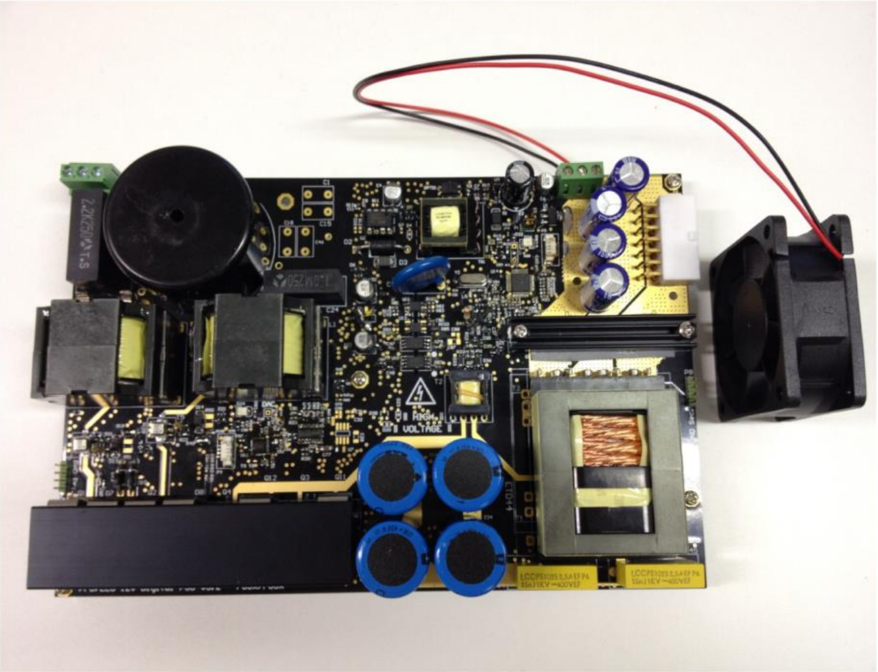
UM2064
User manual

Getting started with the 500 W fully digital AC-DC power supply (D-SMPS) evaluation board

Introduction

The STEVAL-ISA147V3 500 W digital power supply evaluation board consists of a semi-bridgeless PFC circuit and an isolated DC-DC converter used to deliver 500 W at 12 V DC. It operates with input voltages ranging from 90 to 264 V_{AC} and can be supplied at 50 and 60 Hz. The board employs a fully digital control algorithm based on two microcontrollers from the STM32 family. PFC control is implemented on an STM32F051K8 microcontroller, while LLC half-bridge control is implemented on an STM32F334C8 microcontroller. The LLC converter has a synchronous rectification (SR) stage for high conversion efficiency.

