

# Enabling Small-Form-Factor AC/DC Adapters With the use of Integrated GaN Technology



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## ABSTRACT

With the trend of fast-charging systems and growing power demands comes the imminent need for creating convenient, portable designs with small footprints. Small-form-factor, high-power-density power supply designs have taken an imminent share of the consumer AC/DC market with emphasis on efficient and reliable energy conversion. This application note discusses how two key points (managing thermals and increasing switching frequency with the use of *integrated GaN technology*) must be considered to create reliable, power-dense designs. These discussions reference consumer adapters to provide a well-known context to discuss the background and challenges for these types of designs. However, the information presented in this application note can be applied to any power supply system where high power density and efficiency are an integral part of the design.

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## 1 Introduction

### 1.1 Design Requirement 1: Managing Thermals Induced by Power Losses

Perhaps the most discussed figure-of-merit in any power supply conversation is efficiency. While it is true that efficient power conversion systems save on overall energy consumption, for many applications, the greater motivation behind an efficient design is the ability to reduce power losses in the system that manifest themselves as undesired sources of heat. Within the context of a small, enclosed power adapter, for example, the heat must be contained to provide a reliable system operation. This includes keeping the temperatures to an acceptable level on all components – from semiconductors to energy storage components such as inductors or capacitors. In inefficient power systems, high power losses can cause an excessive amount of mutual heating, which makes it almost impossible to dissipate heat without large heatsinks. In addition, commercial power adapters have external case temperature requirements that must be followed to provide safety and ease of use for the consumer. The smaller the enclosure becomes, containing the individual component temperatures becomes more difficult.

As the market continues to see the trend in miniaturizing these adapters, reducing power losses (or increasing the efficiency) becomes crucial to provide adequate thermal management within a small case. The fundamental problem is as follows - creating smaller power supplies requires better thermal management, and better thermal management requires higher efficiency of operation. With this in mind, if the objective is to create a small-form-factor design, the design question is not *how can the highest efficiency be obtained?* Instead the question is *how can the required efficiency be obtained to create a thermally reliable design given the size requirements?*

### 1.2 Design Requirement 2: Reducing Energy Storage Requirement by Switching at High Frequency

Another aspect of power-dense designs that must be discussed is the switching frequency and the relation to the energy storage requirements of the system. This is what is commonly stated as *increasing the switching frequency reduces the size of the power converter*. Analyzed at a deeper level, the DC power delivered to a load is processed by a power converter which fundamentally works on the principle of storing energy from the input for some time and then releasing it to the load. The power that is delivered to the load is mandated by two factors: the amount of energy that can be stored then released every cycle, and the frequency at which the process happens.

As an analogy, suppose a large shipment of goods has to be made from one port to another across a body of water within a set amount of time. On one hand, consider *a*) a cargo ship that can deliver the goods in just a few trips. On the extreme contrary, consider *b*) a speed boat that can make multiple quick trips with less goods per trip. In this analogy, the goods on the vessel represent the energy stored, while the number of trips represent the switching frequency. In the end, both the cargo ship and the speed boat deliver the same amount of goods (energy) in the same amount of time, maintaining constant power. Although the net result of the delivery is the same, there are two differences in the two scenarios: *a*) transfers more stored energy at a slower frequency, and *b*) one transfers less stored energy at a higher frequency, or [Equation 1](#).

$$P = \text{constant} = E_{\text{stored}} \times f_{\text{sw}} \quad (1)$$

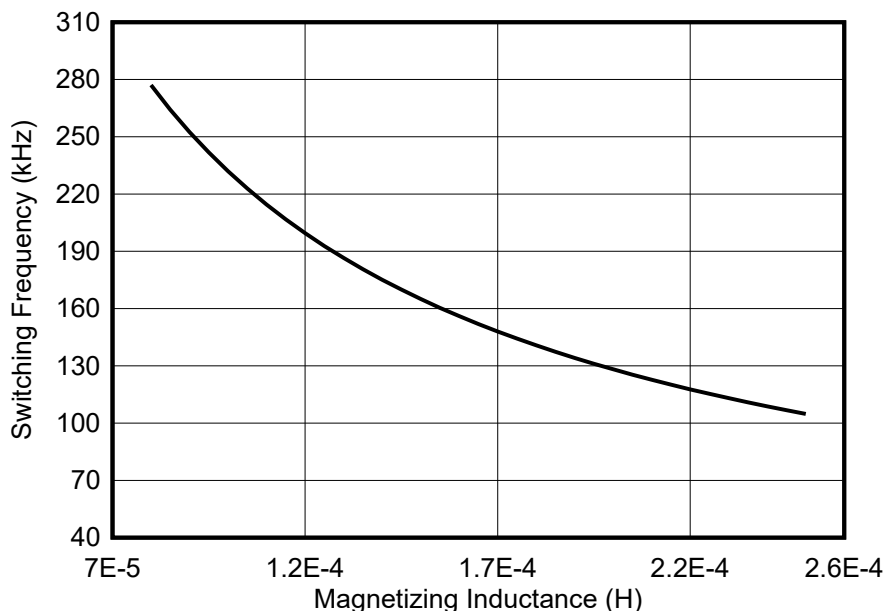
In a power converter, this energy storage mechanism is carried out by the largest components, primarily the magnetics such as inductors and transformers. For magnetics, size is directly proportional to energy storage, while energy storage is directly proportional to inductance, or [Equation 2](#).

