Application Report
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Minimize Standby Consumption for UCC287xx Family

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ABSTRACT

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Trademarks

1 Introduction

Any appliance that is constantly plugged in such as washing machines, microwaves, and coffee makers, requires either a mechanical disconnect switch or dissipates power in standby condition. In end applications, the microcontroller is surrounded by peripheral circuits, like display or other similar units, to make user interface easier. These circuits act like a resistive circuit and consume some energy during standby. The power consumption of this standby load can range from a couple to few hundreds of mW, depending on the application. It is becoming a growing trend to keep these standby losses to zero power levels in next-generation devices. IEC 62301:2011: clause 4.5 specifies the standby power less than 5 mW as “Zero Standby”. Any appliance that adheres to this can achieve a zero power label.

International Electrotechnical Commission (IEC) is a standard international organization that publishes international standards for various electrical and electronic equipment performances like power generation, transmission, and distribution to home appliances. IEC 62301 “Household Electrical Appliances – Measurement of Standby Power” standardizes measurement methods of standby power in various appliances and electronic equipment. IEC 62301:2011 specifies measurement of electrical power in low power modes (network mode), also called standby.

2 Where Does Standby Power Go?

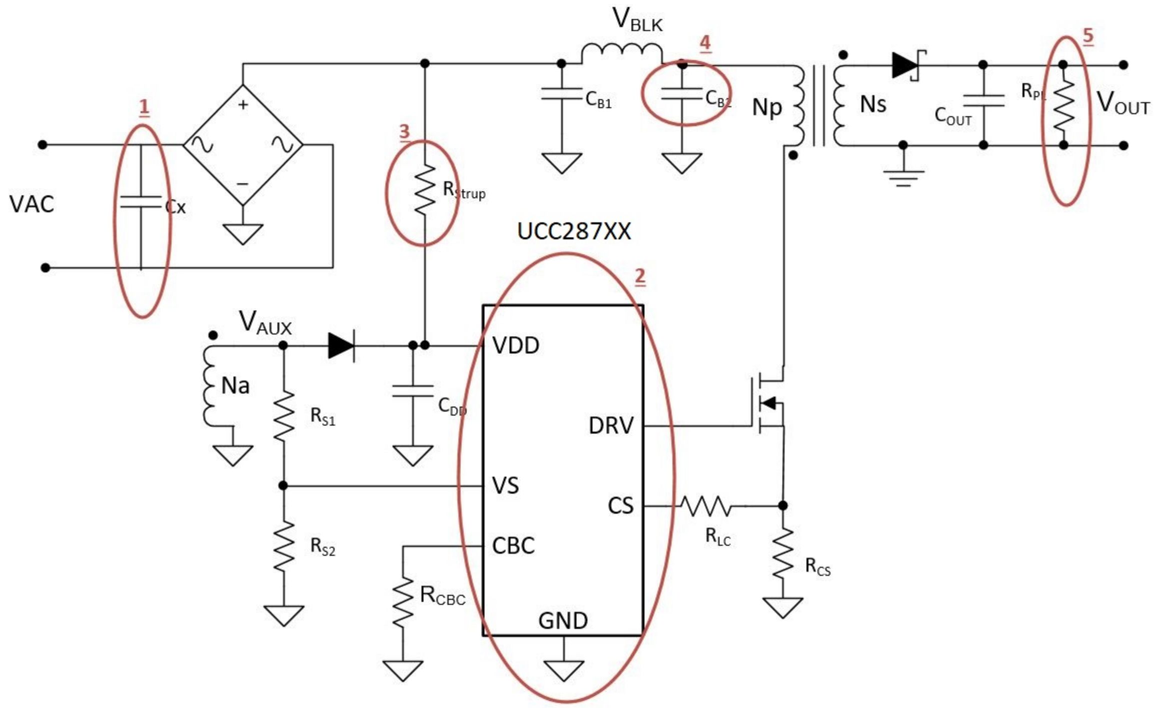


Figure 1. Typical ADDC Flyback Application

The standby power dissipation can be broken down into the following areas as highlighted in Figure 1:

2.1 X-cap Discharge

The filter capacitor known as "X-cap" (Cx in Figure 1) is connected between the live and neutral in order to help filter out the differential mode noise from the power supply. According to the IEC 62368 standard para 5.5.2.3, the circuit connected to mains supply should have a means of discharge, resulting in a time constant not exceeding two seconds. This calculates the time constant of the discharge period based on the X-cap capacitance and resistive values:

$$\zeta = R_X \times C_X$$

where

- C_x is the capacitance of the X-cap
- R_x is the discharging resistance
- P_{dis} is the power dissipation across the X-cap (1)

You can assume that some power would be constantly dissipated by this discharging resistor. The power dissipation can be calculated as:

$$P_{dis} = \frac{V_{AC\_rms\_max}^{2}}{R_X} \quad (2)$$

This P_{dis} is very significant during the no-load condition, especially at high line. Practically, lower discharge resistance is associated with a higher X-cap value, so there is a trade-off between the standby power and EMI performance.

