Application Report

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# Optimizing PFC Standby Power Using the UCC28064A

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## ABSTRACT

New requirements for standby power have become a game-changing paradigm for not just PFC IC architecture but also for power-supply design. Meeting low standby power while keeping the PFC ON and having the smallest number of external circuits has become a very big challenge. This document shows how to optimize the standby power performance of the PFC using the UCC28064A device. The UCC28064A device has some innovative features that allow it to obtain very low standby power and also reduces a number of external components while doing so. This document explores all the key variables that influence standby power performance and also demonstrates some of the tradeoffs involved in obtaining a low standby power for a PFC.

For more information, see *Power Factor Correction* at *www.ti.com* .

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# 1 Introduction

Recently most regulations such as DOE Level VI, COC5 Tier 2, and Energy Star 5.0 for reducing power consumption and improving efficiency have all focused on light load performance and standby power. These requirements have placed interesting challenges to solve from a power supply standpoint especially in consumer sector end equipment such as digital television (DTV), gaming adapters, and desktop PCs which are highly cost sensitive. Among the requirements, standby power has become the most challenging to solve and involves a considerable amount of engineering effort in the last 2–3 years. This application note discusses all aspects of standby power for a power factor correction circuit (PFC) from accurate measurement, implication to system complexity, sources of standby losses, and ways to improve the same. While discussing the ways to improve standby power, it is clear to see that for power levels above 300 W, the UCC28064A device presents a number of key benefits in terms of improving the standby power of the PFC solution. Also, the combination of the UCC28064A device as a PFC controller along with the UCC25630 device as a LLC controller can offer a number of additional system level benefits to design a simple system which meets all key standby power standards.

# 2 Implications of Standby Power to Power Supply Complexity

Typical standby power requirements for a DTV driven by standards such as DOE or COC5-Tier 2. Detailed standards for these requirements are available in *Optimizing PFC Standby Power Using UCC28064A* and are summarized in Table 1:

**Table 1. Summary of Typical Standby Power Requirements for AC/DC Power Supply**

| LOAD CONDITION | LINE CONDITION | EFFICIENCY | POWER LOSS |
|---|---|---|---|
| 100%, 75%, 50%, 25% | 115 V, 230 V | Average efficiency of 4 pts > 88% | N/A |
| 150 mW | 115 V, 230 V | 50% | 150 mW |
| 1 W–10 W | 115 V, 230 V | 75% | N/A |
| No load | 115 V, 230 V | N/A | 150 mW |

From Figure 1, using the previous state of the art such as the UCC28063 device, a number of additional system-level complexities are required to meet the standby power. To conserve energy and power dissipation, an auxiliary flyback converter which is dedicated for standby operation and housekeeping is required. During standby, the entire power train is switched OFF. Additional circuits needs to be added to realize this feature. Also, resistors cannot be used to discharge x-capacitors and active IC solutions are needed for x-cap discharge to maintain good standby power performance. Using a modern LLC controller such as the UCC25630 device, the need for the standby flyback converter can be eliminated due to its innovative switching scheme and efficiency at light load. In addition, the UCC25630 device has integrated X-capacitor discharge which eliminates the need for a dedicated additional circuit to achieve the same function. While the UCC25630 device eliminates the need for the standby power flyback converter, if the UCC28063 device is used, it is still necessary to have an isolated circuit which disables the PFC during the standby condition.

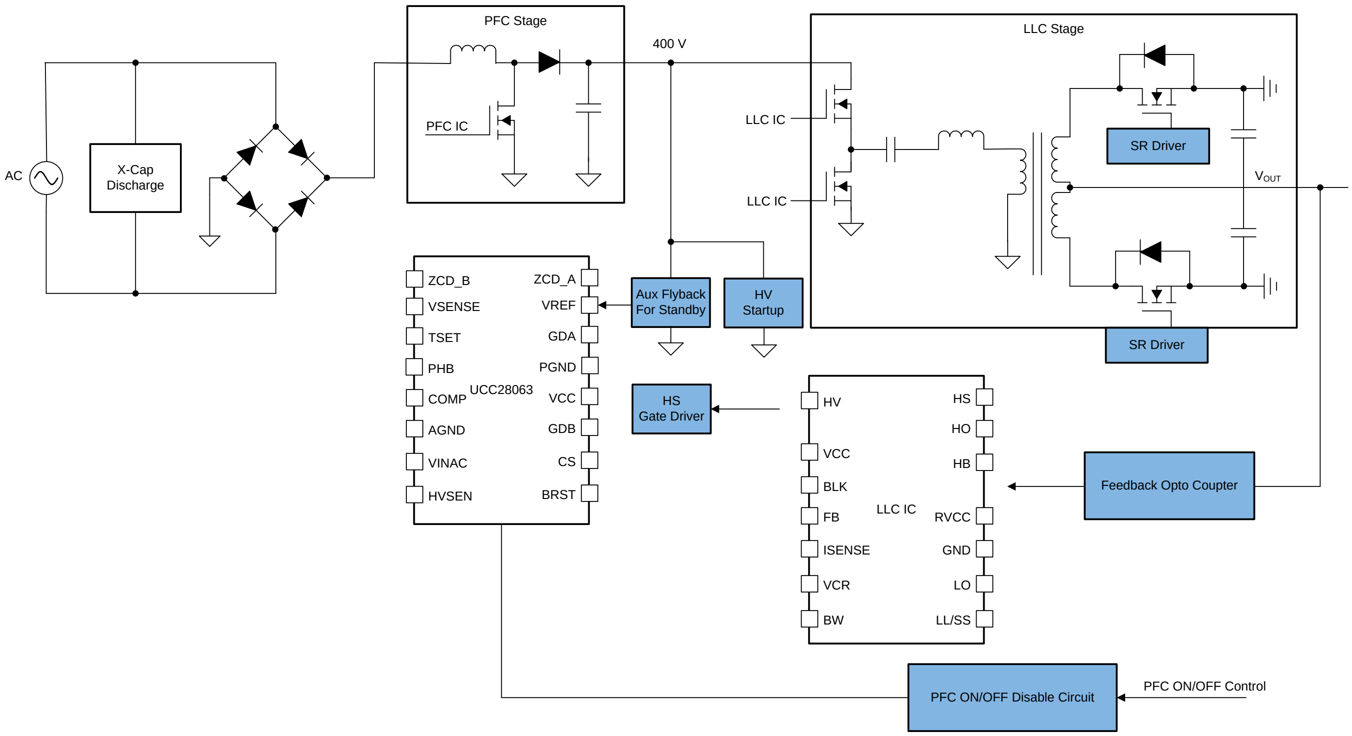


**Figure 1. UCC28063 + LLC IC Based AC-DC Solution for Low Standby Power**

Disabling the PFC at standby presents multiple challenges to the power-supply designer. Some of these translate into performance tradeoffs and others have direct cost implications. They are as follows:

