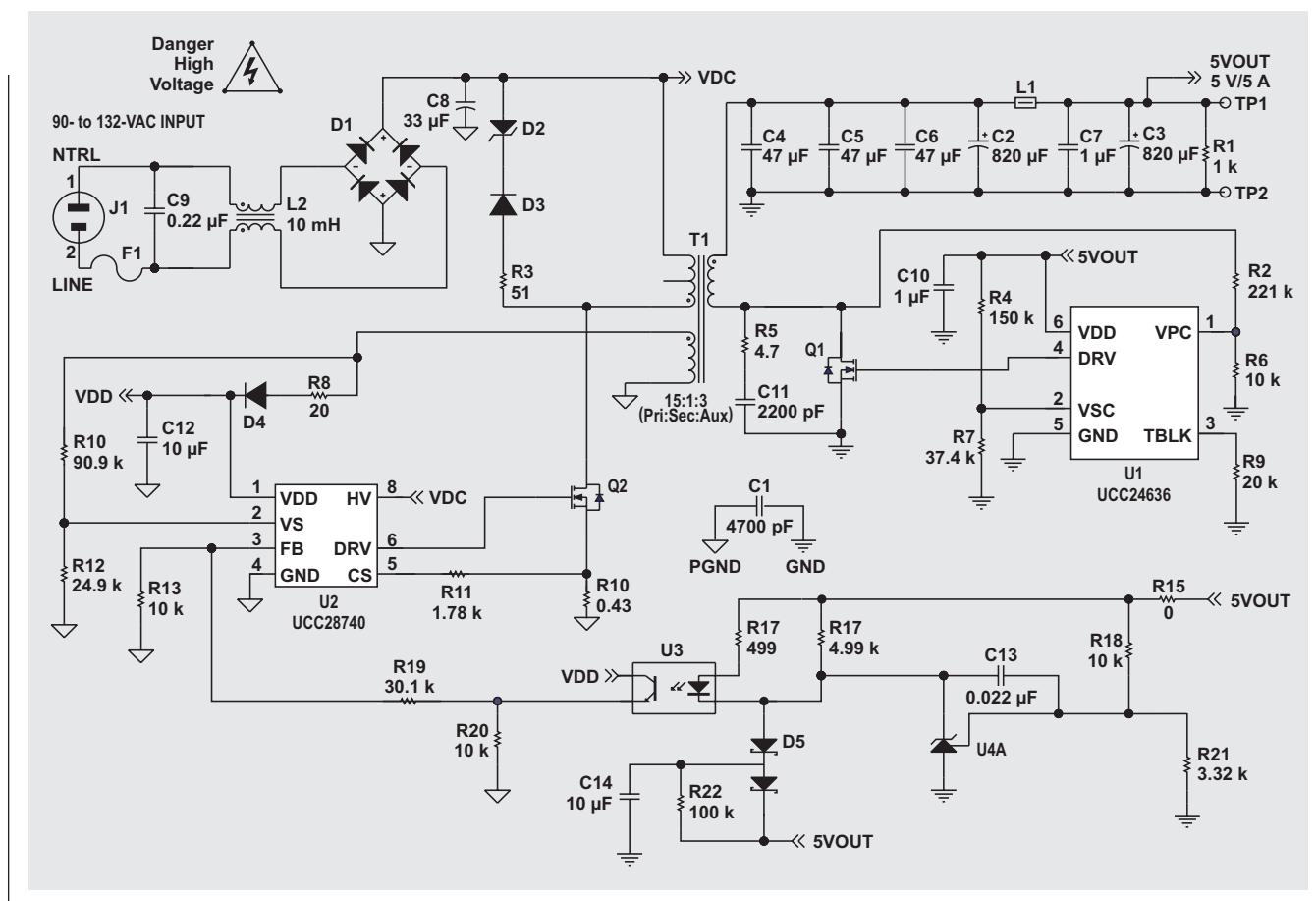
The four-point average efficiency of the offline supply is 85.1%, with a peak efficiency of 85.45% occurring at 25% rated load. Offline supply efficiency is shown in Table 1 with all other supplies disabled during the test. The no-load power dissipation is 61 mW.

