

How to use the 75 W digitally controlled constant current HB LED driver

Introduction

The **STEVAL-LLL004V1** digitally controlled constant current LED driver features a PFC stage and two DC-DC converters designed to work in transition mode (TM) for optimized efficiency.

The LED driver can deliver 75 W output power and can dim LEDs down to 0.5% maximum brightness level via analog and digital control, and still retain flicker operation. Testing results show high efficiency, a power factor near unity, and low THD% under wide input voltage and load conditions due to the performance of the ST power products as well as the control strategies implemented through the 32-bit **STM32F0** series microcontroller.

Figure 1. STEVAL-LLL004V1 evaluation board - top

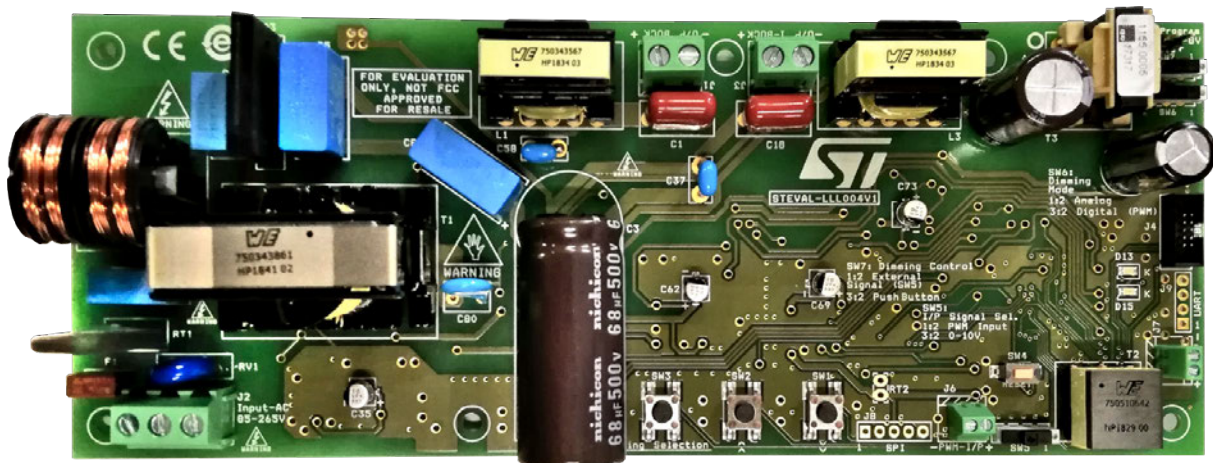
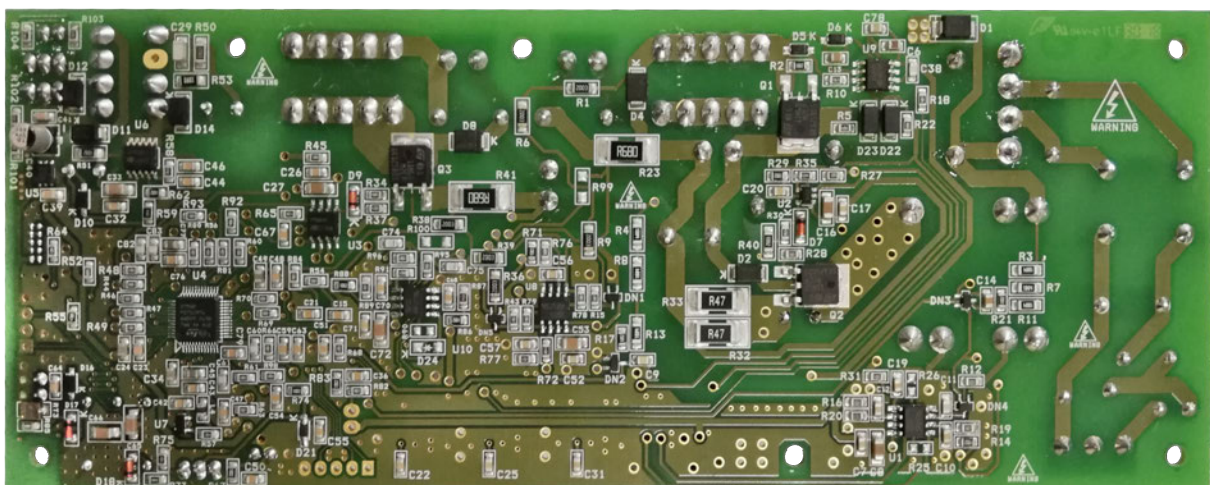


Figure 2. STEVAL-LLL004V1 evaluation board - bottom



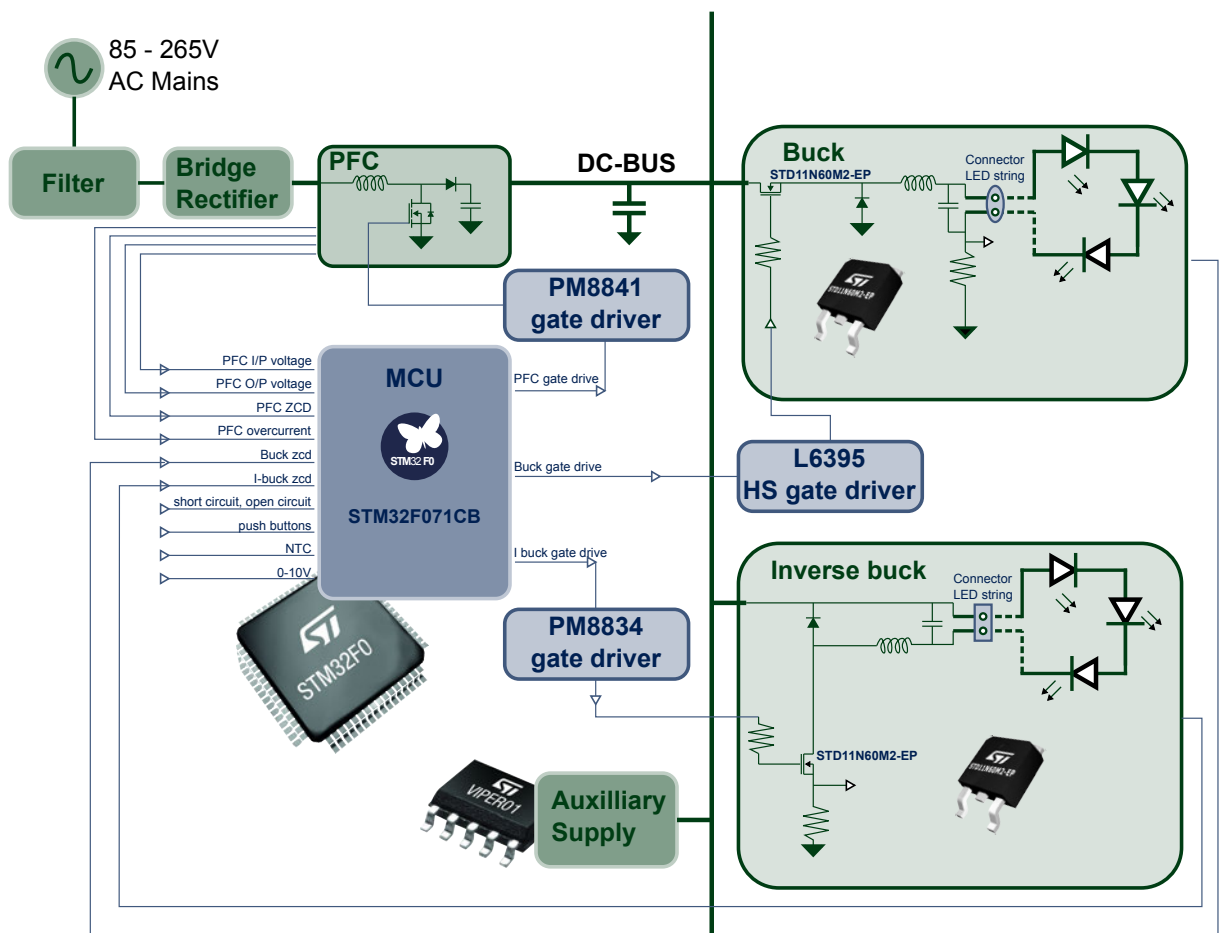
1 STEVAL-LLL004V1 evaluation board overview

