Application Report

SLUA373−January 2006

Bootstrap Circuit for Green Mode Applications

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1 Introduction

To conserve energy there has been a big push to lower the standby power in offline power supplies. Many countries around the world are adopting green mode standards. A good example of this is the EU code of conduct in Europe that has very stringent standby power consumption specifications. In 2001 the input standby power in Europe for an offline converter was limited to roughly 1 W and in 2007 the standby power requirement will be less than 0.5 W in most applications. In offline power supplies, designers have been meeting these specifications with quasi resonant converters and frequency fold back techniques to reduce switching losses. Every trick that can be used is being used to eliminate losses when the supply is in standby mode. Even the power dissipated by the boot strap circuit could cause the power supply to fail these stringent standby input power requirements. This application brief reviews a technique to bootstrap a power supply that only dissipates power during startup and make it easier to meet these new green mode specifications.

Table 1. EU Code of Conduct by Date from 2001 to 2007

	STANDBY POWER			
OUTPUT POWER	JAN 2001	JAN 2003	JAN 2005	JAN 2007
0 W to 1.5 W	1.00 W	0.75 W	0.30 W	0.150 W
15 W to 50 W	1.00 W	0.75 W	0.50 W	0.250 W
50 W to 60 W	1.00 W	0.75 W	0.75 W	0.375 W
60 W to 150 W	1.00 W	0.75 W	1.00 W	0.500 W

2 Traditional Boot Strap Circuits

Figure 1 shows an offline flyback converter being controlled by a pulse width modulator (PWM). The input to this converter is a universal input of 85 V ($V_{IN(min)}$) to 265 V RMS ($V_{IN(max)}$). The schematic shows the bias (V_{AUX}) to the PWM controller is supplied by an auxiliary winding off the flyback transformer. Resistor R_t and C_{HOLD} form the bootstrap circuit.