$$\text{Size} \propto E_{\text{stored}} \propto L \quad (2)$$

**Note**

While the larger bulk capacitors form an integral part of AC/DC systems, the capacitors are not considered here because there is little that can be done to reduce the size as capacitors are dependent on the slow 50/60-Hz line frequency rather than the much faster switching frequency. In small form-factor AC/DC designs, most attention is given to the magnetics, where energy storage is directly mandated by the switching frequency.

Because of this relationship, small-form-factor designs must switch at high frequency to reduce the energy storage requirement, and as a result, reduce the overall size. As shown in Figure 1-1 the inductance (energy storage) requirement for a given power level is inversely proportional to the switching frequency. However, it is important to keep in mind that switching losses are incurred by increasing the switching frequency, and can become a thermal concern. Techniques on how to mitigate these losses are explained in the following sections.

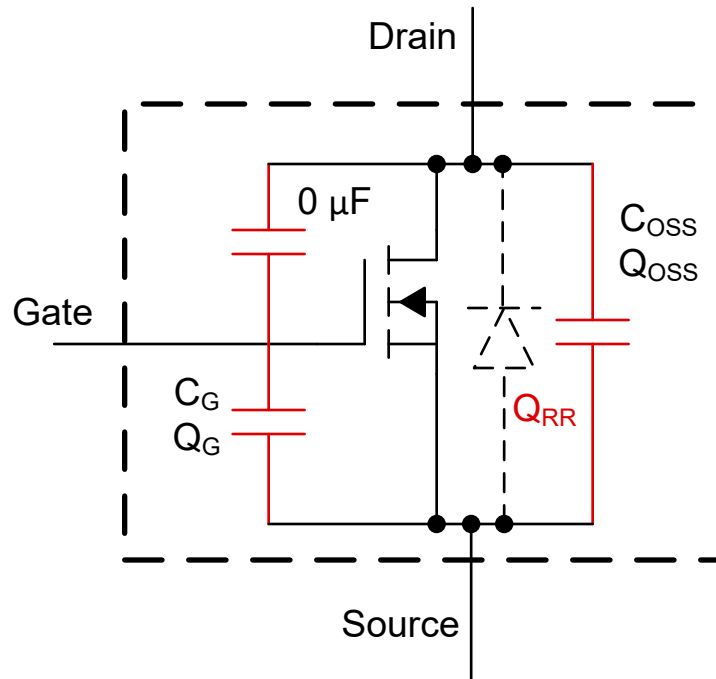


**Figure 1-1. Resulting Switching Frequency vs. Magnetizing Inductance of Transformer in a 65 W Transition-Mode Flyback Converter**

## 2 A Brief Introduction to GaN's Value

Keeping the last two design requirements in mind, GaN technology can be used to address the challenges that come with managing thermals and switching at high frequencies. This is accomplished by three main advantages that GaN holds over silicon: reduced capacitance for a given resistance, faster switching speeds (not to be confused with switching frequency), and zero reverse-recovery losses due to the absence of a body diode.

Integrated GaN devices switch faster with low gate capacitance and gate charge (1 nC-Ω vs Si 4 nC-Ω), reduce switching losses with low output capacitance and output charge (5 nC-Ω vs Si 25 nC-Ω), and eliminate reverse recovery losses with the absence of a body diode



**Figure 2-1. High Level GaN Structure Showing  $C_g$ ,  $Q_g$ ,  $C_{oss}$ ,  $Q_{oss}$ , Absence of Body Diode**

### 3 The Active Clamp Flyback

One of these properties of GaN can prove to be extremely valuable in one of the most efficient power converter topologies that addresses thermal and energy storage challenges: the Active-Clamp Flyback (ACF).

