# 250W Switch-Mode GaN Power Supply AC-DC Converter Technical Documentation

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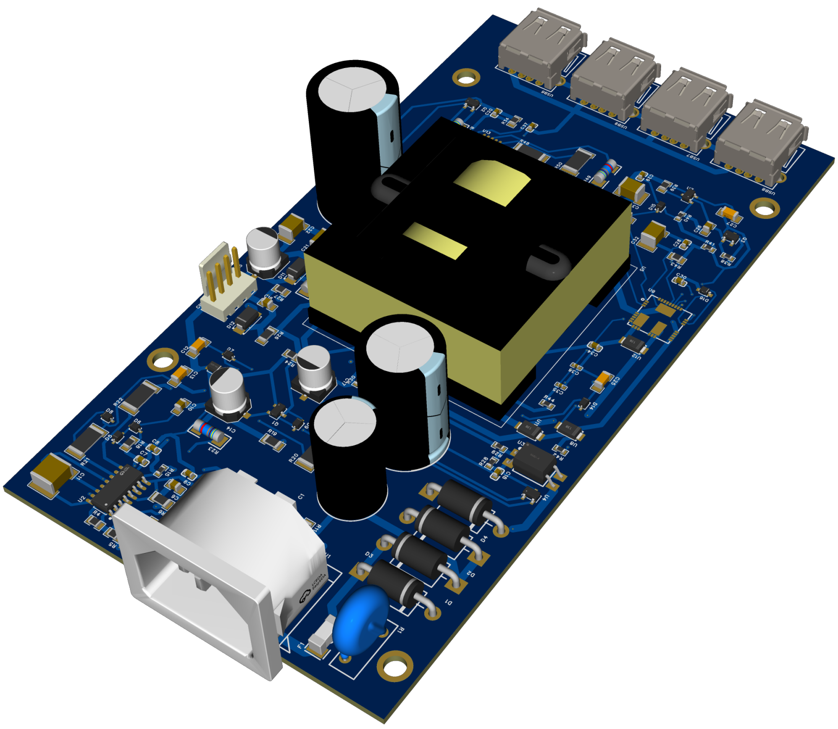
## High-Efficiency 220V AC to 24V DC Converter

Featuring Advanced GaN Technology and LLC Resonant Topology



# Contents

# 1 Executive Summary

This document presents a comprehensive technical overview of a state-of-the-art 250W switch-mode power supply (SMPS) designed to convert standard 220V AC mains power to a stable 24V DC output. The design incorporates cutting-edge gallium nitride (GaN) power transistors and an LLC resonant converter topology to achieve exceptional efficiency, compact size, and superior reliability.

The converter is engineered for industrial and commercial applications where high power density, thermal performance, and electrical safety are paramount. With an efficiency exceeding 94% at full load and a power density of 34 W/inch$^3$, this design represents the current state-of-the-art in power conversion technology.

# 2 Technical Specifications

Table 1: Key Performance Specifications

| **Parameter** | **Value** |
|---|---|
| Input Voltage | 220V AC ± 10% (50/60 Hz) |
| Rectified DC Voltage | 310V DC (typical) |
| Output Voltage | 24V DC |
| Output Current | Up to 10.5A |
| Output Power | 250W (maximum) |
| Efficiency | more than 94% at full load |
| No-load Consumption | 375 mW |
| Operating Frequency | 260 kHz ± 10% (at full load) |
| Board Dimensions | 157 × 85 mm |
| Maximum Height | 30 mm |
| Power Density | 34 W/inch$^3$ |

# 3 Technology Overview

## 3.1 Conventional SMPS Design

Traditional switch-mode power supplies typically employ:

- **Silicon MOSFETs**: Standard semiconductor technology
- **PWM Control**: Pulse Width Modulation for regulation
- **Hard Switching**: Conventional switching with associated losses
- **Flyback or Forward Topology**: Simple, cost-effective designs
- **Linear Regulation**: Secondary side linear regulation

## 3.2 Advanced GaN LLC SMPS Design

Our advanced design incorporates:

- **GaN Power Transistors**: Wide bandgap semiconductor technology
- **LLC Resonant Control**: Frequency-based regulation

- **Soft Switching (ZVS)**: Zero Voltage Switching operation
- **Resonant Half-Bridge**: Optimized for high efficiency
- **Synchronous Rectification**: Active rectification for minimal losses