The 75 W digitally controlled HB LED driver evaluation board has two power conversion stages:

1. A front end power factor correction (PFC) converter to provide a regulated DC output.
2. A downstream conversion stage with the following converters connected in parallel:
 - a. buck converter
 - b. inverse buck converter

Both converters in the second stage operate in constant current (CC) mode. In inverse buck topology, the power switch is connected to ground rather than to the high side switch, as in a standard buck topology.

Figure 3. STEVAL-LLL004V1 block diagram



The 32-bit **STM32F071CB** microcontroller provides digital control for both PFC and buck DC-DC conversion stages, which is highly advantageous in terms of cost and flexibility.

The control algorithm of the LED driver is proven on the 32-bit STM32F071CB MCU from the STM32 family. The MCU controls all three power stages in transition mode, turning ON MOSFET gate just after the inductor current reaches zero. A proportional-integral (PI) control loop has been implemented for the PFC stage, improving control loop stability, line transition and dimming steps behavior, and reducing current and voltage overshoot at start-up. Buck and inverse buck converters work in hysteretic mode. The dimming technique and control can be selected from the toggle switches on the board.

The on-board fast protection circuits provide reliable management of all the essential protection features.

1.1 Features

- Wide input voltage range 85 – 265 V_{AC}
- Transition Mode PFC
- Two constant current outputs working in transition mode based on different topologies:
 - Buck topology
 - Inverse buck topology
- Output current: 500 mA ±2.5%
 - Number of LEDs connected at output: 16 – 24 white LEDs (3.3 V each)
- PFC > 0.97 and THD < 20% at full load with input voltage 85-265 V_{AC}
- Peak Efficiency at maximum load ≅ 90%
- Comprehensive safety protections:
 - Open/no-load circuit protection
 - Short-/overload circuit protection
- Soft start implementation
- LED dimming range: 0.5% to 100%
 - Analog dimming
 - Digital dimming
- Dimming control options:
 - Push button
 - 0-10 V input
- Meet IEC55022 Class B
- WEEE and RoHS compliant

1.2 Electrical specifications

Table 1. STEVAL-LLL004V1 electrical specifications

Parameter	Operation/Mode/Topology	Value/Range
Input voltage range	-	85 - 265 V _{AC}
Power factor at full load	85 -265 V _{AC}	> 0.96
THD at full load	85 -265 V _{AC}	< 20%
PFC output voltage	-	450 V ±2.5%
Min. PFC switching frequency	Transition Mode	35 kHz
Min. PFC switching frequency	Discontinuous Mode	20 kHz
Maximum output power	Buck and inverse buck	75 W
Output voltage (V _{out})	Buck	50 - 80 V _{DC}
Buck Converter switching frequency at full load	Transition mode	~100 kHz
Output current (I _{out})	Buck (CC)	500 mA ±5%
Output voltage (V _{out})	Inverse-buck	50 - 80 V _{DC}
Inverse buck converter switching frequency at full load	Transition Mode	~100 kHz
Output current (I _{out})	Inverse buck (CC)	500 mA ±5%
LEDs connected at output	HB white LEDs	16 - 24 (3.3 V each)
Digital dimming frequency	-	500 Hz
Default brightness level	-	100%
Minimum dimming level	-	0.5%

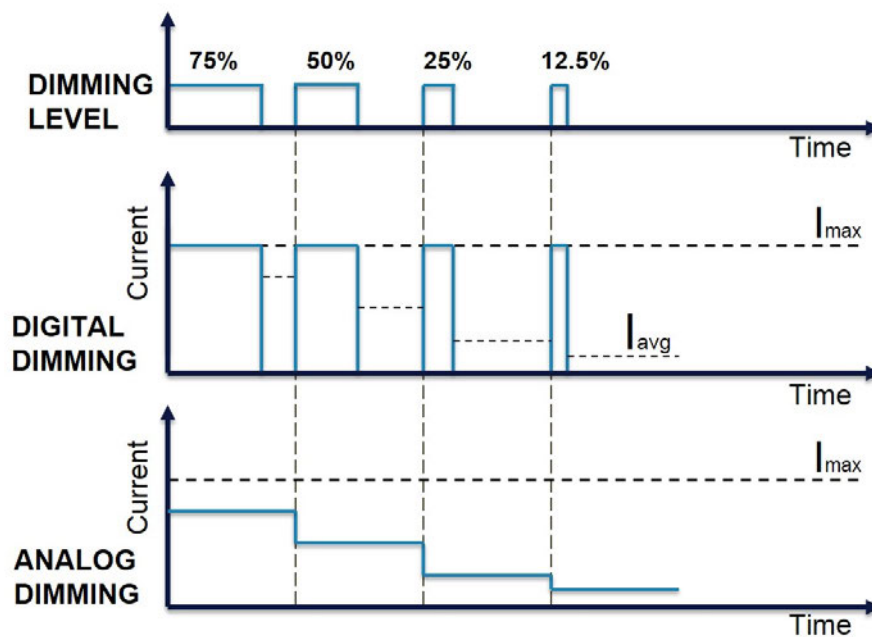
2 Digital and analog dimming with the STEVAL-LLL004V1

The STEVAL-LLL004V1 evaluation board provides for 0-10V input and user buttons to control the brightness of the LEDs, and you can select between analog or digital.