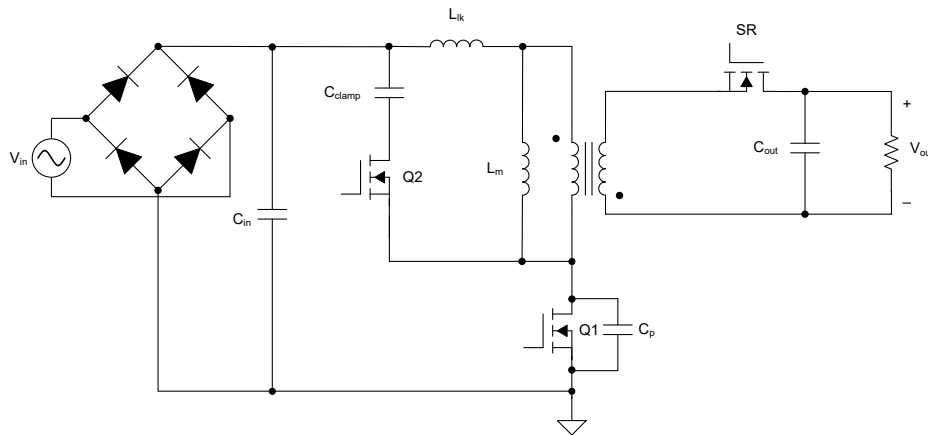


Figure 3-1. Active-Clamp Flyback Power Stage

Compared to the traditional flyback, ACF greatly saves on power loss by:

1. Eliminating losses in the traditional *snubber clamp* with zero-clamp-loss
2. Reducing switching losses with Zero-Voltage-Switching (ZVS)

Both of these mechanisms are carried out by the configuration of the switching devices, magnetizing inductance, clamp capacitors, and parasitic elements, such as leakage inductance and device capacitance. The fundamental operation of these power loss-saving mechanisms is explained in more detail in [Section 3.1](#) and [Section 3.2](#).

#### 3.1 Power Loss Saving 1: Zero-Clamp Loss

Typically, low-power applications employ a flyback converter for simplicity and cost. Such designs use a flyback transformer with inherent leakage inductance that can cause uncontrolled voltage spikes on the primary FET (Q1). In the ACF, excess energy from the leakage inductance of the transformer,  $L_{lk}$ , is stored in the clamp capacitor,  $C_{clamp}$ , through the high-side FET, Q2. This leakage energy is then released to the output, together with the magnetizing inductance energy, through a resonant process. The key benefit here is that the leakage energy can be released to the output instead of being dissipated through a passive clamp. The  $C_{clamp}$  capacitor acts as an active clamp, hence the name *active-clamp flyback*.

#### 3.2 Power Loss Saving 2: Zero-Voltage-Switching

Since high switching frequency operation is required to reduce the size of the system, special attention must be given to the frequency-dependent switching losses, as shown in [Equation 3](#).

$$P_{\text{loss, switching, turn-on}} = \frac{1}{2} C_p \times V_{ds}^2 \times f_{sw} \quad (3)$$

Here, it is important to note that the switching losses are linearly proportional to the switching frequency,  $f_{sw}$ . These incurred switching losses must be mitigated through ZVS. To achieve ZVS, the energy stored in the device output capacitance,  $C_p$ , of the low-side FET, Q1, must be discharged before Q1 is turned on. This is achieved by building a negative current,  $I_{M-}$ , in the magnetizing inductance,  $L_M$ , that is sourced from  $C_p$  immediately after Q2 is turned off. When it is time for Q1 to turn on,  $C_p$  is discharged and there are zero volts from drain to source, enabling a zero-loss turn-on transition as shown in [Equation 4](#).

$$P_{\text{loss, switching, turn-on, ZVS}} = \frac{1}{2} C_p \times V_{ds}^2 \times f_{sw} = 0 \quad (4)$$