Figure 1: STEVAL-ISA147V3 500 W digital power supply system with 12 V output

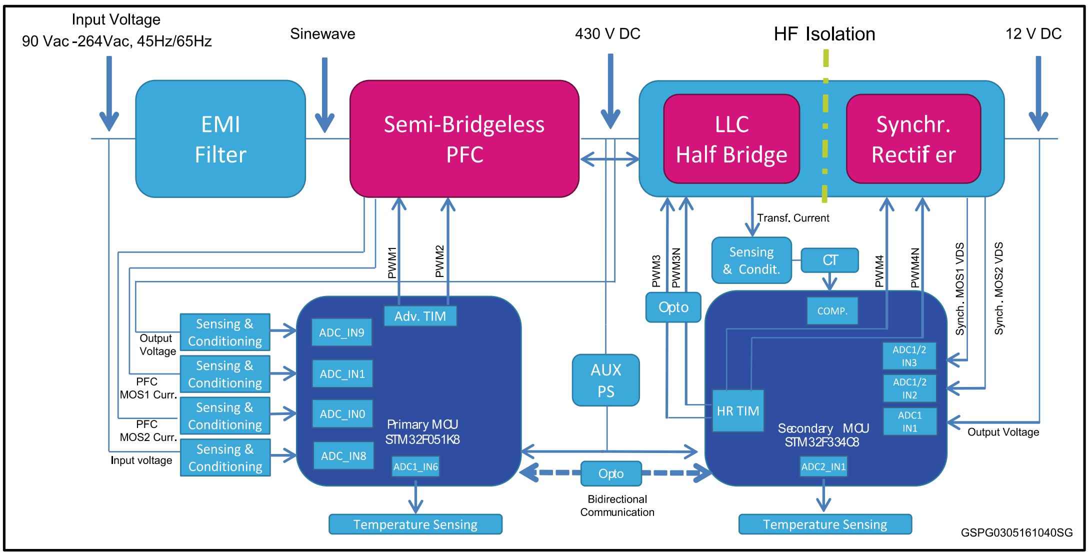


Contents

1 Evaluation board overview

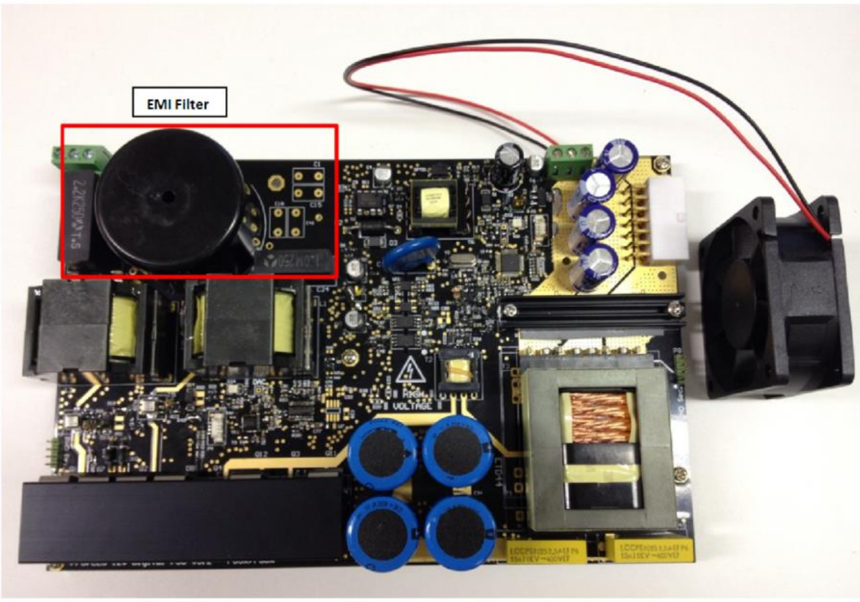
The STEVAL-ISA147V3 500 W dual-stage converter is digitally controlled by two 32-bit STM32 microcontrollers; the power supply architecture is figured below.

Figure 2: STEVAL-ISA147V3 system architecture



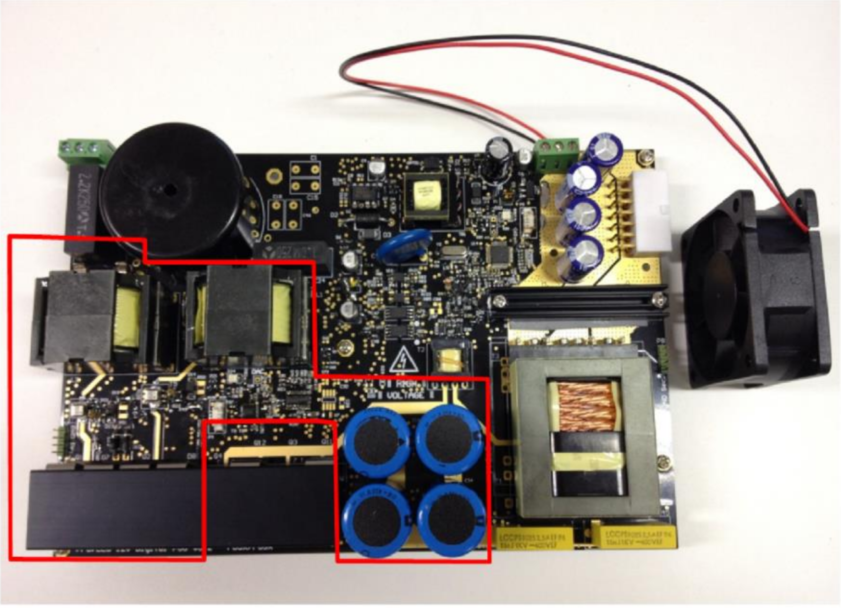
The first, EMI filter block is clearly indicated in *Figure 3: "Two-stage EMI filter"*; a two-stage topology is implemented.