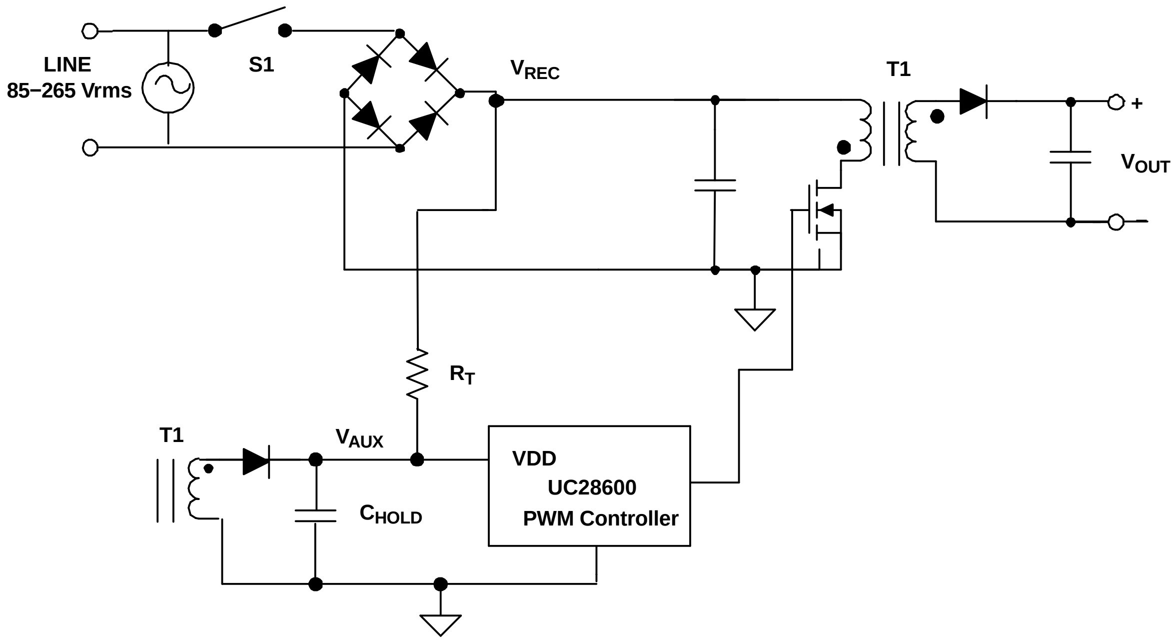

Figure 1. Offline Power Supply with Traditional Bootstrap Startup

3 Problem with Traditional Bootstrap Circuit

The PWM controller dissipates roughly 0.25 W once the device is active driving the switching FET. The holdup capacitance (C_{HOLD}) is generally sized to supply energy to the device during supply startup. In most applications C_{HOLD} is between 50 μF and 100 μF. For this example we will use the worst case holdup capacitance of 100 μF. The PWM in this example has a turnon threshold of roughly 9 V and roughly 500 μA of startup current. A designer might use an 82-kΩ resistor as a trickle charge resistor. This allows roughly 1.5 mA to 4.5 mA of trickle charge current to charge up the holdup capacitor. The R_t, C_{HOLD} and the PWM controller's startup threshold determine the minimum amount of time needed for startup. The boot strap circuit in this configuration turns on in roughly 200 ms to 640 ms. The only problem with this is the 82-Ω resistor would dissipate roughly 1.7 W (PRT) at maximum input voltage ($V_{IN(max)}$) and would not pass the EU code of conduct in standby mode.

$$V_{CC} = V_{IN} \times \sqrt{2} \times \left(1 - e^{\frac{-t}{R_t \times C_{HOLD}}}\right)$$

$$t = R_t \times C_{HOLD} \times I_N\left(\frac{V_{IN} \times \sqrt{2} - V_{CC}}{V_{IN} \times \sqrt{2}}\right) \approx 0.2\ \text{s}\ 0.64\ \text{s}$$

$$P_{RT} = \frac{\left(V_{IN(max)} \times \sqrt{2} - V_{CC}\right)^2}{R_t} \approx 1.6\ \text{W}$$

The next approach a designer might take is to allocate a power budget (P_{LIM}) for the trickle charge resistor to pass EU specifications. For this design example we allow the trickle charge resistor to dissipate a maximum of 0.1 W. This would require a trickle charge resistance (R_t) of roughly 1.4 MΩ. The only problem with this approach is the power supply would take roughly 3 to 11 seconds for the power converter to turn on this is too much time for most applications.

$$R_t = \frac{\left(V_{IN(max)} \times \sqrt{2}\right)^2}{P_{LIM}} = \frac{(375\ \text{V})^2}{0.1\ \text{W}} \approx 1.4\ \text{M}\Omega$$

4 Solution

The circuit in Figure 2 can be configured to provide a fast start up for the offline power converter while dissipating little to no energy after power up. This makes it easier for the designer to meet the standby power requirements. The circuit requires a fast turn on to operate correctly. Most offline power supplies have a power switch (S1) that adds input power to the circuit quickly when the switch is turned on.