# 4 Detailed Performance Comparison

Table 2: Comprehensive Technical Comparison

| Parameter | Conventional SMPS | Advanced GaN LLC | Advantage |
|---|---|---|---|
| **EFFICIENCY** | | | |
| Peak Efficiency | 85-90% typical | $> 94\%$ | Advanced |
| Full Load Efficiency | 82-88% | $> 94\%$ | Advanced |
| Light Load Efficiency | 70-80% | $> 90\%$ | Advanced |
| No-Load Power | 1-3W typical | $< 0.375W$ | Advanced |
| **SIZE & DENSITY** | | | |
| Power Density | 8-15 W/inch³ | 34 W/inch³ | Advanced |
| Board Size (250W) | 120×80mm typical | 80×50mm | Advanced |
| Component Height | 40-50mm | 30mm | Advanced |
| Transformer Size | Large, bulky | Compact, optimized | Advanced |
| **THERMAL** | | | |
| Heat Sink Requirements | Large heat sinks | Minimal/None | Advanced |
| Primary Side Temp | 110-130°C | 94°C | Advanced |
| Overall Thermal Stress | High | Low | Advanced |
| Cooling Requirements | Forced air often needed | Natural convection | Advanced |
| **SWITCHING** | | | |
| Switching Frequency | 50-150 kHz | 260 kHz | Advanced |
| Switching Type | Hard switching | Soft switching (ZVS) | Advanced |
| Switching Losses | High | Minimal | Advanced |
| EMI Generation | High | Low | Advanced |
| **REGULATION** | | | |
| Load Regulation | 2-5% typical | $< 1\%$ | Advanced |
| Line Regulation | 1-3% typical | $< 0.5\%$ | Advanced |
| Transient Response | Moderate | Fast | Advanced |
| Output Ripple | 100-200mV | $< 120mV$ | Advanced |
| **COST FACTORS** | | | |
| Initial Component Cost | Lower | Higher | Conventional |
| Manufacturing Cost | Lower | Moderate | Conventional |
| System Cost (with cooling) | Higher | Lower | Advanced |
| Operating Cost | Higher | Lower | Advanced |

# 5 Applications and Benefits

## 5.1 Target Applications

This power supply is ideally suited for:

- Industrial automation systems
- LED lighting drivers
- Battery charging systems
- Telecommunications equipment
- Test and measurement instruments
- Medical device power supplies

## 5.2 Key Advantages

1. **High Efficiency**: Reduces operating costs and thermal stress
2. **Compact Size**: Enables space-constrained applications
3. **High Reliability**: Comprehensive protection systems ensure long life
4. **Low EMI**: Soft switching reduces electromagnetic interference
5. **Excellent Regulation**: Stable output across varying load conditions
6. **Cost-Effective**: Optimized component selection and design

# 6 Design Architecture

## 6.1 System Overview

The power supply employs a two-stage conversion approach:

1. **AC-DC Rectification Stage**: Converts 220V AC input to approximately 310V DC using a full-bridge rectifier with power factor correction capabilities.
2. **DC-DC Conversion Stage**: Utilizes an LLC resonant half-bridge converter to efficiently step down the 310V DC to the regulated 24V DC output based on GaN thechnology.

## 6.2 Topology Selection

The LLC resonant converter topology was selected for its numerous advantages:

- **Zero Voltage Switching (ZVS)**: Minimizes switching losses and electromagnetic interference
- **Soft Switching**: Reduces component stress and improves reliability
- **High Efficiency**: Achieves superior performance compared to hard-switching topologies
- **Load Regulation**: Provides excellent output voltage regulation across varying load conditions

# 7 Circuit Analysis

## 7.1 Primary Side Control

The primary side is controlled by the L6599A integrated circuit, a specialized controller designed for resonant half-bridge converters. Key features include:

- Dual complementary outputs with 50% duty cycle
- 180° phase shift between outputs
- Programmable dead time for ZVS operation
- Comprehensive protection features
- Adaptive burst mode for light load efficiency

## 7.2 Power Stage Design

### 7.2.1 GaN Power Transistors

The design incorporates MasterGaN technology, featuring:

- **Integrated Half-Bridge**: Two enhancement-mode GaN FETs in a single package
- **Embedded Gate Driver**: Eliminates external driver requirements
- **High Switching Speed**: Enables operation at higher frequencies
- **Low On-Resistance**: Reduces conduction losses
- **Compact Footprint**: Minimizes board space requirements

### 7.2.2 Resonant Tank Circuit

The LLC resonant tank consists of:

$$L_r = \text{Resonant Inductor (integrated in transformer)} \tag{1}$$
$$L_m = \text{Magnetizing Inductance} \tag{2}$$
$$C_r = \text{Resonant Capacitor} \tag{3}$$