- As mentioned previously, there is a need to be able detect the standby condition – in the secondary and send an isolated shutdown signal to the PFC. This adds cost and complexity to the system
- The transient response out of the standby is greatly affected. This is because the LLC controller will not be able to deliver full power until the PFC is close to its regulation value. A typical PFC takes hundreds of milliseconds to start up and reach its nominal value. This means that the system will have very slow response if there is a load step when the system is in standby condition
- If the LLC converter needs to be designed to provide fast response out of standby, then the LLC converter has to deliver 100% load from 120 V to 450 VDC input. Designing a wide input LLC converter designed to operate over such a large input range and provide full load across this range is quite challenging and increases cost and complexity.

Figure 2 shows the block diagram of the system when designed with the UCC25630 LLC converter and a PFC that is not optimized for standby power.

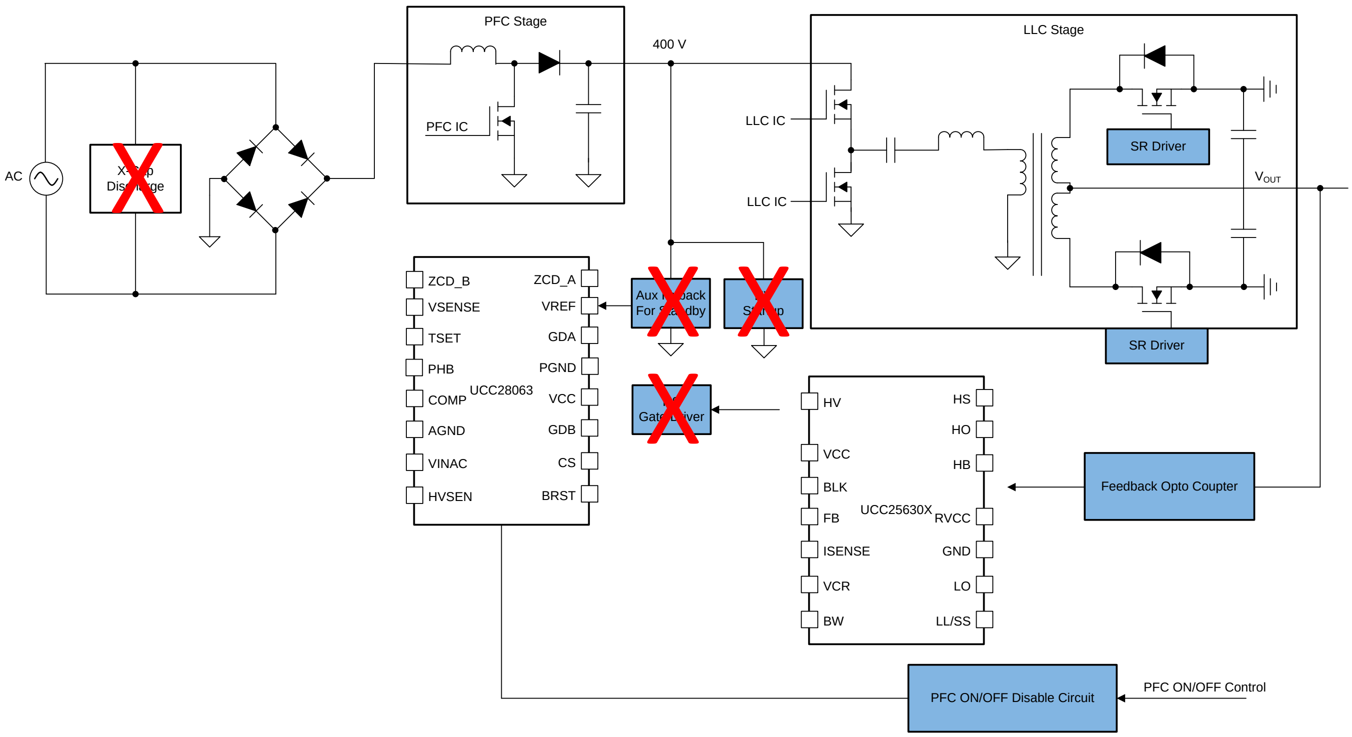


**Figure 2. UCC28063 + UCC25630x Based AC-DC Solution for Low Standby Power**

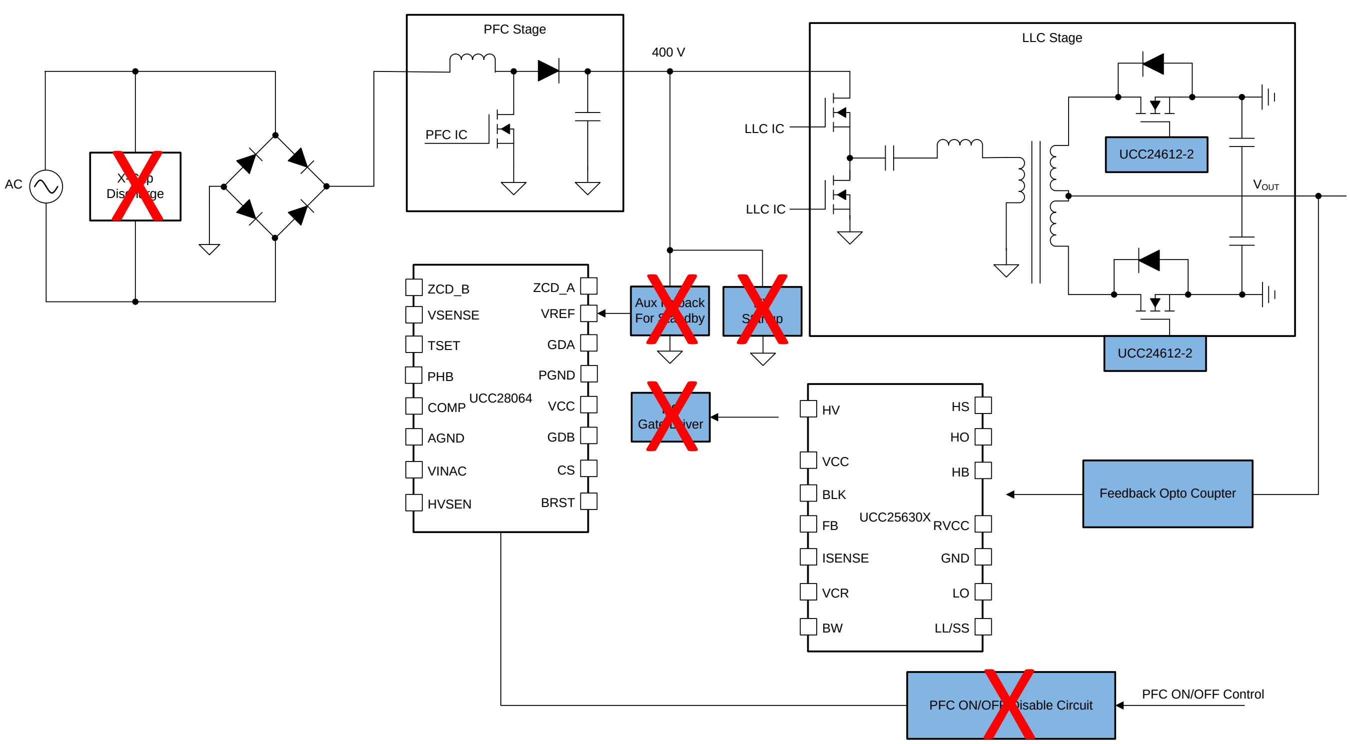