In digital (pulse width modulation (PWM)) dimming, the average current delivered to the LEDs is the product of the total nominal current and the duty cycle of the dimming function. Therefore, the brightness level is adjusted through the duty cycle.

For analog dimming, LED brightness is managed by changing the magnitude of the current.

Figure 4. Digital vs analog dimming



Both dimming approaches have advantages and disadvantages, which are summarised in the following table.

Table 2. Digital (PWM) dimming vs analog aiming

Digital (PWM) dimming	Analog dimming
No color shift as LED current remains the same	Color shift as LED current changes
Possible current inrush problems	No inrush current
Very linear change in brightness	Less linear change in brightness
Lower optical to electrical efficiency	Higher optical to electrical efficiency
Frequency limitations and concerns	No frequency concern

2.1 How to select dimming options on the board

Use the switches and jumpers described below to set the dimming options on the board. The switches for dimming type (SW6) and dimming control (SW7) must be set before the board is powered.

Step 1. Toggle SPDT switch SW6 to select between digital and analog dimming.

Table 3. SW6 switch for digital or analog dimming

Switch position	Digital (PWM) dimming	Analog dimming
1:2	×	TRUE
3:2	TRUE	×

Step 2. Toggle SPDT switch SW7 to select between external signal and user button for dimming control.

Table 4. SW7 switch for external signal or push button control

Switch position	External signal (0-10 V _{DC} or PWM)	Push button
1:2	TRUE	×
3:2	×	TRUE

Step 3. Toggle SPDT switch SW5 to select between 0-10 V_{DC} and PWM (3.3 V) inputs for external signal dimming control.

The signals are delivered through the following jumpers:

- J6 - PWM (3.3 V)
- J7 - 0-10 V_{DC}

Table 5. SW5 switch for 0-10V or PWM external signal control

Switch position	0-10V input (J7)	PWM input (J6)
1:2	×	TRUE
3:2	TRUE	×

3 Interfaces

3.1 User interface buttons

The evaluation board has three push buttons you can use to select specific dimming levels. By default, the brightness level on startup is 100%.

Note: Before powering up the evaluation board, ensure SPDT switch SW7 is at position 3:2 to toggle enable push button control.

Table 6. User interface button functions

User Interface button	Function
SW1	Decrease brightness level
SW2	Increase brightness level
SW3 ⁽¹⁾	String selection

1. The string selection feature is for digital dimming only; i.e., SPDT switch SW6 set to position 3:2.

Table 7. LED string selection for dimming

SW3–Push button	LED string selection to be dimmed
Default	Buck converter string is dimmed Inverse-Buck converter is dimmed
1 st Press	Buck converter string is dimmed
2 nd Press	Inverse-Buck converter string is dimmed
3 rd Press	Buck converter string is dimmed Inverse-Buck converter string is dimmed

Table 8. Level number vs brightness

Level Number	Brightness Level	PFC mode of operation
1	0.5%	Discontinuous
2	1%	Discontinuous
3	5%	Discontinuous
4	10%	Discontinuous
5	25%	Transition
6	50%	Transition
7	75%	Transition
8	90%	Transition
9 (default)	100%	Transition

3.2 0–10V Interface

The evaluation board is equipped with an isolated 0–10V interface. The brightness level of both buck and inverse-buck converter can be adjusted by controlling the voltage at the 0–10V input with a resolution of 0.1%.

Before powering up the evaluation board, ensure SPDT switch SW7 position is 1:2 to enable brightness control through the 0–10V interface.

The PFC section automatically manages the change between Transition Mode and Discontinuous Mode, depending on the input mains voltage and the brightness level.

4 Firmware implementation

The PFC converter, two DC-DC converters, dimming provision and safety mechanisms are all controlled by the STM32 microcontroller.

The following flowcharts summarize the firmware logic.