The UCC287xx family operates in discontinuous conduction mode with valley switching in order to minimize the switching losses of the MOSFET and improve the efficiency. These controllers are designed to detect the resonant ring during the dead time, and the MOSFET is turned on at the valley which is the falling edge of this resonant ring, allowing for a higher frequency operation and a smaller input EMI filter.

2.2 IC Bias Power

The UCC287xx family enables the controller to operate with a very low IC bias current during standby (Iwait) that enables low standby power. The controller current consumption is device specific. For example, the UCC28730 controller has a very low bias current of ~50 µA during standby conditions, which varies for different members of this family. The control law feature enables the UCC28730 controller to vary the switching frequency at very light to no-load condition down to 28 Hz. This is called a wait-state, enabling the power consumption of the controller to be <1 mW.

Table 1 shows the IC bias current (Iwait) comparison of various UCC287xx members.

Table 1. UCC287xx Standby Current Feature

UCC287xx CONTROLLER	IC BIAS CURRENT AT STANDBY (µA)	
	Typ	Max
UCC2870X	85	110
UCC2871X	95	120
UCC2872X	95	150
UCC28730	52	75
UCC28740	95	125
UCC28742	80	115

If standby is a primary concern, then choosing a controller with a lower bias current spec adds a major limit to the IC power consumption during standby.

2.3 Startup Resistor Loss

The start-up resistor is required to provide for the initial charging current across the VDD capacitor to supply for an active source of start-up charging current. The Vdd capacitor is required to provide the initial charge until the auxiliary bias gets high enough to maintain regulation. The value of the start-up resistor depends on the UVLO start threshold and the bias current of the controller. The power dissipation across this resistor can be calculated as:

$$P_{strup} = \frac{{V_{AC\_rms\_max}}^2}{R_{strup}}$$

where

- P_{strup} is the power loss across the startup resistors
- R_{strup} is the resistances required to provide sufficient current to charge the Vdd cap (3)

To eliminate this loss, some members of the UCC287xx family have an integrated high voltage start-up circuit built in as referred to in Table 2. The HV pin connects directly to the bulk capacitor to provide start-up current to the VDD capacitor. The typical start-up current is approximately 250 µA, which provides fast charging of the VDD capacitor. Once the controller is past the start-up state and is running, no current is drawn from the bias cap and the internal FET is disabled, thus enabling the application to save the power loss across it. Choosing a controller with integrated high voltage start-up can help limit this power dissipation. Figure 2 has a tabular comparison of various UCC287xx family members against the high voltage start-up feature.

Table 2. Feature Description of UCC287xx Family

UCC287xx CONTROLLER	INTEGRATED HV START-UP
UCC28700	No
UCC2871X	Yes
UCC28720	Yes
UCC28722	No
UCC28730	Yes
UCC28740	Yes
UCC28742	No

According to the IEC 62368 Para 5.5.2.3: Safety Regulations against Capacitor discharge, for any power supply where a capacitor voltage is or becomes accessible upon disconnection from connector, the circuit should be provided with a means of discharge within 2 sec, complying with ES1 limits. The start-up resistor is required to ensure enough current to charge the VDD capacitor at low-line condition in order to achieve a certain start-up time (<2 s). Typically, the R_{strup} value ranges from 13 MΩ to 20 MΩ.

2.4 Bulk Cap Leakage

The bulk capacitor dissipation is considered in regards to the leakage current: I_{leak}, which is dependent on input voltage, temperature, and operation time. The leakage current becomes practically insignificant after one to five minutes of applying the rectified voltage.

In accordance to the EN130300, the leakage current measured after five minutes should be less than:

$$I_{leak} < \left(0.3 \times V_{AC\_rms\_max} \times C_{bulk}\right)^{0.7} + 4\ \mu A \quad (4)$$

The leakage power dissipation can be calculated as the energy dissipated over time:

$$P_{leakage} = V_{AC\_rms\_max} \times I_{leak} \quad (5)$$

It is recommended to choose a capacitor with low leakage current rating in order to minimize the standby power loss.