**Figure 3. UCC28064A + UCC25630x Based AC/DC Solution for Low Standby Power**

While the UCC25630 device removes a considerable amount of external circuits, there is still additional cost and performance that is not optimal. Figure 4 shows an example of a PFC-disable circuit

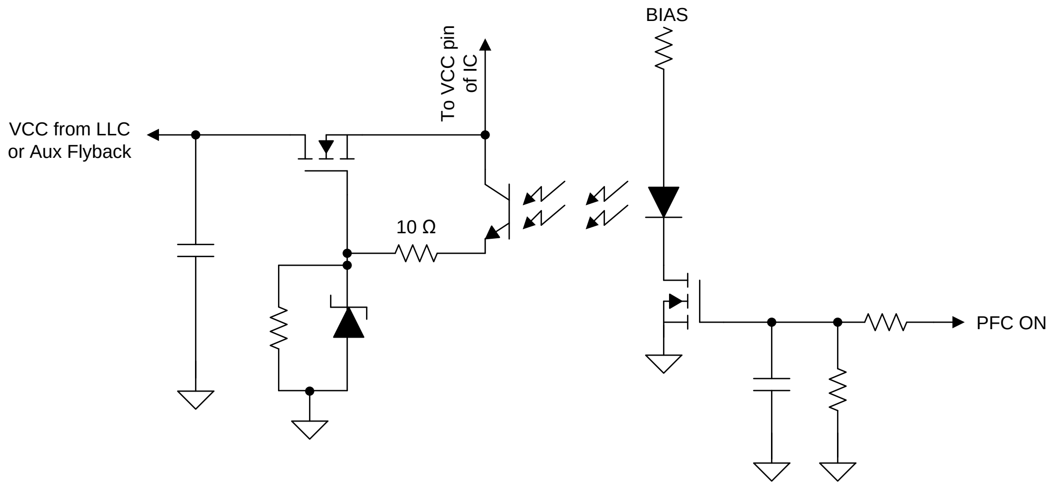


**Figure 4. PFC Disable Circuit**

The UCC28064A device is the next generation PFC IC which is designed to solve these exact problems. Using the UCC28064A device in conjunction with the UCC25630 device, the power-supply designer can meet all key standby power requirements while leaving the PFC and LLC regulating to its output voltage. As Figure 1–Figure 3 show, the combination can greatly simplify the total system design and improve the overall performance as shown in Figure 3.

Section 3 discusses some of the key sources of standby power losses and common practices to overcome these problems in the PFC section. In many of these cases, it is clear that many of the features of the UCC28064A device exactly address these problems and greatly reduce the challenges faced in reducing standby power.

# 3 Identifying and Decreasing Sources of Standby Power Loss

This section looks at the sources of standby losses step by step, starting from the effect of the EMI filter

## 3.1 EMI Filter

The EMI filter capacitors have a surprising effect on standby power losses. Figure 5 shows a typical AC/DC power supply with a representative EMI filter.