Figure 3: Two-stage EMI filter



The EMI filtering stage is directly connected to the input of the semi-bridgeless PFC circuit, highlighted in *Figure 4: "PFC circuit"*, consisting of two inductors, L1 and L2, two MOSFETs, Q1 and Q2, and two rectifying diodes, D7 and D8. The D9 and D13 pre-charge diodes only conduct current when the AC voltage is applied to charge the four 100 µF, 450 V DC bus capacitors in the bottom-right of the area indicated in *Figure 4: "PFC circuit"* by a red line. D12 and D10 are used to keep the negative phase connected to the PFC ground and improve EMI filtering. These two diodes conduct part of the current returning to the source during operation.

Figure 4: PFC circuit



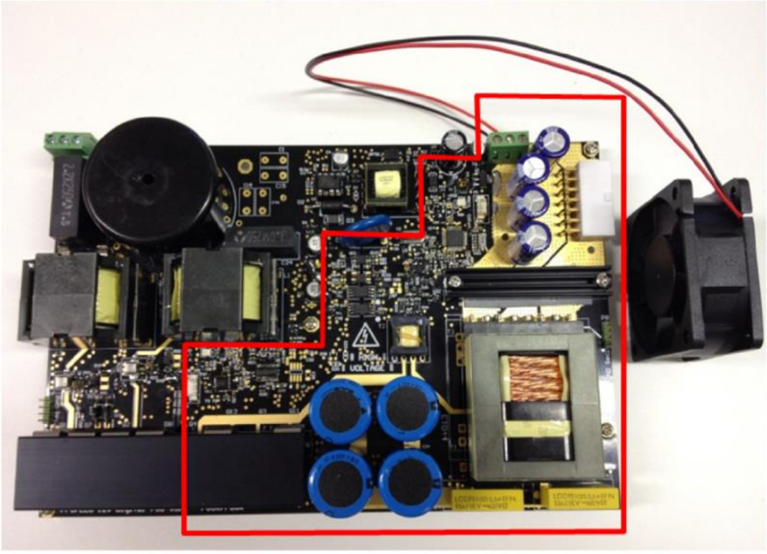
T4 and T5 are the two current sensing transformers used to sense the drain current of each MOSFET.

The LLC stage performs voltage step-down using an HF transformer with a primary-to-secondary turn ratio chosen for favorable efficiency and regulation across the entire operating range. The transformer is supplied with a square-wave voltage generated by the primary-side active switches. On the secondary side, this voltage waveform is rectified and then smoothed by the output filter. On the primary side, switching losses are reduced thanks to zero voltage switching (ZVS), while on the secondary side, synchronous rectification (SR) ensures low conduction losses. The overall effect of these design choices is high system efficiency.

The LLC section of the power supply system is delineated in *Figure 5: "LLC converter"*. This section consists of the two MOSFETs of the half-bridge Q12 and Q3, the high frequency transformer T1, resonant capacitors C84 and C45 and the synchronous rectifier MOSFETs Q6, Q7, Q8, Q10. Although it is possible to mount up to four devices for each side of the rectification circuit, only two devices per side are used and soldered on the PCB. The output filter capacitors are in the upper-right section of the relevant area in *Figure 5: "LLC converter"*.