2.5 Pre-load Resistor Loss

In order to stabilize the power supply during no-load condition, it is required to have a certain load that equalizes the power consumption between the auxiliary winding and secondary winding. A lower bias standby current 52 µA of the UCC287xx controller helps reduce the pre-load resistor value. The power dissipated in the pre-load resistor can be estimated as:

$$P_{pre} - load = \frac{{V_{out}}^2}{R_{PL}}$$

where

- R_{PL} is the pre load resistor value
- $P_{pre\text{-}load}$ is the power loss across the pre load resistors (6)

In order to maintain stable operation, the output load current should be greater than the auxiliary load current or the IC bias current.

2.6 Control Law

The UCC287xx family has implemented a control law function in order to improve the efficiency and standby power, where the IC switches between the frequency modulation and amplitude modulation, depending on the output load. This enables the controller to vary the operating frequency based on the line and load conditions. This flexibility helps the device to achieve better light load efficiency and low standby power.

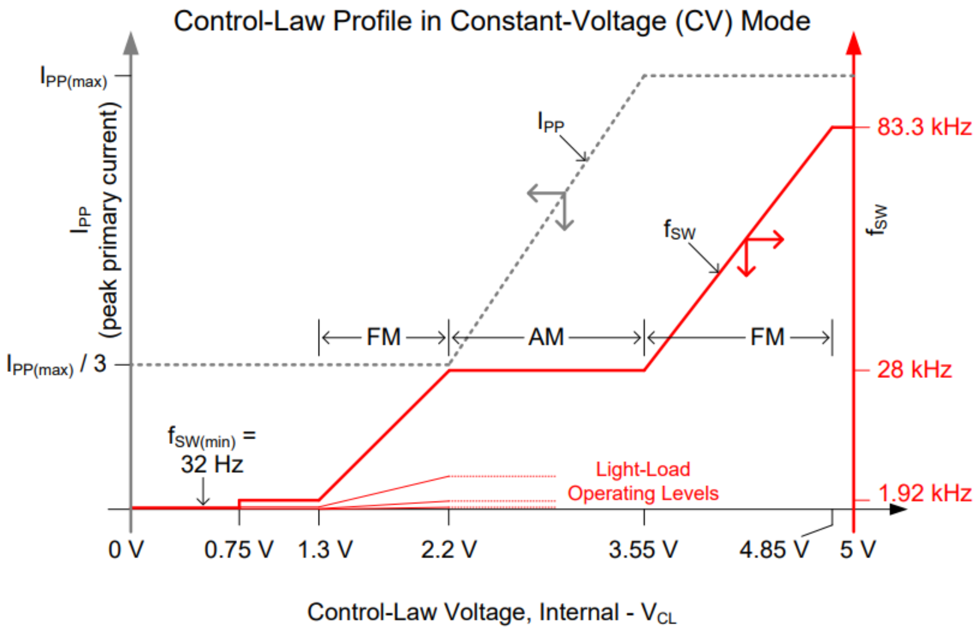


Figure 2. Control Law Profile of the UCC28730

As the output load (x-axis) goes towards zero, the switching frequency (y-axis) can be seen moving from 83.3 kHz to 32 Hz. Along with this, the primary peak current also reduces by a 3-to-1 ratio, also referred to as the “Kam” ratio in the data sheet.

The maximum and minimum input power can be specified by Equation 7 and Equation 8:

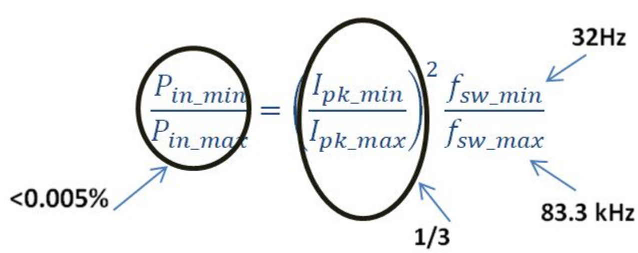
$$P_{in\_max} = \frac{1}{2} L_{pri} \times I_{pk\_max}{}^{2} \times f_{SW\_max} \quad (7)$$

and

$$P_{in\_min} = \frac{1}{2} L_{pri} \times I_{pk\_min}{}^{2} \times f_{SW\_min}$$

where

- $P_{in\_max/min}$ is the power consumption of the power stage
- L_{pri} is the primary inductance
- $I_{pk\_max/min}$ is the primary peak current
- $f_{sw\_max/min}$ is the switching frequency of the controller (8)



Equation 7 and Equation 8 estimate the standby power consumption by looking at the ratio of the min to max input power for the UCC28730 controller.