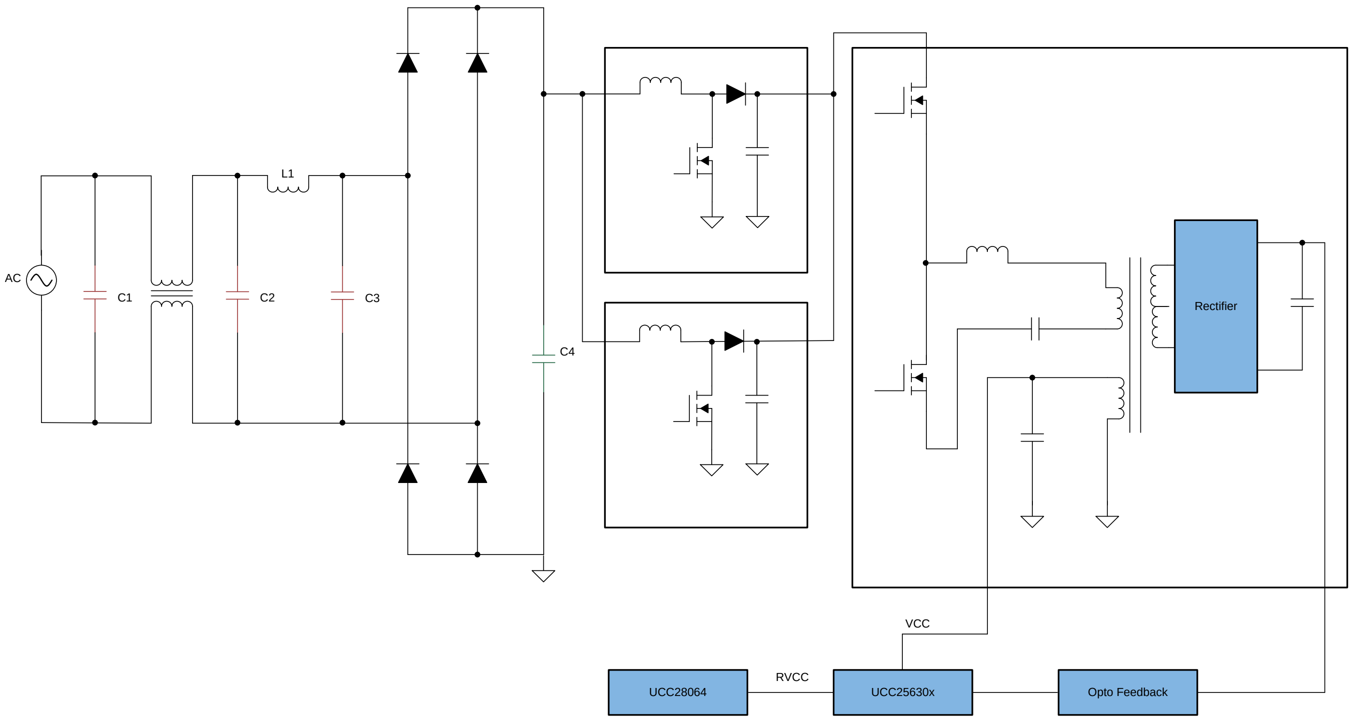


**Figure 5. AC/DC Power Supply With Interleaved Two-Phase PFC and LLC Converter Simplified Schematic**

In this schematic, the common-mode capacitor or Y-capacitors are not represented for simplicity. They are relatively small and they do not contribute to the standby losses. Figure 5 is a typical EMI structure. C4 which is the only filter capacitor to the right of bridge rectifier provides the first line of filtering. It reduces the peak-to-peak ripple current on the line. C3 + C4, C2, and L1 are sized to reduce low-frequency differential mode noise. There is an additional filter higher frequency pole that is induced by C2, C1, and CM1. During light load, there is no power drawn from the line. Hence the voltage across C4 is quite small. However C1, C2, and C3 are capacitors to the left of the bridge rectifier so there is reactive energy transfer during every line cycle. This is proportional to the power delivered to the load. The reactive energy delivered to the load is given by:

$$P_{Xc} = \frac{V_{RMS}^2}{X_c} \quad (1)$$

However, all capacitors have ESR. ESR is usually mentioned as a displacement factor. Table 2 lists the displacement factor comparing 2 separate dielectrics of film capacitors:

**Table 2. Capacitor Displacement Factor**

| COMPONENT DESCRIPTION | MANUFACTURER | PART NUMBER | DISPLACEMENT FACTOR |
|---|---|---|---|
| 305 Vrms, 0.33-µF metallized polypropylene film capacitors | EPCOS | B32922C3334M000 | 0.001 |
| 305 Vrms, 0.33-µF metallized polyester film capacitors | EPCOS | B32932A3334K000 | 0.008 |

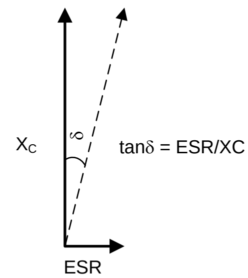


**Figure 6. DPF Tanδ Definition in Phasors**

Metallized polyester film capacitors have 8 times the dissipation for a given reactive current. Table 3 lists the measured standby power of the PFC stage where the UCC28064A device is regulating the PFC to its final output voltage and the UCC25630 based LLC is regulating its output. The measurement shows the difference in standby power between polyester and polypropylene film capacitors in the unloaded condition. The tests were done on the same board with the capacitor change as the only alteration.

**Table 3. Standby Power Performance Variation Across Film Capacitor Dielectric Material**

| TEST CASE | Vac (V) | Pout | Pin (mW) |
|---|---|---|---|
| Polyester Film Capacitors | 230 | 0 | 103 |
| Polypropylene Film Capacitors | 230 | 0 | 58 |

There is a significant improvement in the THD performance just due to the dielectric material of the film capacitors being used.

Alternately, if the low-frequency differential filter were to be on the right side of the bridge rectifier, then further gains in standby power are possible. Figure 7 shows the EMI filter structure and Table 4 compares the results of the same.