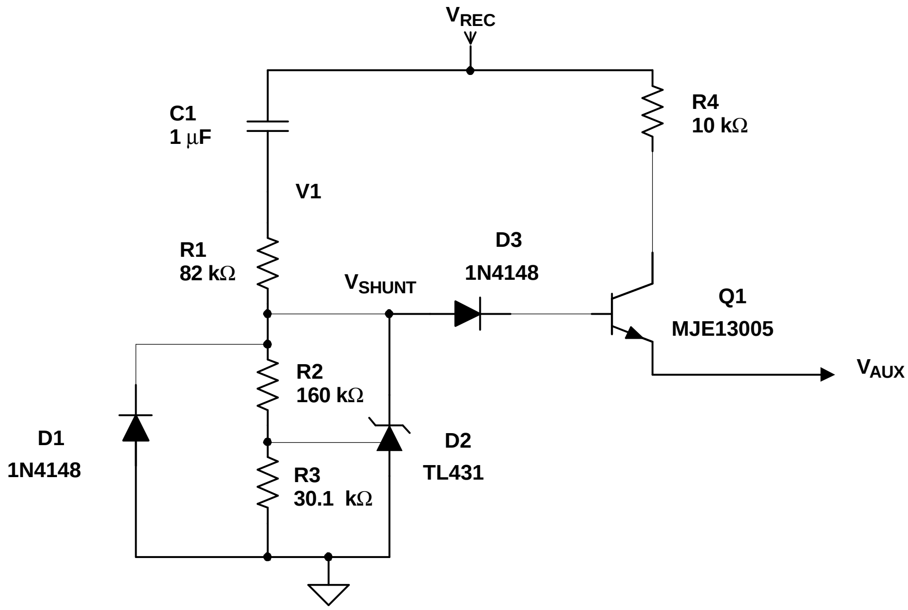

Figure 2. Low Power Standby Bootstrap Circuitry

The circuit forms a timed series pass regulator. Electrical components R1 and C1 form the timing of the bootstrap circuit. Resistors R2, R3 and the shunt regulator D2 set the V_{AUX} voltage during startup. Once the circuit has timed out it will be turned off dissipating no power enabling the designer to meet green mode specifications. Diode D1 protects the other electrical components in the circuit from a negative voltage when C1 discharges. Resistor R4 limits the current into Q4 keeping the transistor within its safe operating area. The circuit is not difficult to setup and can be set up with the following equations.

V_{SHUNT} is sized to set the auxiliary voltage (V_{AUX}) just above the control device's UVLO turn-on threshold. This voltage powers the control device until the series pass regulator times out. Once the circuit has timed out transistor Q1 turns off and the boot strap circuit will not dissipate any power conserving energy, making it easier to meet green mode specifications.

$$V_{SHUNT} \le V_{AUX} + V_{D3} + V_{BE(Q1)}$$

R2 is calculated by selecting R3 and knowing the internal reference (V_{REF}) of the shunt regulator D2.

$$R2 = R3 \times \frac{V_{SHUNT} - V_{REF}}{V_{REF}}$$

Resistor R1 is sized to provide a bias current ($I_{BIAS(D2)}$) to the shunt regulator. The resistor should be sized to allow at least 3 to 4 times the minimum bias current recommended in the shunt regulator's data sheet. This resistor may consist of several resistors in series to meet the high input voltage requirement of 375 V.

$$R1 = \frac{V_{IN(min)} \times \sqrt{2}}{I_{BIAS(D2)}}$$

Capacitor C1 is sized on the amount of bootstrap time (t_{BOOT}) the circuit requires for startup. The boot strap circuit will time out in roughly five RC time constants.

$$C1 = \frac{t_{BOOT}}{5 \times R_1}$$

5 Boot Strap Circuit Performance

The boot strap circuit was constructed and tested in an offline flyback circuit with the components in Figure 2. The holdup capacitance (C_{HOLD}) was two 47-µF capacitors in parallel. The circuit was constructed in the lab and tested. The circuit was tested with 120 V and 375 V dc applied to the input. These input voltages represent the peak input voltages of minimum and maximum line for this design. The testing showed that boot strap circuit applied power to the device for roughly 50 ms to 100 ms. This is roughly 6 to 10 times faster than the trickle charge resistor technique present in Figure 1. The boot strap circuit timed out in roughly 400 ms. This can be observed by trace V1 in the scope plots.