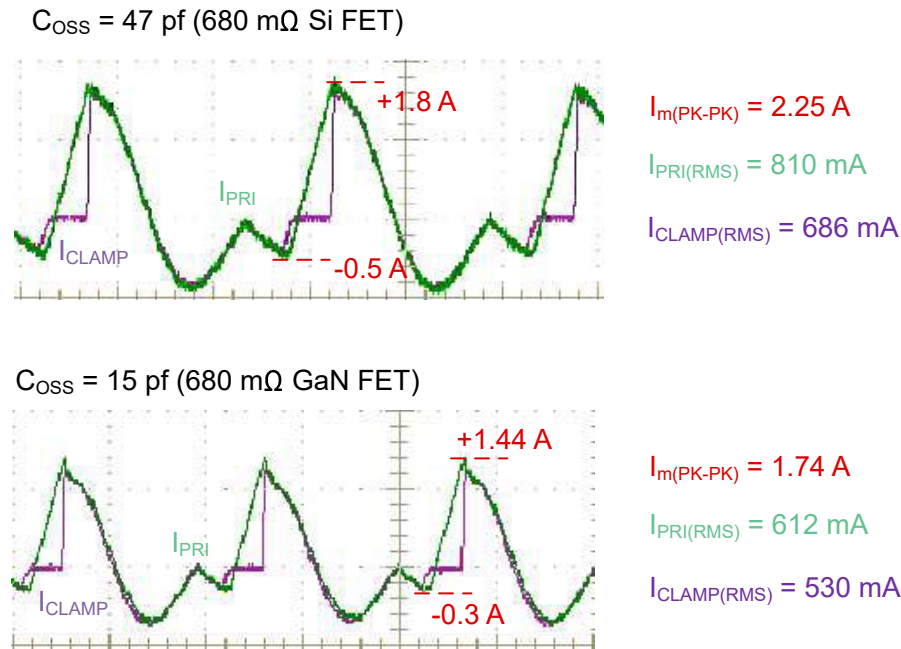
As a result, since the frequency-dependent turn-on loss is eliminated with ZVS, there is more freedom to increase the switching frequency, enabling the goal of a smaller design.

## 4 The Value of GaN in Active Clamp Flyback

The next discussion points highlight the value proposition of GaN within ACF. The required energy to realize ZVS can be explained through Equation 5.

$$E_{ZVS} = \frac{1}{2}L_M \times I_M^2 - \geq \frac{1}{2}C_p \times V_{ds}^2 \quad (5)$$

Equation 5 makes it apparent that larger device capacitance of silicon devices require more energy for ZVS. As a result, this requires a longer on-time of Q2, which reduces the switching frequency and increases the primary peak current. The combination of higher peak current and longer on-time leads to an increase in the RMS currents that show up as conduction losses in Q1 and the transformer windings. In many cases, these incurred conduction losses can completely negate the other benefits of the ACF, such as zero-clamp-loss and ZVS. As a result, the reduced output capacitance of GaN, compared to Si, is valuable in the ACF topology, as it is a crucial factor in keeping the RMS currents low. An empirical comparison of the RMS currents from GaN and silicon based ACF stages is shown in Figure 4-1.



**Figure 4-1. Current Waveforms of ACF Stage Operating with Silicon vs. GaN FETs**

The higher output capacitance of the silicon FET requires more negative magnetizing current and produces higher peak currents, which leads to larger  $I_{rms}^2 R$  losses compared to GaN.

As a result, the ACF can switch at high frequency while providing valuable power loss savings, but only under the condition that the RMS currents are managed. In summary, ACF enables high efficiency and high frequency operation, while GaN successfully enables ACF.

## 5 Leveraging Integrated GaN to Simplify ACF Stage

This application note has analyzed how the GaN-based ACF can address the thermal and energy storage challenges to facilitate small-form-factor designs. However, the next challenge is managing a practical implementation with considerations for cost and integration. Figure 5-1 shows the main components that are required to support the power stage of this topology.

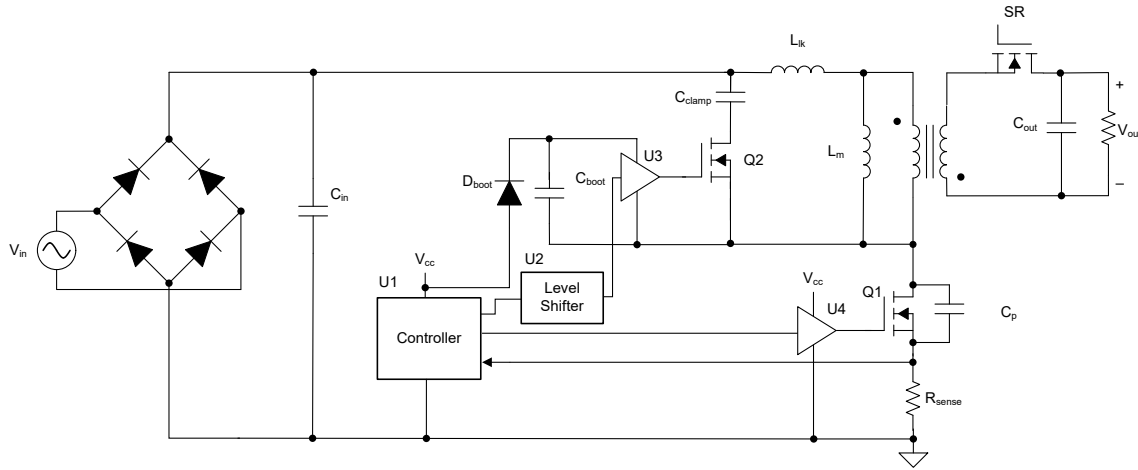


Figure 5-1. Practical Implementation of ACF

Aside from the controller, the semiconductor devices required in the primary side of the power stage are the high-side and low-side FETs, high-side and low-side gate drivers, high-side level shifter, and bootstrap diode. All the devices, together with biasing resistors and bypass capacitors, can add an undesirable increase in the cost, BOM count, and overall board space.