Table 1. Offline power supply efficiency

Load	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	Efficiency
10%	2.97	4.98	4.99	83.81%
25%	7.3	4.98	1.252	85.45%
50%	14.64	4.98	2.503	85.14%
75%	21.94	4.97	3.75	84.95%
100%	29.27	4.97	4.999	84.88%

For set-top boxes using an external power supply (EPS), the external supply must also be ENERGY STAR qualified or meet the no-load and active-mode efficiency levels provided. Without using any energy-saving techniques, a traditional fixed-frequency pulse-width modulator (PWM) flyback converter can easily dissipate too much

Figure 2. Simplified schematic for a flyback and synchronous rectifier controller



energy and prevent a product from achieving ENERGY STAR compliance. To save energy throughout all load levels, a green-mode flyback and synchronous rectifier controller employs numerous loss-reducing techniques, including valley switching, variable frequency control, and pulse-skipping at light loads.

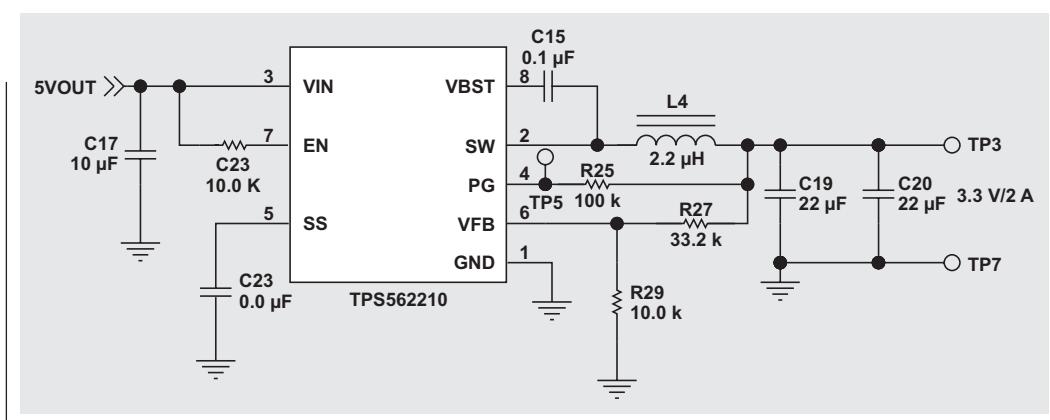
Point-of-load conversion

The POL regulators generating low voltages from the 5-V intermediate bus employ an energy-saving pulse-skipping technique with Eco-mode™ technology. Similar operation modes have traditionally been used in applications that are powered by batteries, such as cell phones and notebook PCs. However, DC/DC converters with such operating modes are becoming more prevalent in the market for non-portable applications due to ENERGY STAR requirements. See Figure 3 for one of these POL converter schematics.

The inductor current in a synchronous buck converter is a triangle wave. As the output current decreases from a heavy-load condition, the inductor current is reduced and the rippled valley of the triangle wave eventually touches the zero level at the boundary between continuous conduction mode (CCM) and DCM. With the pulse-skipping feature, the rectifying MOSFET is turned off when the converter detects zero current in the inductor. As the load current further decreases, the on time is held nearly constant so that the off time is extended and the switching frequency is reduced to maintain regulation. As a result, the power MOSFETs and inductor are idle for longer time periods and conduction losses are greatly reduced. The point at which the DC/DC converter enters the light-load efficiency mode is shown in Equation 1.

$$I_{OUT(LL)} = \frac{L \times f_{SW}}{2} = (V_{IN} - V_{OUT}) \times \frac{V_{OUT}}{V_{IN}} \quad (1)$$