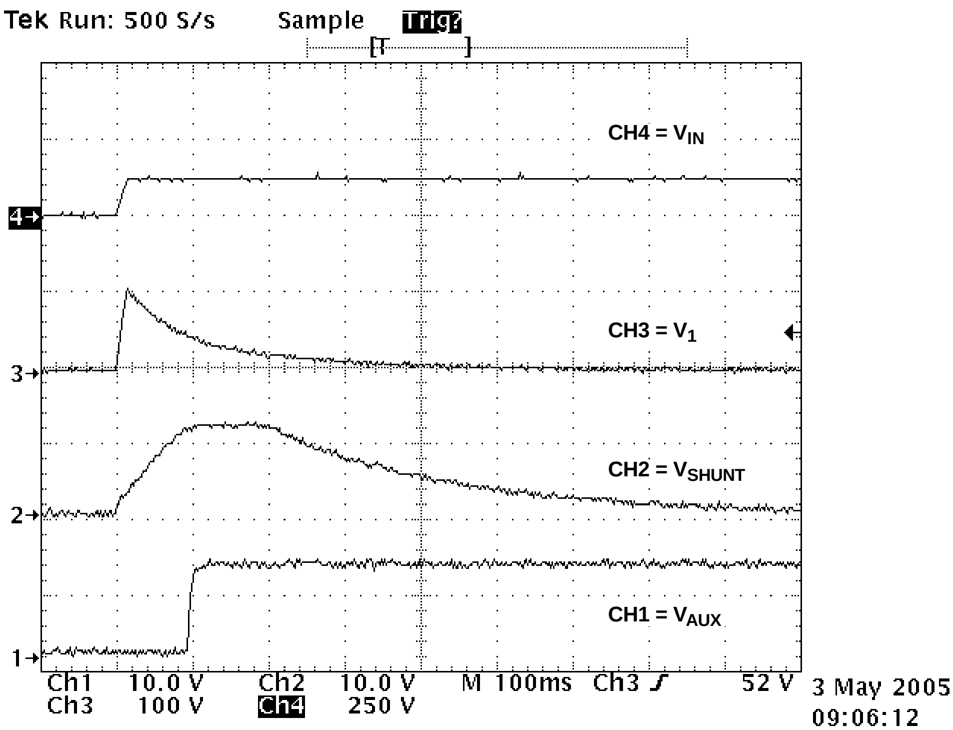

Figure 3. Startup with 120 V DC Applied to the Input.

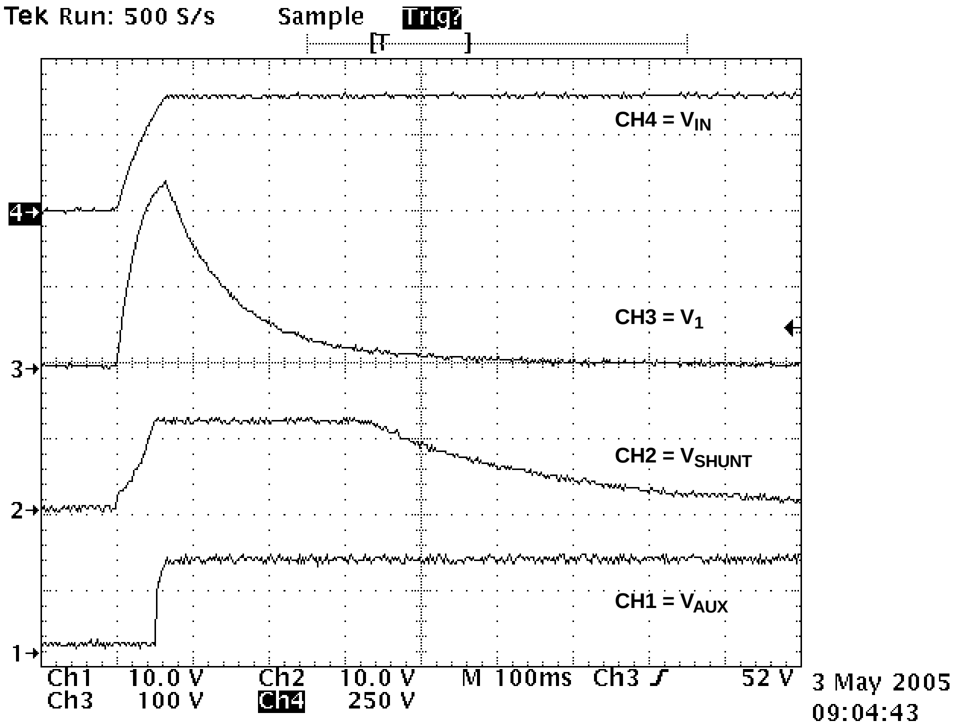

Figure 4. Startup with 375 V DC Applied to the Input.

6 Conclusion

In offline power supply designs the standby power requirements are getting more stringent and tougher to meet. By 2007 the EU code of conduct for standby power will drop to less than 0.5 W. Frequency foldback, zero current and zero voltage switching techniques are being used today to meet these specifications. Designers need to remove losses any place possible to meets these requirements. The bootstrap circuit presented is faster than traditional methods. The circuit also turns itself off after startup removing unwanted power dissipation making it easier for the designer to meet their green mode specifications.