Figure 5. STEVAL-LLL004V1 firmware flowchart - I

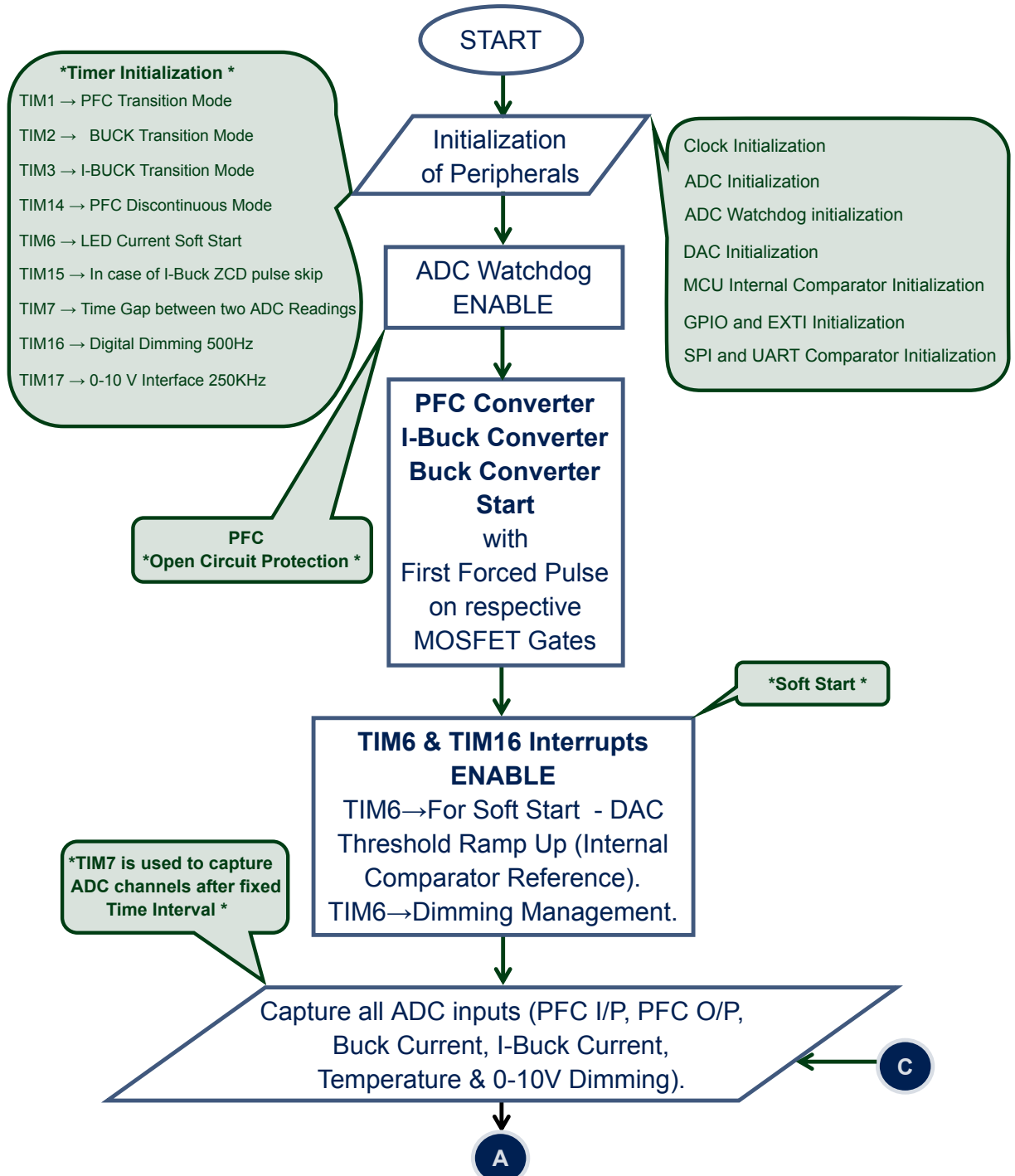
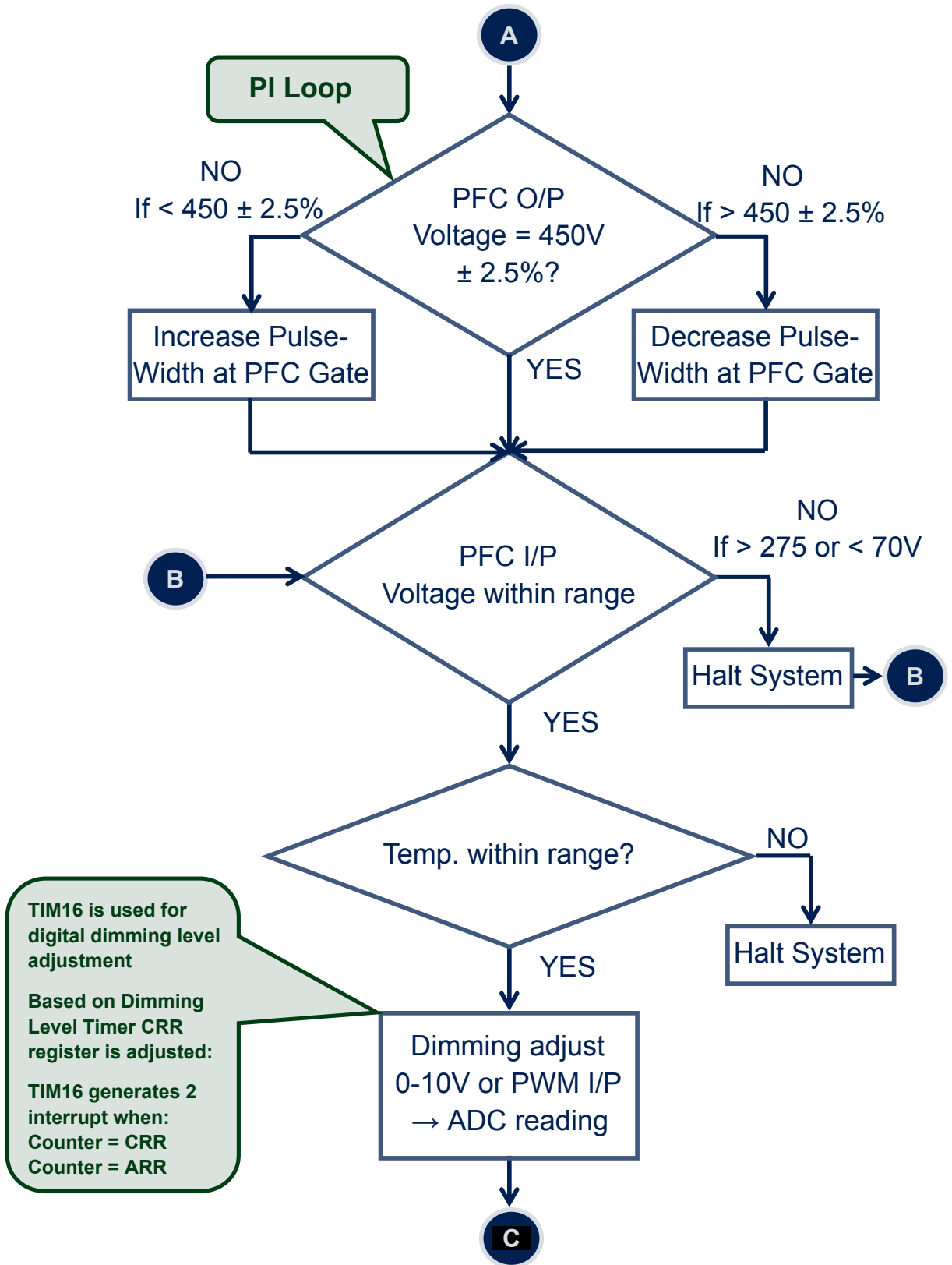