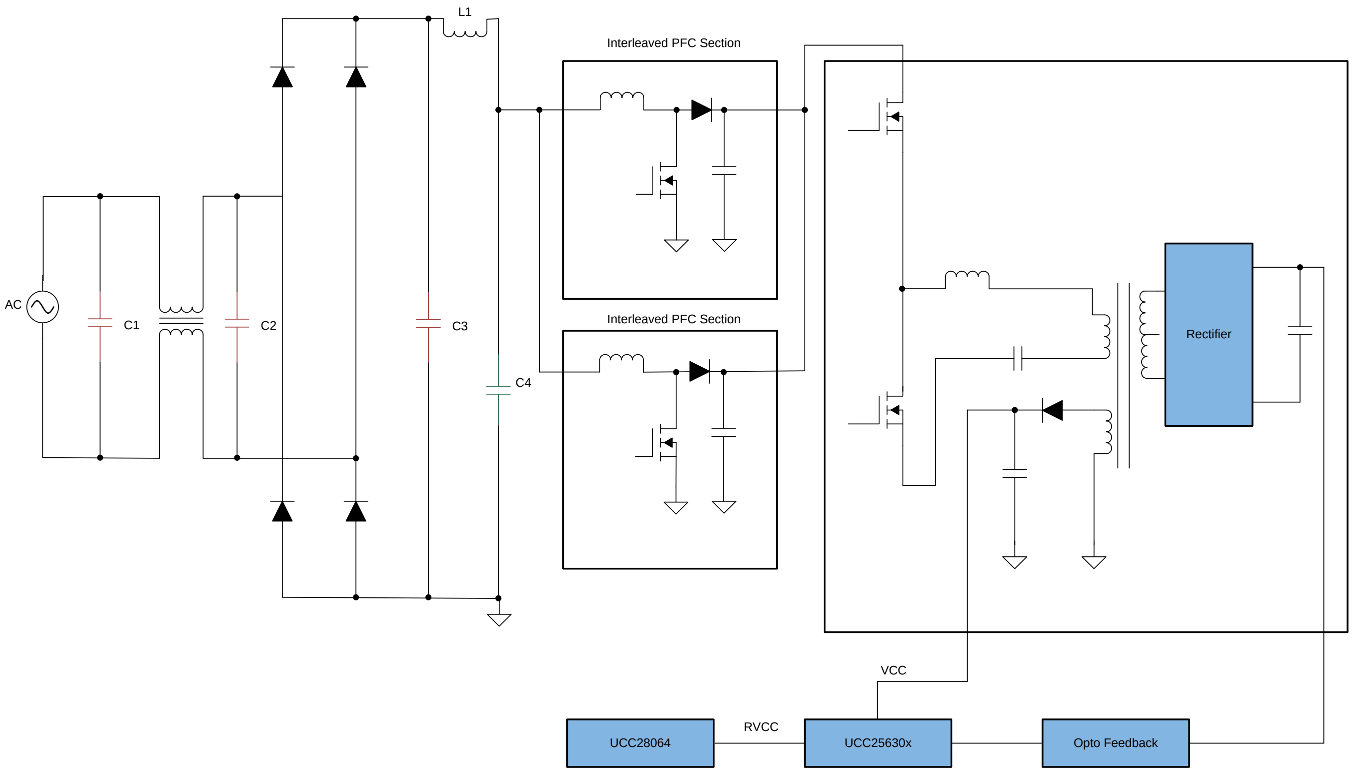


**Figure 7. Most of EMI Filter Capacitance to the Right of Bridge Rectifier**

In this case, assuming that C3 and C4 are much bigger than C1 and C2, Table 4 shows the comparison of the standby power using polyester metal film capacitors on either side of the bridge rectifier.

**Table 4. Standby Power Comparison for Film Capacitor Location**

| TEST CASE | Vac (V) | Pout | Pin (mW) |
|---|---|---|---|
| Original configuration with metallized film capacitors | 230 | 0 | 103 |
| New EMI filter with bulk of EMI capacitor to right of bridge rectifier | 230 | 0 | 51 |

Since the capacitors are to the right of the bridge, they can be DC capacitors and do not need to be AC rated. However, while Figure 7 provides for both the use of cheaper capacitors and the benefit of superior standby power performance, it comes at the expense of crossover distortion and degraded THD performance – especially at light load,or high line, or both.

## 3.2 Burst Mode Switching Efficiency

While there is no load on the output of the LLC, the PFC is loaded with the LLC converter losses and the static losses due to the high-voltage sensing resistors. Typically, PFC efficiency at light load and standby can be improved by using burst mode. In the UCC28064A device, as Figure 8 shows, the burst-mode threshold can be programmed by changing the resistor connected to the BRST pin. The burst pin adjusts the threshold against the COMP pin. When the COMP voltage goes below the BRST pin threshold, PFC stops switching. Since the UCC28064A device has an ideal input voltage feedforward, the COMP voltage is a faithful representation of power.

Table 5 shows standby power measurement under 2 separate burst-mode thresholds. No changes were done to the LLC stage during these measurements The higher the burst power threshold, the lower the standby power consumption. However, the higher the burst power threshold, the susceptibility to audible noise is higher. This is due to the fact that there is a higher amount of impulse energy in the system when the burst-mode threshold is higher.

**Table 5. Standby Power Comparison for Film Capacitor Location**

| TEST CASE | Vac (V) | Pout | Pin (mW) |
|---|---|---|---|
| BRST pin set to 12% load | 230 | 0 | 58 |
| BRST pin threshold set to 16% | 230 | 0 | 54 |

The UCC28064A device has the flexibility to provide the right tradeoff between audible noise, output ripple bandwidth, and standby power.

## *3.3 Bias Voltage Generation*

There are 2 aspects of bias voltage generation that must be considered for standby considerations:

- What is the standby load that the IC presents itself during the standby condition?
- In the previous circuit configuration, the UCC25630 device provides a regulated VCC voltage for the UCC28064A device to operate. There is an inherent power conversion of the PFC output to the auxiliary voltage of the LLC and finally through down to the VCC of the UCC25630 device. The efficiency of this path is critical for standby power

### 3.3.1 Reduce the Power Consumption of the IC During Standby

In a traditional two-phase CRM controller such as the UCC28063 device, the switching frequency increases as the load decreases. The total power consumed by the gate is calculated using Equation 2:

$$P_{GATE} = \frac{\sum_{k=1}^{N} Q_G \times V_{GATE} \times f_{SW}\left[k\right]}{N} \tag{2}$$

where

- $Q_G$ is the gate charge of the power MOSFET
- $V_{GATE}$ is the gate voltage on the MOSFET
- $f_{SW}$ is the switching frequency of the MOSFET at the $k^{th}$ switching instant of the line

The total power is obtained by finding the average of the power dissipated over a line cycle.