Note that this calculation assumes an ideal operating condition and the losses calculated are just across the control law profile of the UCC28730 controller.

3 Relationship Between Standby Power and Design Parameters

While all these features that were previously described can help limit the standby power losses, they are heavily dependent on the choice of controller. In order to resolve this challenge, every data sheet has a standby power number on the first page which is only applicable for a specific operating condition.

The application design specification plays a very critical role in determining the standby power. Equation 9 can be referred to for calculating the estimated standby power:

$$P_{stdby} = \frac{V_{out} \times I_{out} \times f_{min}}{n_{sb} \times K_{am}^{2} \times f_{max}}$$

where

- K_{am} is the ratio of maximum to minimum primary current peak amplitude, 2.99 V/V typical
- n_{sb} is the estimated internal pre-load power efficiency of the flyback converter when its output power is zero. An estimation 50%–70% can be used at beginning of a design.
- f_{min} is the actual minimum switching frequency of the converter, it can be estimated at three to four times fsw (min)
- f_{max} is the full load maximum switching frequency of the converter, referred from the electrical characteristics

(9)

This is assuming the load current during standby condition is greater than the auxiliary or the controller bias current for stable operation.

The parameter n_{sb} represents any associated losses top either the internal consumption of the controller or the power dissipated across the pre-load on the secondary side of the transformer or the bias consumption of the Optocoupler, and so forth.

n_{sb} is the transformer no-load conversion efficiency. This factor is dependent on the bias power consumption of the flyback controller and the pre-load resistance for that design. Typically, the transformer no-load conversion efficiency lies within the range of 0.5 to 0.7. The UCC28730 allows extremely low bias current (52 µA typ), improving the ratio of the internal bias power to the converted power.

The pre-load resistance is dependent on the current consumption of the controller IC during standby condition. The higher the bias current the bigger resistance is required to balance out the currents between the transformer windings.

The UCC287xx family devices with primary side regulation (for example, the UCC28730) eliminates the need of an opto coupler which further improves the converter efficiency.

Considering all these advantages from choosing the UCC28730, you can assume a higher factor of 0.6 to 0.7 for an initial estimate.

The UCC287xx family allows the converter to minimize the standby losses by minimizing the switching frequency at no load conditions and lower bias power, therefore, smaller secondary to aux turns ratio.

4 Design Example

The TIDA-01560 is an example where the UCC28730 can achieve less than 4 mW standby power at high line. This reference design is an example of how the UCC28730 in conjugation with the UCC24650 can provide ultra-low standby power without sacrificing start-up time or output transient response. The UCC28730 uses the following in its control algorithm to maximize efficiency over the entire operating range:

- Frequency modulation
- Peak primary current modulation
- Valley switching
- Valley skipping

This design is a 15 W bias supply with two isolated outputs (12 V/1.125 A and 3.3 V/0.3 A). The average standby power for this design is:

$$P_{stdby} = \frac{P_{out} \times f_{min}}{n_{sb} \times K_{am}^{2} \times f_{max}} \quad (10)$$

$$P_{stdby\_theo} = \frac{15\ \text{W} \times (4 \times 32\ \text{Hz})}{0.7 \times 2.99^2 \times 83.3\ \text{kHz}} = 3.68\ \text{mW} \quad (11)$$

NOTE: Equation 11 is an estimation of the standby losses and calculates the minimum loss this design can achieve without any additional circuitry. Practically, the losses across the X-cap and bulk caps are dependent on line condition and you might see some deviation from the theoretical value at high line.

The practical results in the following table can be seen aligning with the theoretical values.

Vin_ac	STANDBY POWER (mW)
115 V	3.1
220 V	4.2

Figure 3 shows the block diagram of the TIDA-01560 reference design. The main parts of this reference design are the isolated-flyback power supply controller (UCC28730), voltage monitor (UCC24650) as a wake-up device, and next-generation, low-dropout regulators (TLV74333).