Figure 3. DC/DC converter with advanced Eco-mode™



POL efficiency comparison

The efficiency measurements for each POL converter were taken with the demonstration board from no-load to full-load and summarized in Table 2. Many designers will inspect an efficiency curve to verify performance. In this case, however, it is advantageous to inspect the actual power dissipation in watts to verify whether excessive power dissipation precludes meeting an agency approval's specification. Note that the total power dissipation for all four converters, while enabled and switching, is only 29 mW at no-load and 36 mA at 10 mA. The low power-loss performance is due to pulse-skipping and low operating quiescent current of each device.

Table 2. Power dissipation with Eco-mode™ converters

Load	Power Dissipation (W)				Total Dissipation (W)
	POL 1 V/5 A	POL 1.5 V/3 A	POL 2.5 V/2 A	POL 3.3 V/2 A	
No load	0.008	0.006	0.007	0.008	0.029
10 mA	0.008	0.007	0.01	0.011	0.036
100 mA	0.027	0.03	0.036	0.037	0.13
25% full load	0.03	0.14	0.11	0.1	0.38
50% full load	0.23	0.32	0.26	0.26	1.07
100% full load	3.23	1.15	0.97	1.09	6.44

To illustrate the effectiveness of pulse-skipping, the devices in the POL design were replaced with traditional DC/DC converters operating in CCM without a pulse-skipping feature. The task to replace the components in the design was not difficult since the devices are footprint

compatible. Table 3 shows the total dissipation for all four converters at no load and 10 mA is 242 mW, which is almost 10 times the power dissipation of the pulse-skipping converters at no-load. Using advanced Eco-mode DC/DC converters translates to a 2.1-kWh/yr savings in the POL architecture alone when operating in the standby mode. For efficiency curves and more power-loss data, please see the test report of the PMP11180 reference design.^[2]

Table 3. Power dissipation with CCM converters

Load	Power Dissipation (W)				Total Dissipation (W)
	POL 1 V/5 A	POL 1.5 V/3 A	POL 2.5 V/2 A	POL 3.3 V/2 A	
No load	0.08	0.062	0.054	0.046	0.242
10 mA	0.08	0.062	0.054	0.046	0.242
100 mA	0.083	0.066	0.059	0.05	0.258
25% full load	0.066	0.14	0.11	0.1	0.416
50% full load	0.26	0.32	0.26	0.26	1.1
100% full load	3.4	1.16	0.97	1.1	6.63

Trade-offs to light-load efficiency

When a DC/DC converter enters a pulse-skipping mode, the pulses of the PWM are further apart causing the peak-to-peak output ripple voltage to increase. In most cases, the set-top box is not sending or receiving data and the tuner circuitry is less likely to be affected by noise. However, the designer must pay special attention to the ripple voltage to be sure it does not hamper performance results.

Conclusion

When designers need to reduce power consumption for every component in their product, the offline and point-of-load architecture must not be overlooked. Selecting a high-efficiency flyback controller with a synchronous rectifier controller and synchronous DC/DC buck converters with advanced Eco-mode technology will save hundreds of milliwatts of dissipation under light-load conditions. This translates to a savings of several kWh/yr without sacrificing cost or performance. Please visit our TI AC/DC and isolated DC/DC or the non-isolated DC/DC converter E2E™ forum to ask questions about implementing energy-saving features in your application.

References

1. "ENERGY STAR® Program Requirements for Set-top Boxes," Partner Commitments (Version 4.1)
2. "High Light-Load Efficient 120VAC Input, 25W/5VDC Reference Design with 4 POL Outputs," Texas Instruments reference design (PMP11180.1)
3. "High-performance DC/DC power conversion for any application," Texas Instruments power management online product folder
4. "Products for Offline and Isolated DC/DC Controllers and Converters," Texas Instruments power management online product folder

Related Web sites

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