Figure 6. STEVAL-LLL004V1 firmware flowchart - II



5 STEVAL-LLL004V1 layout

Figure 7. STEVAL-LLL004V1 layout top layer silk screen and drill

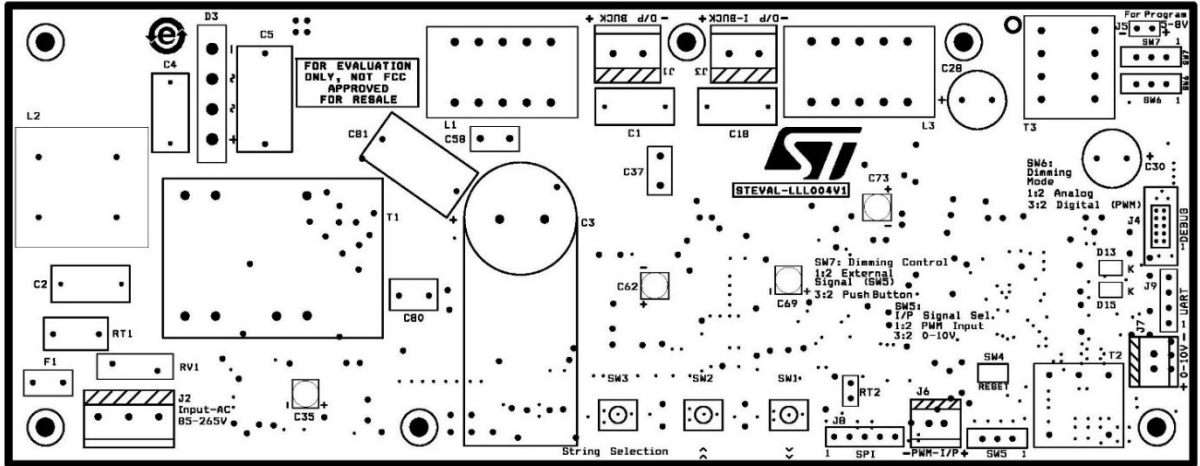


Figure 8. STEVAL-LLL004V1 layout top layer

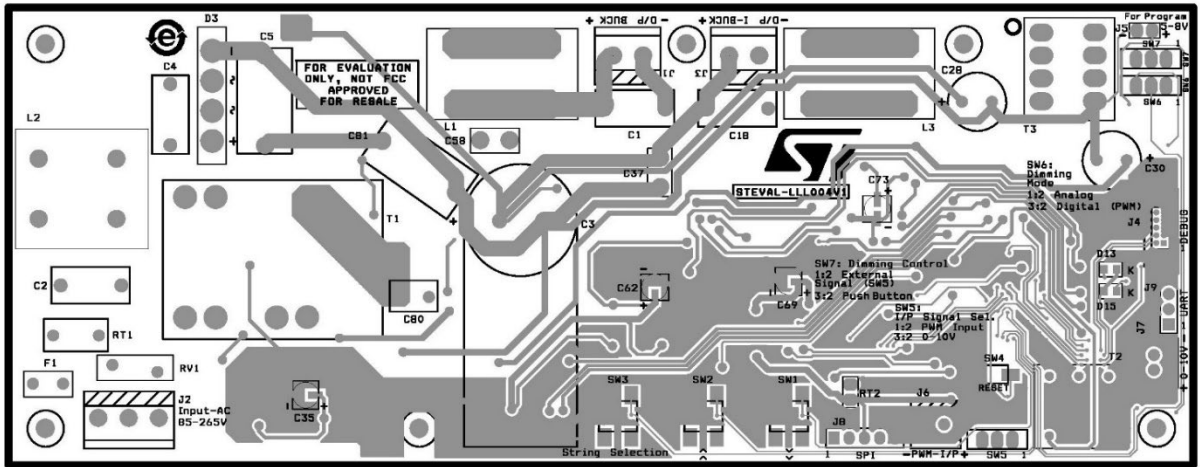


Figure 9. STEVAL-LLL004V1 layout bottom layer silk screen and drill

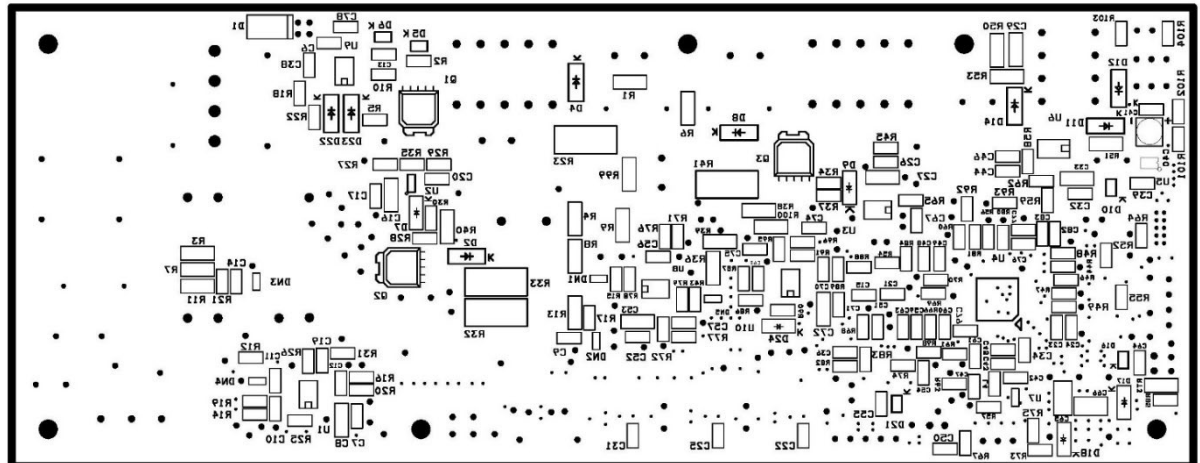
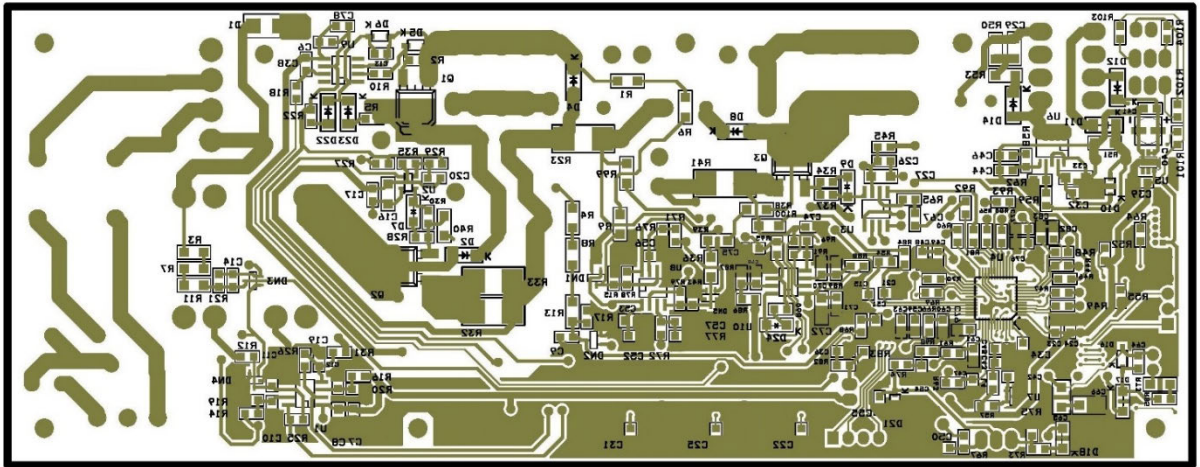