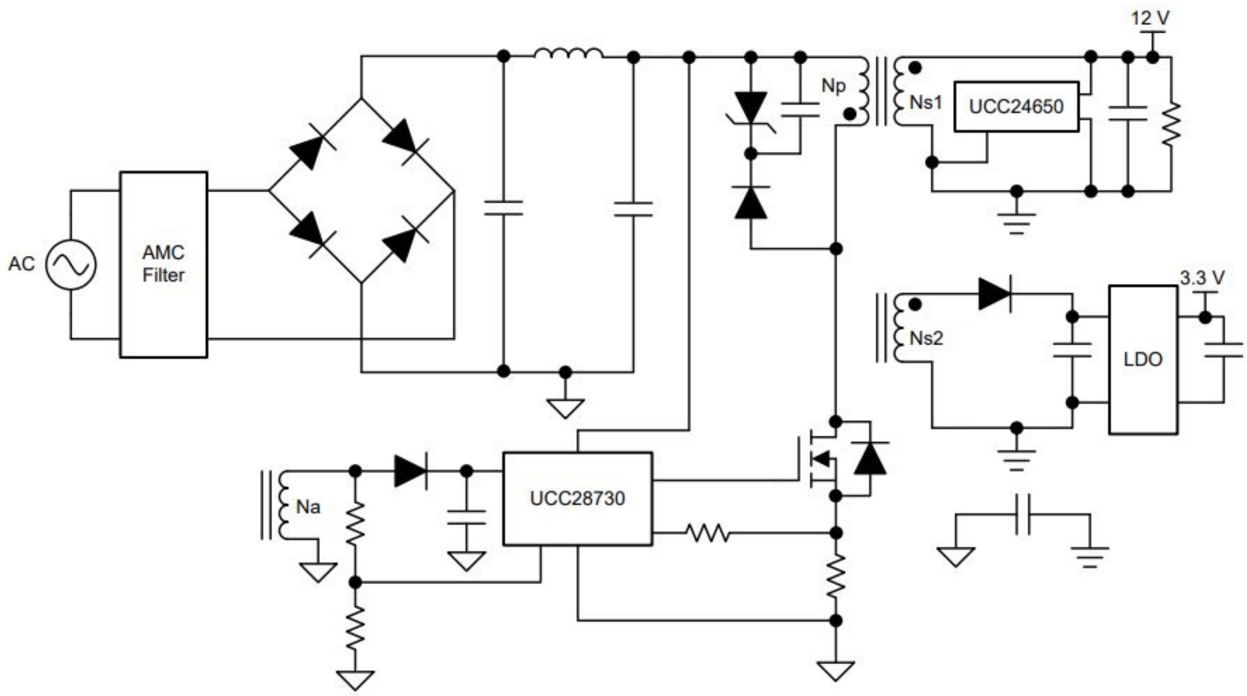


Figure 3. Block Diagram of TIDA-01560

5 UCC287xx Progression Towards Standby

All the members of the UCC287xx family are different in terms of factors like bias power consumption, switching frequency, integrated start-up, and so forth. Hence, the standby performance differs from each other. The following table shows the progression of achievable standby power for the various controllers of the UCC287xx family. The standby measurement comparisons are for a universal input 5 Vout/2 A flyback power supply design.

		INPUT VOLTAGE		
		115 Vac	230 Vac	
Regulation	TI controller	Standby Power (mW)		Design Out: 5 V/2 A
PSR	UCC28730	2.7	3.2	UCC28730EVM-552
	UCC28710	14	16	PMP9202
	UCC28700	24	35	PMP4351
	UCC28704	45	63	PMP11600
SSR	UCC28742	30	40	PMP40487
	UCC28740	57	64	PMP9204

6 Conclusion

1. Choose a suitable X-cap to optimize the standby consumption losses and balance the EMI performance.
2. Try to optimize the controller losses by choosing a UCC287xx member with lower standby bias current, thereby limiting pre load resistor losses.
3. Try to eliminate the losses on the start-up resistor by choosing a UCC287xx member with integrated HV start-up.
4. Appropriate bulk capacitors with relatively low leakage current specification should be used. Beware of the increased cost.

Following these suggestions help limit the standby power consumption losses by either reducing the loss on each component or eliminating the need of it.

NOTE: The transformer design single-handedly has a significant impact on the power stage efficiency and EMI performance of the controller. The Flyback Transformer Design Considerations for Efficiency and EMI Seminar is a detailed description of the core and switching losses of the transformer, the snubber clamp levels, and how to improve the overall transformer performance.

7 References

- Texas Instruments, *UCC28730-Q1 Zero-Power Standby PSR Flyback Controller for Automotive Data Sheet* (SLUSCR9)
- Texas Instruments Training, *Introduction to EMI in Power Supply Designs: Sources, Measurements and Mitigation Methods*
- *Commission guidelines: Eco Design Requirements For Off Mode, Standby and Networked Standby*
- Texas Instruments, *TIDA-01560 Reference Design*