In a pure CRM converter, this number tends to infinity since the switching frequency tends to infinity. In reality, the switching frequency of the converter is limited by practical circuit limitations such as the oscillator frequency of the IC, the switching speed of the MOSFET, delays in the gate driver path, the feedback loop accounting for switching losses in the system, and so on. In a CRM controller which does not have any additional circuits to manage light load, the power dissipation in driving the MOSFET is the dominant loss mechanism. The current consumption by the IC for its analog functions is much smaller in comparison to the current consumed by the gate of the MOSFET.

To reduce the gate charge and improve overall efficiency and standby power, the BRST pin threshold can be optimized for optimal standby power and burst-mode efficiency.

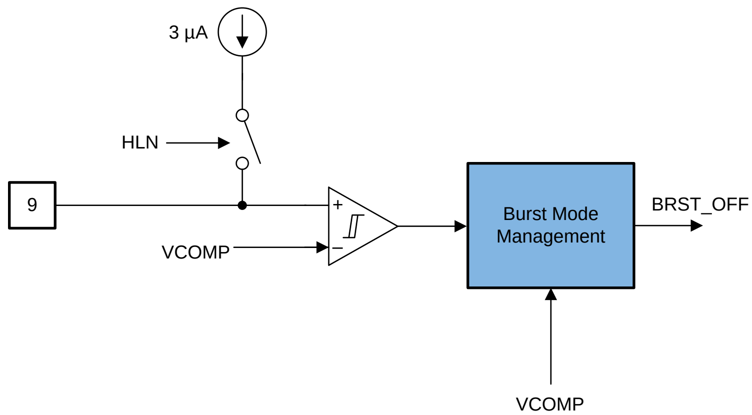


**Figure 8. Burst Mode Block Diagram**

When the COMP voltage goes below the burst-mode threshold, the PFC stops switching. The burst off threshold and the hysteresis are configurable using a resistor on the pin.

When the PFC enters burst mode, the IC can tell that it is not switching. Burst mode allows for the controller to drastically reduce its consumption when the IC is in burst mode by turning off internal analog circuits, unlike in a traditional CRM controller. Also, because the frequency of burst is a function of the burst threshold and the load, the burst frequency is extremely low and can be < 1 Hz. The current consumption of the IC is dominated by the analog circuits and not by the gate charge. The gate charge consumption is negligible and can be ignored for the calculation.

Table 6 shows the UCC28064A IC current consumption

**Table 6. UCC28064A IC Current Consumption**

| CONDITION | ICC (mA) |
|---|---|
| Normal Operation | 5 |
| Burst Mode | 0.5 |

The gate charge current of the MOSFET can be ignored in standby condition since the UCC28064A device is in burst mode, the total consumption of the IC is calculated with Equation 3:

$$P_{Vcc} = 0.5 \times V_{CC} \quad (3)$$

Since the RVCC is nominally around 12 V, VCC is around 6 mW.

### 3.3.2 VCC Power Generation

The block diagram in Figure 9 highlights the section of the circuit which helps generate VCC for the UCC28064A device from the line.