Figure 10. STEVAL-LLL004V1 layout bottom layer



6 STEVAL-LLL004V1 schematic diagrams

Figure 11. STEVAL-LLL004V1 schematic - PFC converter

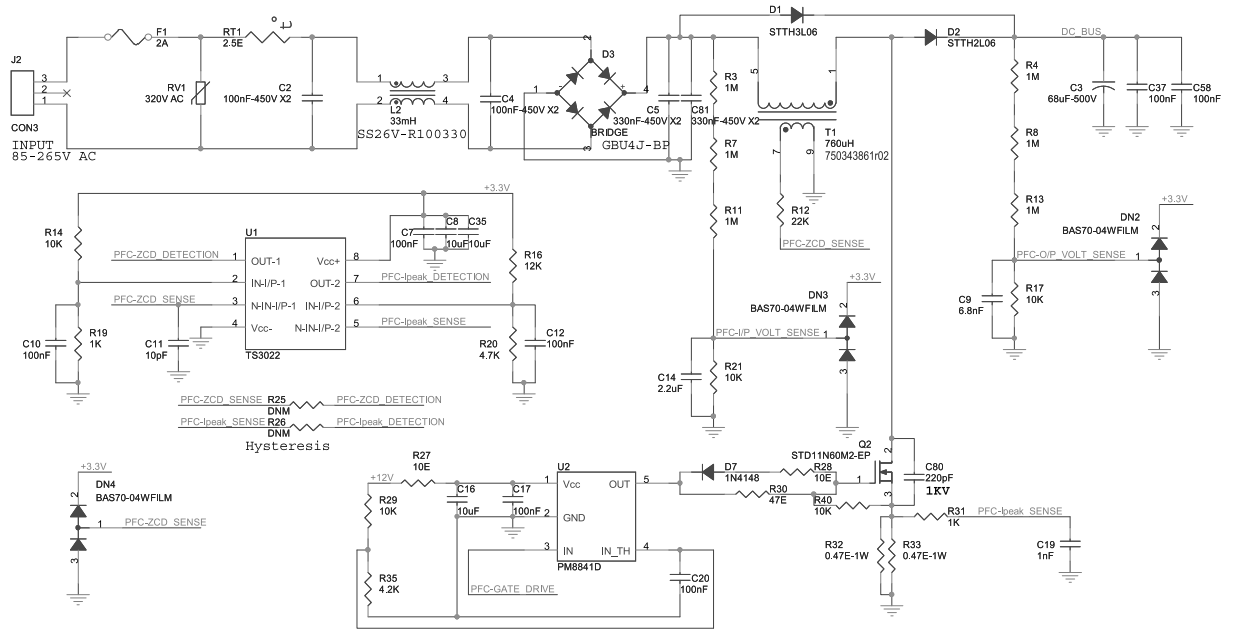


Figure 12. STEVAL-LLL004V1 schematic - inverse buck converter

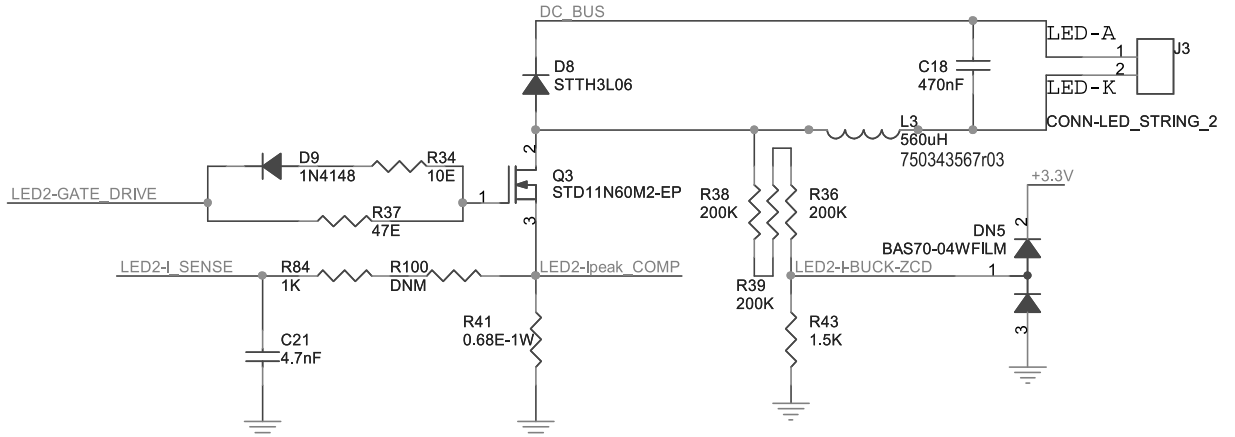
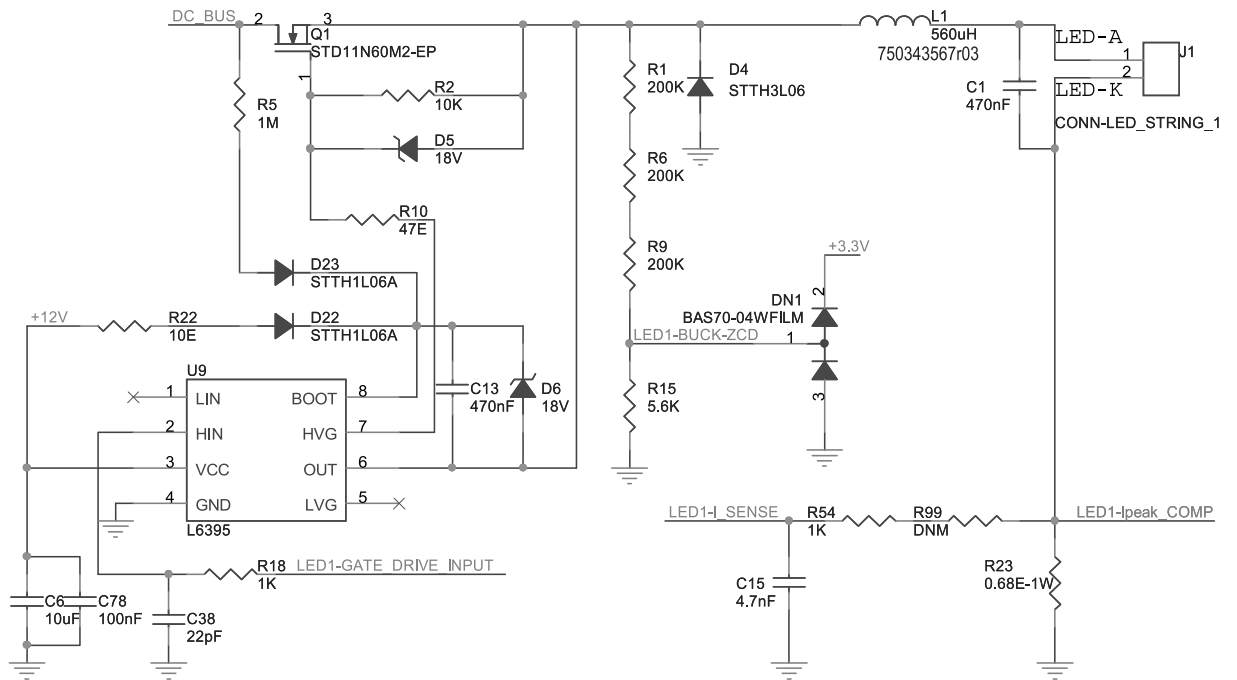
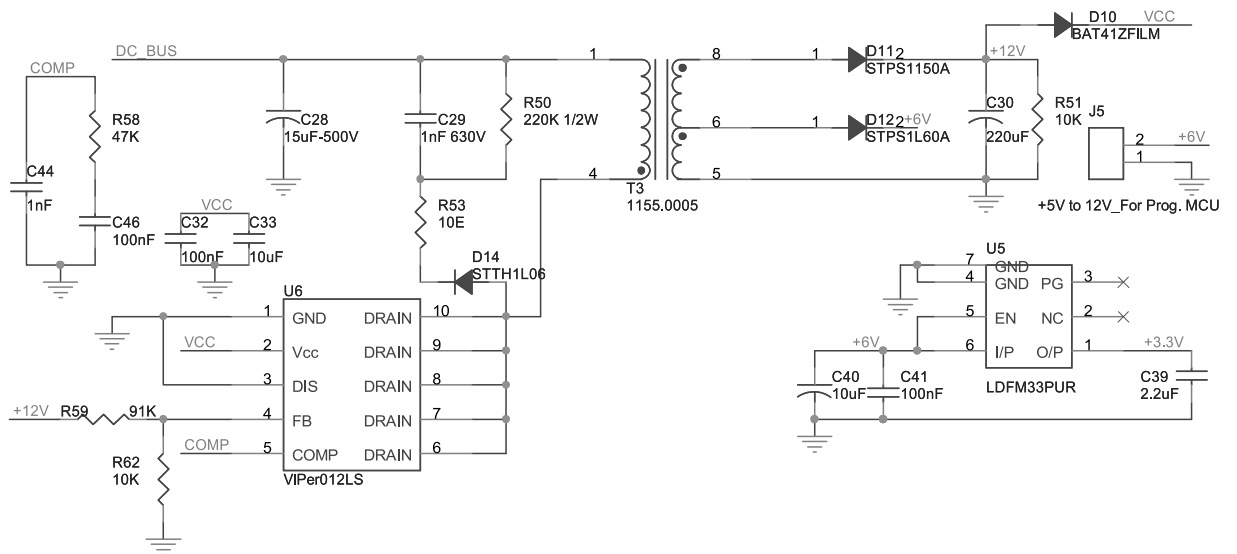