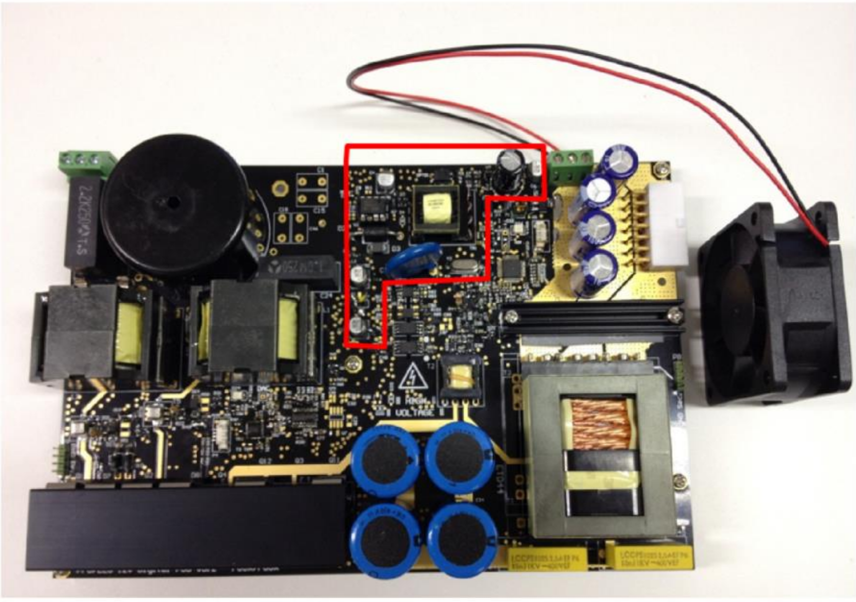
The driver of the half-bridge is an L6491D, U8, mounted close to Q12 and Q3. The driver of the synchronous rectification devices is a PM8834, IC2, mounted on the bottom of the PCB. Opto-isolators U10 and U9 supply the gate signals generated by the STM32F30x to Q12 and Q3 through driver U8. Two additional opto-isolators U11 and U12 are used for bidirectional communication between the U13 PFC microcontroller, and the U14 LLC microcontroller.

Figure 5: LLC converter



P4 and P5 are the two connectors used to program U13 and U14, respectively. The two microcontrollers can be programmed using IAR Embedded Workbench for ARM ver. 6.50 and a suitable debugger/programmer, such as IAR J-Link or the STMicroelectronics ST-LINK. The auxiliary power supply section with a VIPER27H circuit is indicated by the red area in *Figure 6: "Auxiliary power supply circuit"*.

Figure 6: Auxiliary power supply circuit



The main specifications of the system are given in *Table 1: "500 W AC-DC converter specifications"*.

Table 1: 500 W AC-DC converter specifications

Parameter	Value
Input AC voltage range	90 to 264 V_{AC}
Input AC frequency range	45 to 65 Hz
Output voltage	12 V_{DC}
Output current	42 A
PFC output voltage	430 V_{DC}
Output power	500 W
PFC switching frequency	60 kHz
DC - DC switching frequency	80 kHz up to 115 kHz (burst mode above)
HF transformer isolation	4 kV
Peak efficiency	94% at 230 V_{AC}
Cooling	Natural convection up to 300 W; forced above
Input short-circuit protection	10 A fuse
Input under/overvoltage	Managed by STM32F051K8
Input under/overfrequency	Managed by STM32F051K8
Bus DC under/overvoltage	Managed by STM32F051K8
Output short-circuit protection	Managed by STM32F334C8
Output under/overvoltage	Managed by STM32F334C8
Overtemperature protection	Managed by STM32F051K8 (PFC) and STM32F334C8 (LLC)

The converter accepts universal input voltage and produces a 12 V regulated output. The continuous power rating of the unit is 500 W. Natural convection is used up to 300 W, above which, a cooling fan is activated to provide forced air cooling. The ambient operating temperature range is 0 to 50 °C.

The intermediate high-voltage DC bus is regulated at 430 V by the PFC, which draws a sinusoidal input current from the AC input, maintaining a high power factor and low current total harmonic distortion (THD%). The LLC circuit converts this high DC voltage to low DC voltage, proving isolation (4 kV) by means of an HF transformer and high efficiency thanks to ZVS. Input and output current and voltage protection are also provided, together with overtemperature protection.