To address the complexity of all these devices, the LMG2610 simplifies the power stage by integrating all the devices into a single 7 mm × 9 mm package.

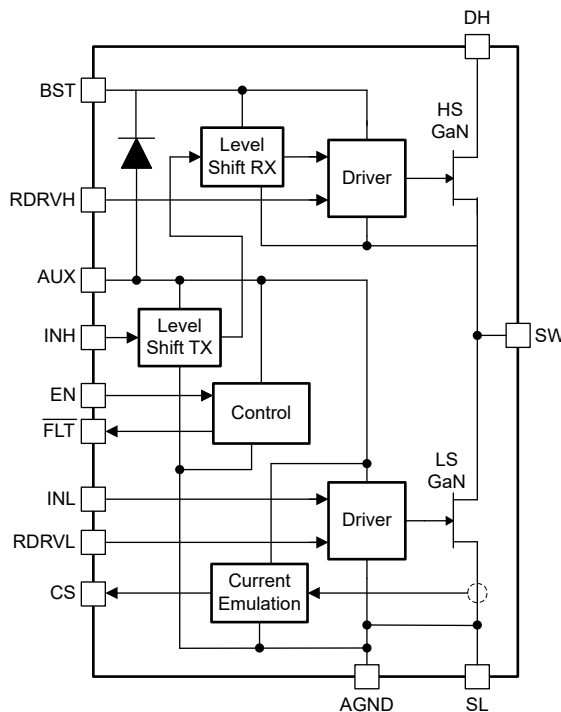


Figure 5-2. LMG2610 Block Diagram

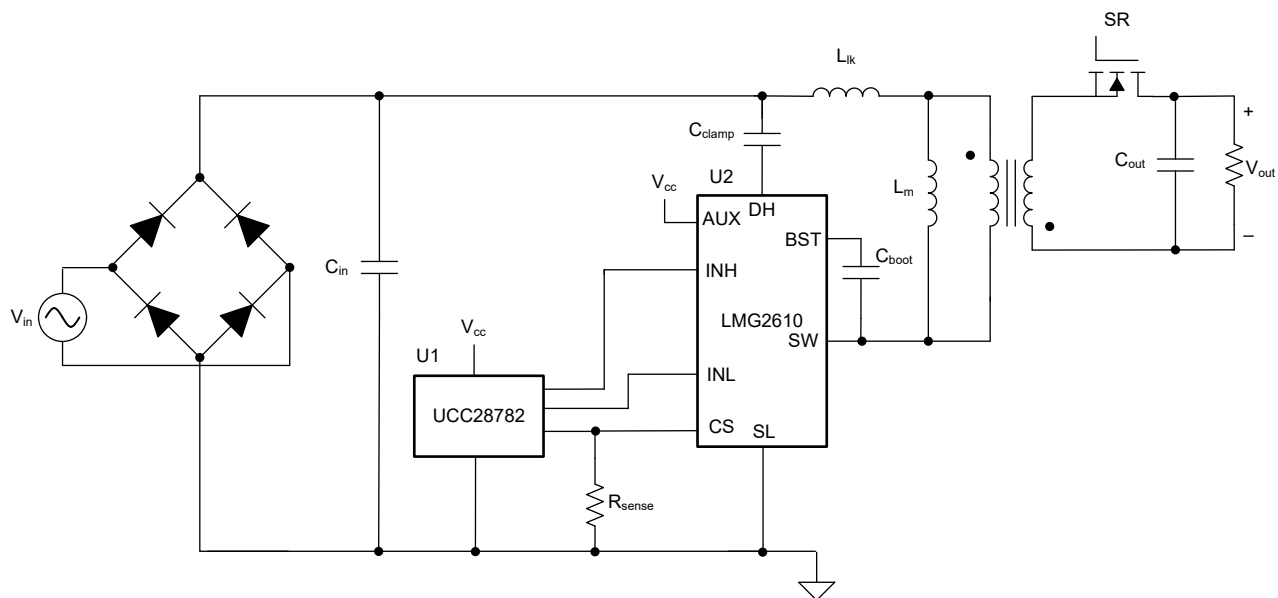
As shown in [Figure 5-2](#), LMG2610 integrates 170 mΩ/248 mΩ GaN half-bridge, gate drivers, level shifter, and bootstrap diode. This device can support ACF designs up to 75 W.