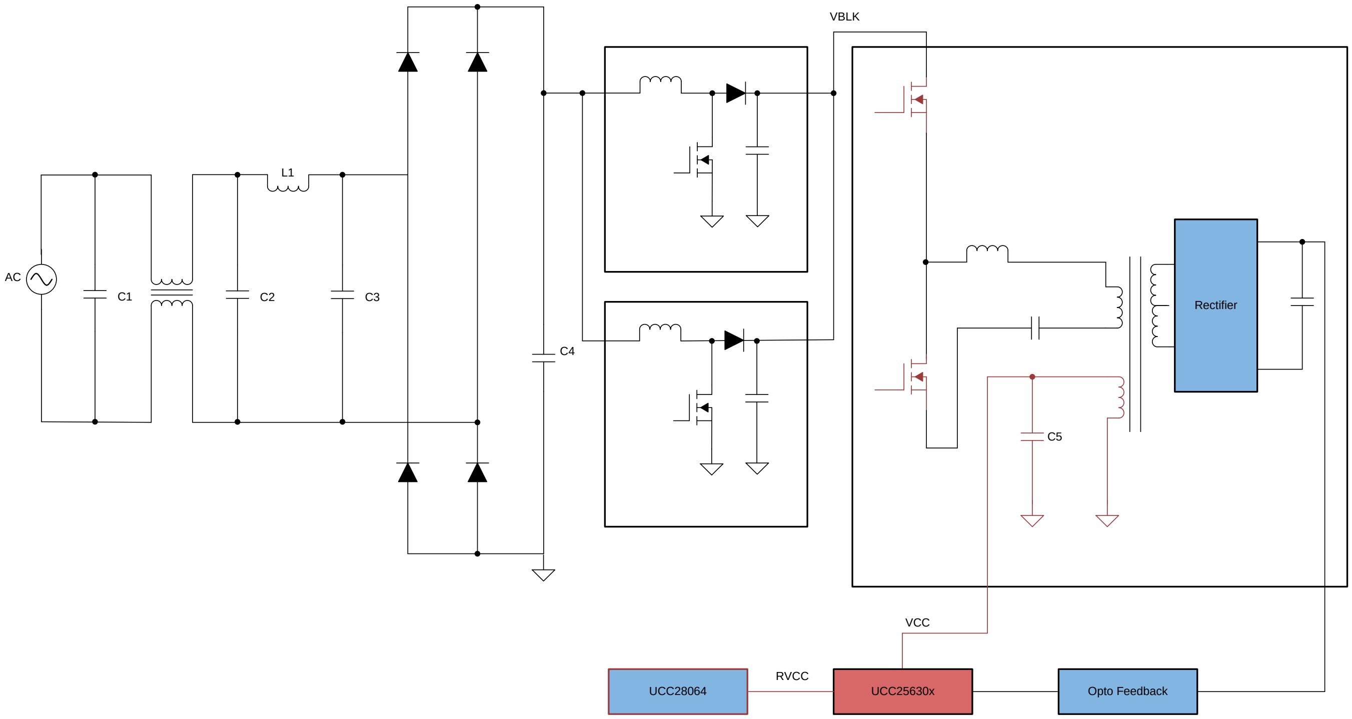


**Figure 9. Power Transfer Model for RVCC Generation**

The VCC capacitor C5 gets a packet of charge every time there is a switching activity on the LLC converter. During light load condition, the LLC converter goes into burst mode. The UCC25630 EVM is designed such that the VCC voltage is set to about 16V nominal under burst-mode condition. The burst-mode threshold in the UCC25630x device is configurable based on a resistor at its pin. Depending on the burst-mode setting of the UCC25630x device, the burst frequency at standby is found to vary anywhere from 10Hz to 100Hz. For high-efficiency operation during standby, make the auxiliary winding provide all the energy delivered to the UCC28064A device.Turn the HV startup circuit off in the UCC25630x device. Hence the design of C5 should consider this as well.

From *UCC28064A Natural Interleaving™ Transition-Mode PFC Controller With Improved Light- Load Efficiency* , $VCC_{ReStartJfet}$= 10.8 V, VCC nominal = 16 V.

Just as in the case with the PFC, LLC gate charge losses under standby are negligible as the duty cycle of the burst-mode ON pattern is small. Therefore, C5 must be greater than:

$$C_5 \geq \frac{\left(I_{CCSleep} + I_{VCC(BURST)}\right) \times T_{BURST}}{VCC_{NOM} - VCC_{ReStartJfet}} \quad (4)$$

Find $I_{CCSleep}$and $VCC_{ReStartJfet}$ in the UCC25630x data sheet, and $I_{VCC(BURST)}$ in *UCC28064A Natural Interleaving™ Transition-Mode PFC Controller With Improved Light- Load Efficiency* .

$T_{BURST}$ is heavily dependent on the bandwidth of the loop and the burst-mode threshold. While it can be calculated provided the total losses in the LLC during standby are known, it is complicated. Alternately, it can be measured in the lab as the burst rate is relatively consistent for a given load condition.

However, there are other factors that must be considered in the sizing of C5, such as startup condition, which are not discussed in this application note. Equation 4 only establishes the criteria for ensuring the best possible efficiency for VCC generation and hence good standby performance.

To understand the efficiency of this power transfer, look at the power transfer as 2 stages:

- Switching converter efficiency from VBLK to $V_{CCNOM}$

- UCC25630x efficiency from $V_{CCNOM}$ to RVCC

Figure 10 illustrates a simple representation of this power transfer.

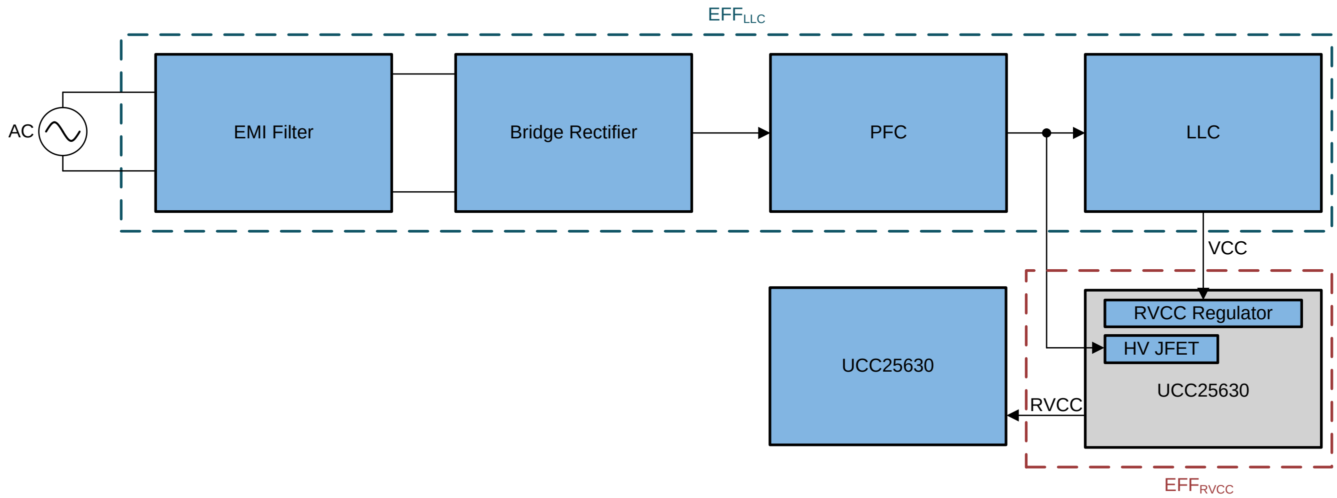


**Figure 10. VCC Generation Power Transfer Representation Along With Efficiency**

The efficiency of the RVCC regulator is easy to calculate as it is dropping a 16-V output into 12V,so the efficiency is 75%.

Predicting the efficiency of the switching converter is more difficult. It is also an iterative process and varies with the burst-mode threshold. The efficiency of this converter can be optimized further by modifying the resistor on the LL/SS pin of the UCC25630x device. For the UCC25630-1EVM-291, $Eff_{LLC}$ is assumed to be about 75%. The total efficiency of the VCC generation circuit is 56%.

From here, during standby, the total power consumed from the line due to ICC consumption = 21.33 mW.

The following are some key insights that can be made from this analysis:

- Increase in power consumption of the IC has a multiplicative effect in terms of energy drawn from the line due to losses in power conversion going from the line to the VCC of the IC
- The UCC28064A device burst-mode power greatly reduces the ICC consumption during standby
- There is a tradeoff between the size of the C5, the nominal VCC voltage of the UCC25630 device and the standby power
- The UCC25630x device has a highly-efficient burst mode that reduces both the size of C5 and also improves the overall efficiency of the VCC regulation circuit, thereby achieving low standby power
- The UCC25630x device has a programmable burst-mode threshold which can also be set to help provide very good standby power and will have implications on the size of C5
- To obtain good standby power performance, the HV JFET should never turn ON during standby mode

### 3.4 Static Sense Resistor Losses

The static resistor losses are usually the dominant loss mechanism at standby. In a typical PFC + LLC system, the following high-voltage signals must be measured.