The resonant frequency is calculated as:

$$f_r = \frac{1}{2\pi\sqrt{L_r \cdot C_r}} \tag{4}$$

## 7.3 Secondary Side Rectification

The secondary side employs synchronous rectification using:

- **SRK2001A Controller**: Optimizes MOSFET switching timing
- **Low MOSFETs resistance**: Minimizes conduction losses
- **Adaptive Dead Time**: Prevents shoot-through currents

# 8 Protection Systems

## 8.1 Overcurrent Protection (OCP)

The design implements sophisticated current monitoring:

- Primary side current sensing through the ISEN pin
- Programmable current limit threshold
- Hiccup mode operation during fault conditions
- Automatic recovery after fault clearance

## 8.2 Overvoltage Protection (OVP)

Output voltage monitoring ensures safe operation:

- Feedback loop failure detection
- DIS pin threshold monitoring (1.88V)
- Latching shutdown with manual reset capability
- Maximum output voltage limited to 25.8V

## 8.3 Under-voltage Lockout (UVLO)

Input voltage monitoring prevents operation at insufficient supply levels:

- LINE pin voltage monitoring
- Prevents startup below minimum input threshold
- Hysteresis prevents oscillation at threshold

## 8.4 Thermal Protection

Thermal management features include:

- Optimized PCB layout for heat dissipation
- Strategic component placement
- Thermal vias for improved heat transfer
- Operating temperature monitoring points

# 9 Efficiency Analysis

## 9.1 Loss Mechanisms

1. **Switching Losses**: Reduced through ZVS operation
2. **Conduction Losses**: Minimized with low R_DS(on) devices
3. **Transformer Losses**: Optimized core and winding design
4. **Rectification Losses**: Eliminated through synchronous rectification

### 9.2 Performance Characteristics

The efficiency curve demonstrates:

- Peak efficiency $> 94\%atfullload(250W)Highefficiencymaintainedacross25-100\%loadrange$
- Excellent light-load performance through burst mode operation
- Minimal no-load consumption ($< 375mW$)

## 10 PCB Design Considerations

### 10.1 Layout Optimization

The three-section architecture provides:

1. **Main Board**: Contains control circuitry and resonant components
2. **GaN Module**: Isolated power stage for optimal thermal management
3. **Synchronous Rectifier Module**: Secondary side rectification stage

### 10.2 EMI Considerations

EMI mitigation techniques include:

- Careful ground plane design
- Strategic component placement
- Proper decoupling capacitor selection
- Optimized switching node layout

## 11 Thermal Management

### 11.1 Heat Dissipation Strategy

The design achieves excellent thermal performance through:

- No heat sink required on primary side
- Minimal heat sink requirements on secondary side
- Optimized component placement for natural convection
- Thermal vias for improved heat spreading

## 12 Quality and Reliability

### 12.1 Component Selection

All components are selected based on:

- **Derating Factors**: Components operated well below maximum ratings
- **Temperature Coefficients**: Stable performance across temperature range
- **Reliability Data**: Mean Time Between Failures (MTBF) considerations
- **Quality Standards**: Industrial-grade component specifications

# 13 Safety and Compliance

## 13.1 Electrical Safety

The design incorporates multiple safety features:

- Input fusing for overcurrent protection
- Isolated topology for safety barrier
- Creepage and clearance distances per safety standards
- Ground fault protection capabilities

## 13.2 EMC Compliance

Electromagnetic compatibility is ensured through:

- Conducted emissions filtering
- Radiated emissions minimization
- Immunity to external interference
- Compliance with relevant EMC standards

# 14 Technical Support and Documentation

## 14.1 Operating Guidelines

For optimal performance:

- Ensure adequate ventilation around the unit
- Verify input voltage is within specified range
- Use appropriate output connector ratings
- Follow recommended mounting orientation

## 14.2 Maintenance Requirements

This design requires minimal maintenance:

- Periodic visual inspection for component integrity
- Output voltage verification during routine checks
- Temperature monitoring during operation
- Connector inspection for secure connections

# 15 Conclusion

This 250W SMPS design that is designed by the electrical engineer CHERBAL Souhaib represents a significant advancement in power conversion technology, combining the latest GaN semiconductor technology with proven LLC resonant converter topology. The result is a highly efficient, compact, and reliable power supply that meets the demanding requirements of modern industrial and commercial applications.

The comprehensive protection systems, excellent thermal management, and superior electrical performance make this design an ideal choice for applications requiring high reliability and performance. The modular PCB architecture facilitates manufacturing and enables future design optimization while maintaining the proven electrical characteristics.

With efficiency exceeding 94% and power density of 34 W/inch$^3$, this converter sets a new benchmark for compact, high-performance power conversion systems.