In addition to the integration, a key feature of LMG2610 that can further decrease power losses in ACF designs is the current sense emulation. All current-mode controllers sense the current through the low-side FET to control the on-time of the device. However, instead of having to sense the actual FET current through a traditional sense resistor, LMG2610 outputs a scaled-down replica (1 mA/A) of the low-side FET current through the CS pin. This replicated current signal is then fed into a resistor and produces the same voltage required by the controller that a traditional current sensing scheme produces. The difference here is that the power loss is a small fraction of the traditional sensing scheme as shown in [Equation 6](#).

$$\frac{P_{sense,emulation}}{P_{sense,traditional}} = \frac{.001I_{LS,avg} \times 1.5V_{aux}}{I_{LS,rms}^2 \times R_{sense}} \quad (6)$$

Using this feature in conjunction with ZVS and zero-clamp-loss enables the highest efficiency for ACF.

Pairing the LMG2610 Integrated GaN Half-Bridge with the UCC28782 ACF controller provides a simple, cost-effective solution compared to a discrete design. This combination allows for high frequency operation, high efficiency across all load levels, low standby power, and a reduced EMI signature at high input voltages. Compared to [Figure 5-1](#), [Figure 5-3](#) is much simpler due to the integration provided by LMG2610.



**Figure 5-3. ACF Power Stage with UCC28782 Controller and LMG2610 Integrated GaN Half-Bridge**



## 6 Physical Design Implementations Using LMG2610 Integrated Half-Bridge and UCC28782 ACF Controller

The small-size and high-efficiency performance achieved by combining these two devices can be seen in the two designs featured in this section.

### 6.1 UCC28782EVM-030

The first design is a 65-W USB-C PD adapter with the following specifications in [Table 6-1](#).

**Table 6-1. UCC28782EVM-030 Specifications**

Application	USB-C PD Adapters
Input Voltage	85 – 265 Vac
Output	20 V/3.25 A, 15 V/3 A, 9 V/3 A, 5 V/3 A
Max. Power	65 W

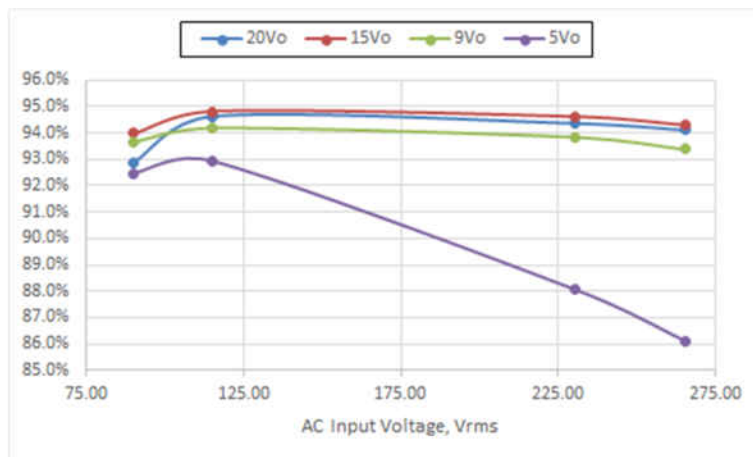
The UCC28782EVM-030 is able to achieve a power density of  $30 \frac{W}{in^3}$  or  $1.83 \frac{W}{cc}$ . The UCC28782EVM-030 compact form-factor is show in [Figure 6-1](#).



**Figure 6-1. UCC28782EVM-030 in High-Density Configuration**

This small size is achieved by operating with a maximum switching frequency of approximately 240 kHz, which allows a smaller inductance requirement, and as a result, a smaller transformer core size.

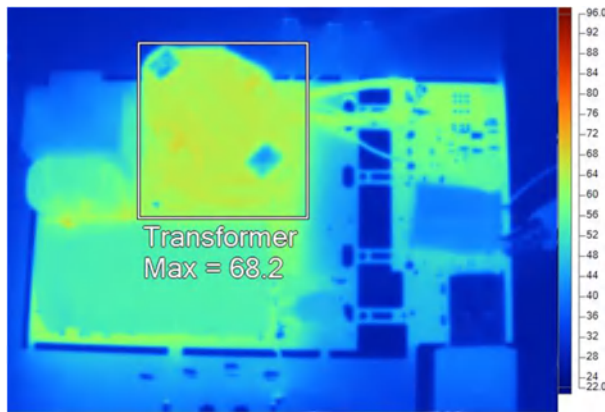
The full load efficiency across input voltage is shown in [Figure 6-2](#).