Figure 13. STEVAL-LLL004V1 schematic - buck converter

Figure 14. STEVAL-LLL004V1 schematic - auxiliary power supply


7 Bill of materials

Table 9. STEVAL-LLL004V1 bill of materials

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
1	3	U1, U8, U10		Rail-To-Rail 1.8 V High-Speed Dual Comparator	ST	TS3022IDT
2	1	U2	1A	1 A Low-Side Gate Driver	ST	PM8841D
3	1	U3	4A	4 A Dual Low-Side MOSFET Driver	ST	PM8834TR
4	1	U4		ARM®-based 32-bit MCU	ST	STM32F071CBT6
5	1	U5	3.3V	500 mA very Low Drop Voltage Regulator	ST	LDFM33PUR
6	1	U6	240mA	Energy Saving Off-Line High Voltage Converter	ST	VIPer012LS(TR)
7	1	U7		Dual Transil™ Array For ESD Protection	ST	ESDA5V3L
8	1	U9		High Voltage High And Low-Side Driver	ST	L6395D
9	3	Q1, Q2, Q3	600V	N-channel Power MOSFET In A DPAK Package	ST	STD11N60M2-EP
10	3	D14, D22, D23		Turbo 2 Ultrafast High Voltage Rectifier	ST	STTH1L06A
11	1	D10		Low Capacitance Small Signal Schottky Diodes	ST	BAT41ZFILM
12	1	D11	150V	Power Schottky Rectifier	ST	STPS1150A
13	1	D12	60V	Power Schottky Rectifier	ST	STPS1L60A
14	5	DN1, DN2, DN3, DN4, DN5		Low Capacitance, Low Series Inductance And Resistance Schottky Diodes	ST	BAS70-04FILM
15	3	D1, D4, D8		Turbo 2 Ultrafast High Voltage Rectifier	ST	STTH3L06U
16	1	D2		High Efficiency Ultrafast Diode	ST	STTH2L06A
17	2	C1, C18	470nF, 450VDC, ±10%	Film Capacitors	PANASONIC ELECTRONIC COMPONENTS	ECW-FD2W474Q1
18	2	C2, C4	100nF, 305 VAC, ±20%	Film Capacitors 10mm L/S Class X2	EPCOS / TDK	B32921C3104M

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
19	1	C3	68 μ F, 500V, \pm 20%	Aluminum Electrolytic Capacitors	NICHICON	UCY2H680MHD
20	2	C5, C81	330nF, 305VAC, \pm 20%	Film Capacitors	EPCOS (TDK)	B32922C3334M000
21	6	C8, C16, C27, C33, C53, C72	10 μ F, 50V, \pm 20%	Multilayer Ceramic Capacitors	ANY	ANY
22	1	C6	10 μ F, 35V, \pm 20%	Ceramic Capacitors	ANY	ANY
23	5	C35, C40, C62, C69, C73	10 μ F, 35V, \pm 20%	Aluminum Electrolytic Capacitors	PANASONIC	EEE-FK1V100UR
24	34	C7, C10, C12, C17, C20, C22, C23, C25, C26, C31, C32, C36, C41, C42, C43, C46, C47, C48, C50, C51, C52, C54, C55, C56, C57, C59, C63, C64, C68, C70, C71, C76, C78, C79	100nF, 50V, \pm 10%	Ceramic Capacitors	ANY	ANY
25	2	C37, C58	100nF, 630V, \pm 10%	Multilayer Ceramic Capacitors MLCC - Leaded	MURATA ELECTRONIC S	RDER72J104K4K1H03 B
26	1	C9	6.8nF, 25V, \pm 10%	Ceramic Capacitors	ANY	ANY
27	3	C11, C74, C75	10pF, 25V, \pm 10%	Ceramic Capacitors	ANY	ANY
28	1	C13	470nF, 50V, \pm 10%	Ceramic Capacitors	ANY	ANY
29	2	C14, C39	2.2 μ F, 25V, \pm 10%	Ceramic Capacitors	ANY	ANY
30	2	C15, C21	4.7nF, 16V, \pm 10%	Ceramic Capacitors	ANY	ANY
31	3	C19, C44, C67	1nF, 25V, \pm 10%	Ceramic Capacitors	ANY	ANY
32	2	C65, C66	1nF, 2KV, \pm 5%	Ceramic Capacitors	AVX Corporation	1210GC102KAT1A
33	5	C24, C34, C45, C49, C77	1 μ F, 16V, \pm 10%	Ceramic Capacitors	ANY	ANY
34	1	C28	15 μ F, 500V, \pm 20%	Aluminum Electrolytic Capacitors	NICHICON	UCY2H150MHD
35	1	C29	1nF, 630V, \pm 5%	Ceramic Capacitors	TDK CORPORATION	C3216C0G2J102J085 AA
36	1	C30	220 μ F, 63V, \pm 20%	Aluminum Electrolytic Capacitors	Nichicon	UPW1J221MPD
37	1	C38	22pF, 16V, \pm 10%	Ceramic Capacitors	ANY	ANY
38	4	C60, C61, C82, C83	100pF, 16V, \pm 10%	Ceramic Capacitors	ANY	ANY