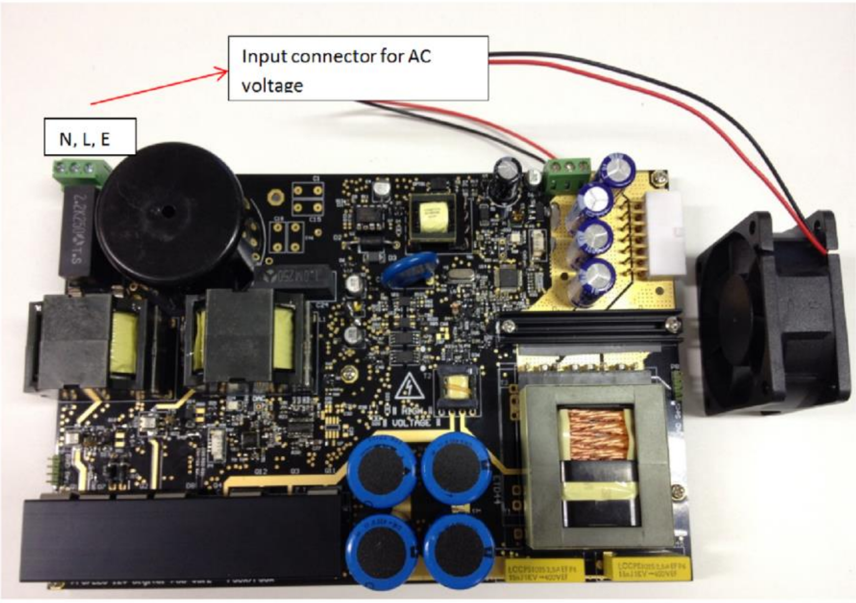
2 Operating the board

The board can be easily tested up to 500 W and across the operating input voltage and frequency range. The following equipment can be used to perform functional and efficiency testing:

- 750 VA programmable AC source
- 12 V/42 A DC electronic load
- Power analyzer
- Digital oscilloscope

The programmable AC source must be connected to JP1 as per *Figure 7: "Connection of the AC cables"*, showing line, neutral and earth connections.

Figure 7: Connection of the AC cables



The output load must be connected to P6 (*Figure 8: "Output connector P6 for load connection"*), using the cable provided with the board, as shown in *Figure 9: "Cable for output load connection (42 A max.)"*, or another suitable cable capable of carrying the desired load current (42 A max).

A cooling fan is also provided with the board and should be activated by the user when the power output of the board is higher than 300 W. The fan connects to the P7 dedicated 12 V connector shown in *Figure 10: "Connection of the cooling fan to P7 connector"*.

Once the input power supply (90 to 264 V_{AC}, 45 to 65 Hz) and output load (12 V, 0 to 42 A) are connected, the power supply is ready to start.

As soon as the input voltage rises above 58 V, the auxiliary power supply starts powering the microcontrollers, drivers and signal conditioning circuitry. In this operating condition, the PFC and LLC converter are idle. Since the microcontrollers are powered, the programming cable and debugger can be connected to P4 or P5 to re-flash the microcontroller if and when necessary.

When the input voltage rises above 90 V_{AC}, the PFC starts. LED D24 blinks 3 times and the DC bus is charged to 430 V. Once the DC bus is charged, a serial message is sent from the PFC microcontroller U13 to the LLC converter microcontroller U14, which enables the modulation of the LLC half-bridge devices and SR devices. The output voltage ramps up from 0 to 12 V.