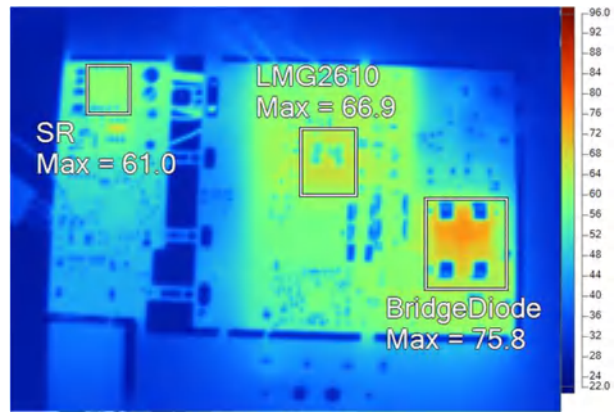
**Figure 6-2. UCC28782EVM-030 Efficiency Across Load**

As shown, the design exceeds CoC and DoE efficiency requirements. Additionally, the standby power consumption is kept at a minimum of 48 mW at 115-VAC input and 58 mW at 230-VAC input. This is achieved by the standby modes of operation of LMG2610 and UCC28782.

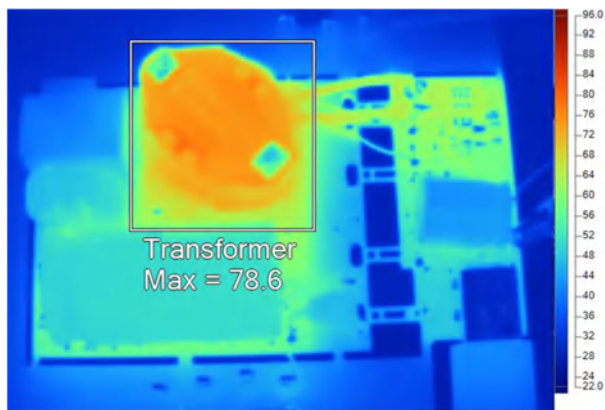
The thermals, captured at full load after 30 minutes, are shown in the following images.



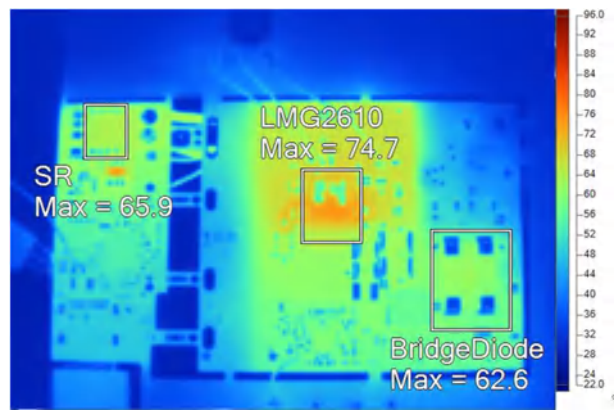
**Figure 6-3.  $V_{in} = 115 V_{ac}$  Top Side**



**Figure 6-4.  $V_{in} = 115 V_{ac}$  Bottom Side**



**Figure 6-5.  $V_{in} = 230 V_{ac}$  Top Side**



**Figure 6-6.  $V_{in} = 230 V_{ac}$  Bottom Side**

Temperatures are managed all across the board to provide a thermally reliable operation. This is achieved through the previously discussed power-saving mechanisms such as ZVS, zero-clamp-loss, and current sense emulation.

In summary, this design achieves the small-form-factor goal by successfully managing thermals and switching at high frequency.

## 6.2 PMP23146

The second design is a 45 W auxiliary power supply for server applications with the following specifications in [Table 6-2](#).

**Table 6-2. PMP23146 Specifications**

Application	Server Auxiliary Power Supplies
Input Voltage	250-410 Vdc
Output	12 V/3.7 A
Max. Power	45 W

The PMP23146 achieves an astounding power density of  $60 \frac{W}{in^3}$  or  $3.7 \frac{W}{cc}$ . The sleek form factor is shown in [Figure 6-7](#).



**Figure 6-7. PMP23146 Server Auxiliary Power Supply Reference Design**

This size is achieved by using a planar transformer while switching at 400 kHz. The planar transformer drastically reduces the overall height by implementing the windings in multiple layers of the PCB. The high switching frequency greatly reduces the energy storage requirement.

Additionally, the integration provided by LMG2610 reduces the total required board space as seen in [Figure 6-8](#). The Small 7 mm × 9 mm package of LMG2610 greatly reduces the board footprint compared to a discrete design. This integration can significantly improve the power density for miniaturized designs



**Figure 6-8. PMP23146 Back-side**

Figure 6-10 shows the efficiency across several input voltage levels.