PFC section:

- PFC output voltage
- Input line voltage
- 2nd independent PFC output voltage for FMEA

LLC section:

- Bulk input voltage
- Resonant capacitor voltage

If the PFC and the LLC are working, then the power lost due to each of these resistor strings can be given using Equation 5:

$$P_{SENSE} = \frac{V_{BLK}^2}{R_{TOT}} \quad (5)$$

In the UCC25630 + UCC28064A based system, the following are the HV resistor strings that must be present:

- PFC output voltage (also the LLC input voltage on the same string)
- Input line voltage
- 2nd independent PFC output voltage sense for FMEA testing

Figure 11 shows the UCC28064A application schematic, the HV resistor strings are highlighted in **blue**.

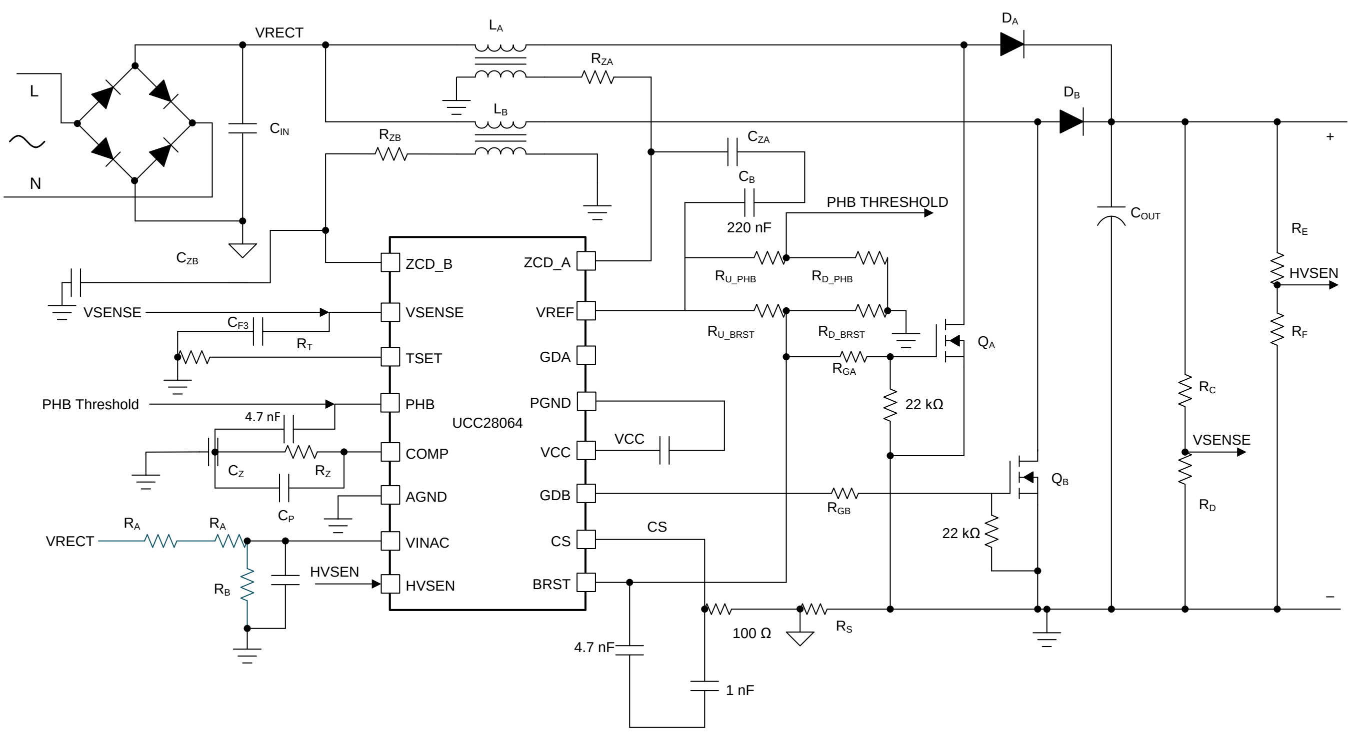


**Figure 11. UCC28064A Application Schematic**

The UCC25630 device does not need resistors to sense the resonant capacitor voltage, and the bulk voltage can be shared between the two ICs. Also, the pin leakage has been significantly reduced to a level where the HV pin resistors can be as high as 10MΩ without adversely affecting setpoint accuracy of the signal There is significant savings in the total standby power consumption of the power supply by both working with higher impedance resistor dividers as well as removing HV resistor divider strings altogether.

### 3.5 Other Sources of Standby Power Losses

IN addition to these, there are other sources of standby power losses. They are listed as follows:

- Bridge rectifier leakage losses
- LLC optocoupler losses
- Electrolytic capacitor losses

The optocoupler losses in the LLC do not impact the standby losses on the PFC and are excluded from this discussion. The other losses were all observed to be negligible for standby power measurement at room temperature.

## 4 Conclusion

The UCC28064A + UCC25630 based solution offers significant system-level benefits to solving key challenges in standby power. At 230 Vrms and full standby, the solution can provide a standby power of less than 120 mW and the PFC stage will have a standby power of less than 55 mW which is the best in the industry for these power levels.

## 5 References


- *UCC28064AEVM-004 300-W Interleaved PFC Pre-Regulator User's Guide*
- *UCC28064A Natural Interleaving™ Transition-Mode PFC Controller With Improved Light- Load Efficiency Data Sheet*
- *UCC256301 Hybrid Hysteretic Mode Wide VIN LLC Resonant Controller Enabling Ultra-Low Standby Power Data Sheet*
- *Optimizing Efficiency and Standby Power With the UCC28056 in Offline Applications Application Report*


## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Original (March 2018) to A Revision | Page |
|---|---|
| • Changed UCC28064 to UCC28064A throughout the document. | 1 |

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