Figure 8: Output connector P6 for load connection

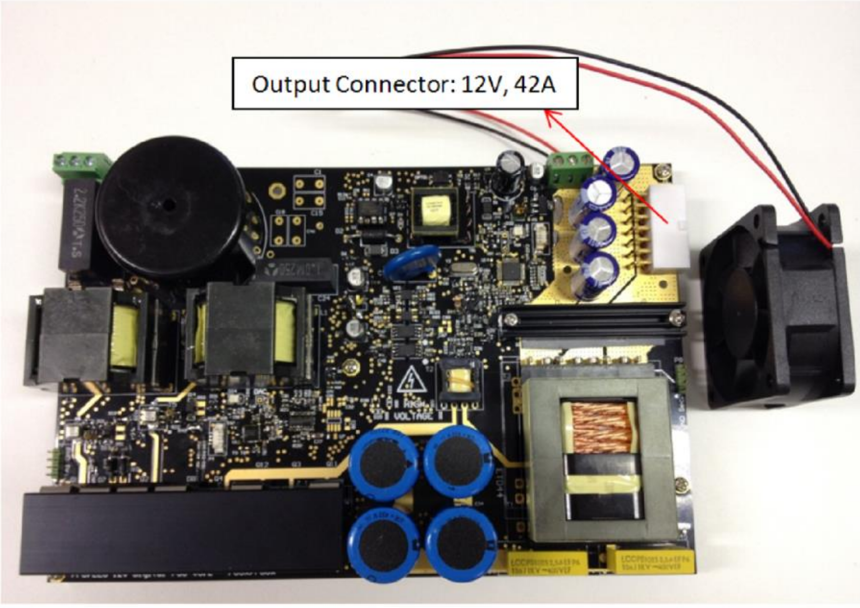
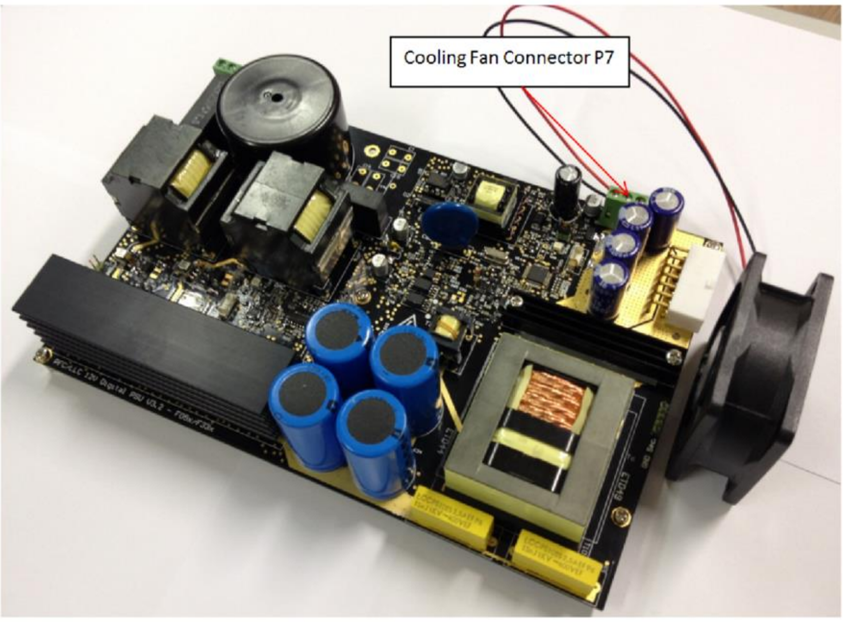


Figure 9: Cable for output load connection (42 A max.)

Figure 10: Connection of the cooling fan to P7 connector



3 Test results

The test was conducted with an open frame at an ambient temperature of 25 °C. The cooling fan was activated above 300 W and supplied by an external 12 V power supply, so the test results do not include cooling fan power consumption.

All test results were collected using a Voltech PM6000 universal power analyzer. An electronic DC load was used to draw constant current at every testing point. The results are summarized in *Table 2: "Test results for 120 VAC input operation"* and *Table 3: "Test results for 230 VAC input operation"*.

Table 2: Test results for 120 VAC input operation

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)	PF	THD%
120	0.712	82.6	12.07	6	72.76	88.08	0.965	5.4
120	1.33	157.98	12.03	12	144.58	91.51	0.9842	5.4
120	1.96	234.01	12.01	18	216.49	92.51	0.992	4.2
120	2.61	312.34	12.02	24	288.74	92.44	0.994	3.5
120	3.05	365.2	12,03	28	337.48	92.40	0.996	3.2
120	3.72	445.24	11.99	34	409.37	91.94	0.996	3.2
120	4.63	554.2	12.01	42	505.69	91.24	0.997	4.3

Table 3: Test results for 230 VAC input operation

V_{IN} (V)	I_{IN} (A)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)	PF	THD%
230	0.45	81.71	12.1	6	72.62	88.87	0.78	13.6
230	0.73	156.37	12.04	12	144.47	92.38	0.925	11.4
230	1.04	232.65	12.01	18	216.56	93.08	0.9642	9.7
230	1.37	309.26	12.04	24	288.63	93.32	0.977	8.9
230	1.59	360.98	12.03	28	336.62	93.25	0.983	7.9
230	1.94	441.15	11.99	34	410.26	92.99	0.986	7.6
230	2.40	546.81	12.01	42	505.5	92.44	0.989	7.4

4 Revision history

Table 4: Document revision history

Date	Revision	Changes
09-May-2016	1	Initial release.