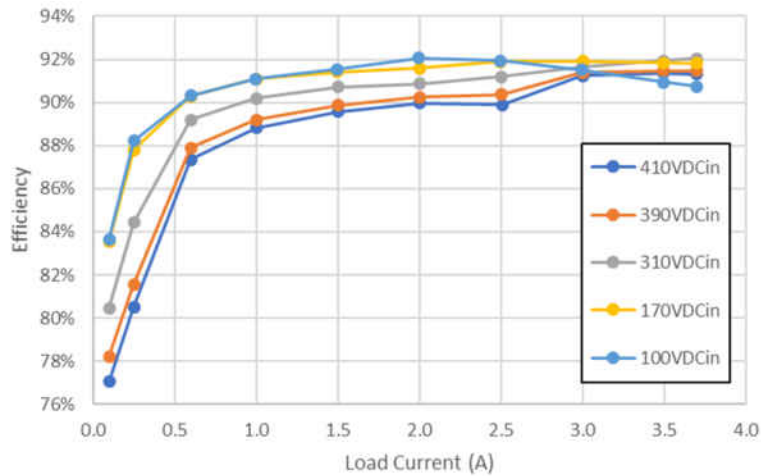
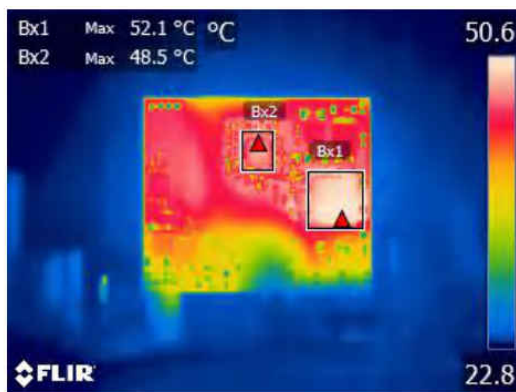


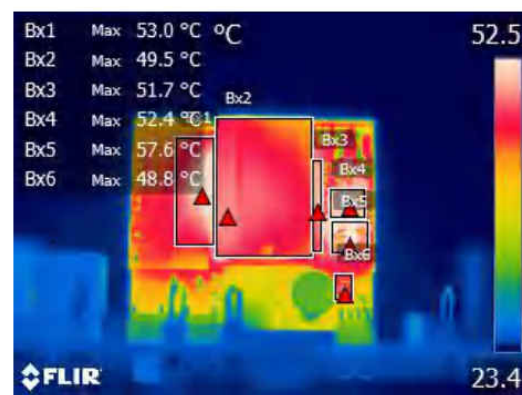
Figure 6-9. PMP23126 Efficiency Across Load

Additionally, the standby power consumption is kept below 100 mW.

Figure 6-10 shows the thermals captured at 390-VDC input at full load. Forced air was used with fan current limited to 200 mA.



Thermal Image Full Load (GaN-Side of Assembly)



Thermal Image Full Load (Transformer-Side of Assembly)

Figure 6-10. PMP23126 Thermal Images

Temperatures are managed in this design to provide a thermally reliable operation.

In all, the miniaturization of this power supply design is enabled by the combination of the ACF, LMG2610, and UCC28782.

## 7 Leverage Design Tools for ACF

This application note discussed how increased power demands and small form factors can be achieved through the use of TI's integrated GaN technology. To facilitate next the ACF design, see [ACF Power Stage Design Calculator](#), and [LMG2610 SIMPLIS model](#). These tools facilitate the design process when selecting the main power stage components and the initial evaluation of the converter operation.

## 8 Summary

Implementing small-form factor designs depends on the feasibility of managing thermals and reducing the energy storage requirement. Addressing these challenges can be achieved through the use of a high-frequency active-clamp flyback topology enabled by GaN technology. Furthermore, this implementation is simplified through the integration provided with LMG2610 with control provided by UCC28782. It was demonstrated that the performance provided with ACF, LMG2610, and UCC28782 enables high efficiency at high frequency operation, enabling a small design.

## 9 References

- Texas Instruments, [Comparison of GaN- and Silicon FET-Based Active Clamp Flyback Converters](#), power supply design seminar.
- Texas Instruments, [Using the UCC28782EVM-030 65-W USB-C PD High-Density Active-Clamp Flyback Converter](#), user guide.
- Texas Instruments, [45-W Server Auxiliary Supply, High-Power Density Active Clamp Flyback With GaN Reference Design](#), test report.
- Texas Instruments, [ACF Power Stage Design Calculator](#)
- Texas Instruments, [LMG2610 Integrated 650-V GaN Half Bridge for Active-Clamp Flyback Converters](#) data sheet.

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