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
39	1	C80	220pF, 2KV, ±5%	Film Capacitors	MURATA ELECTRONICS	DEA1X3D221JA2BS
40	1	D3	4A/600V	Bridge Rectifiers	MICRO COMMERCIAL COMPONENTS (MCC)	GBU4J-BP
41	2	D5, D6	18V, 500mW, ±5%	Diodes - Zener - Single	ON SEMICONDUCTOR	MMSZ5248BT1G
42	4	D7, D9, D17, D18	1N4148, 75V	Switching Diode	Nexperia USA Inc.	PMLL4148L,115
43	1	D13	1.8V/20mA	LED Red Diffused	OSRAM OPTO SEMICONDUCTORS INC.	LH R974-LP-1
44	1	D15	2.2V/20mA	LED Green Diffused	OSRAM OPTO SEMICONDUCTORS INC.	LG R971-KN-1
45	1	D16	12V, 1/2 W, ±5%	Zener Diodes	VISHAY SEMICONDUCTORS	MMSZ4699-E3-18
46	1	D21	3.6V, 500 mW, ±5%	Zener Diode	ON SEMICONDUCTOR	MMSZ4685T1G
47	1	D24	Do not mount			
48	1	F1	2A, 2A/300V	Fuses with Leads	LITTLEFUSE	36912000000
49	2	J1, J3	10A/300V	Connector - LED Output: Fixed Terminal Blocks 2P 5.08mm	PHOENIX CONTACT	651-1888687
50	1	J2	20A/300V	Connector - AC Input: Conn Term Block 3Pos 5.08mm	PHOENIX CONTACT	1888690
51	1	J4		Header 5X2: Box Header,0.050 10 POS	CNC Tech	3220-10-0100-00
52	1	J5		Header 2x1: 2.54 mm Pitch Berg Stick Male	ANY	ANY
53	1	J6	PWM Input	Terminal Blocks 2Pos 2.54mm	ANY	ANY
54	1	J7	0-10V Input	Terminal Blocks 2Pos 2.54mm	ANY	ANY
55	1	J8	Do not mount	Header 5x1: 2.54 mm Pitch Berg Stick Male		
56	1	J9	Do not mount	Header 4x1: 2.54 mm Pitch Berg Stick Female		

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
57	2	L1, L3	560µH	Inductor	WURTH ELECTRONIC S	750343567r03
58	1	L2	33mH, 1A	Common Mode Choke	KEMET	SS26V-R100330
59	1	L4	10µH - BEAD, 150mA, ±10%	Fixed Inductor	TAIYO YUDEN	LBR2012T100K
60	6	MH1, MH2, MH3, MH4, MH5, MH6		Mounting Holes Diameter=3.5mm: Screws and Nuts	ANY	ANY
61	1	RT1	2.5E, 230 V AC	Inrush Current Limiters	EPCOS / TDK	B57364S259M54
62	1	RT2	Do not mount	Header 2x1: 2.54 mm Pitch Berg Stick Male		
63	5	R25, R26, R90, R99, R100	Do not mount	Thick Film Resistors		
64	12	R2, R14, R17, R21, R29, R62, R67, R71, R74, R83, R86, R88	10K, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
65	2	R40, R51	10K, 1/4 W, ±1%	Thick Film Resistors	ANY	ANY
66	1	RT3	30V/0.12A	Fuse	BOURNS INC.	MF-NSMF012-2
67	1	RV1	DISC 10mm, 320V AC	Varistor	ANY	ANY
68	6	R1, R6, R9, R36, R38, R39	200K, 1/4 W, ±1%	Thick Film Resistors	ANY	ANY
69	2	R78, R79	200K, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
70	1	R5	1M, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
71	6	R3, R4, R7, R8, R11, R13	1M, 1/4 W, ±1%	Thick Film Resistors	ANY	ANY
72	3	R10, R30, R37	47E, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
73	1	R12	22K, 1/8W, ±5%	Thick Film Resistors	ANY	ANY
74	1	R15	5.6K, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
75	1	R16	12K, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
76	18	R18, R19, R31, R47, R48, R49, R54, R60, R61, R63, R64, R66, R68, R80, R81, R82, R84, R98	1K, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
77	7	R20, R57, R77, R101, R102, R103, R104	4.7K, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
78	5	R22, R27, R28, R34, R45	10E, 1/8W, ±1%	Thick Film Resistors	ANY	ANY
79	1	R53	10E, 1/2W, ±1%	Thick Film Resistors	STACKPOLE ELECTRONIC S INC.	RNCP1206FTD10R0

Item	Q.ty	Ref.	Part / Value	Description	Manufacturer	Order code
80	2	R23, R41	0.68E, 1W, $\pm 1\%$	Thick Film Resistors	PANASONIC ELECTRONIC COMPONENTS	ERJ-1TRQFR68U
81	2	R32, R33	0.47E, 1W, $\pm 1\%$	Thick Film Resistors	PANASONIC ELECTRONIC COMPONENTS	ERJ-1TRQFR47U
82	1	R35	4.2K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
83	1	R43	1.5K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
84	9	R44, R46, R56, R69, R70, R92, R93, R95, R96	100E, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
85	1	R50	220K, 1/4W, $\pm 1\%$	Thick Film Resistors	PANASONIC INDUSTRIAL DEVICES	ERJ-8ENF2203V
86	2	R52, R76	560E, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
87	1	R55	470E, 1/8W, $\pm 5\%$	Thick Film Resistors	ANY	ANY
88	1	R58	47K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
89	1	R59	91K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
90	1	R65	510E, 1/8W, $\pm 5\%$	Thick Film Resistors	ANY	ANY
91	1	R72	11K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
92	1	R73	24K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
93	1	R75	18K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
94	1	R85	680E, 1/8W, $\pm 5\%$	Thick Film Resistors	ANY	ANY
95	1	R87	9.1K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
96	1	R89	6.8K, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
97	1	R91	22E, 1/8W, $\pm 1\%$	Thick Film Resistors	ANY	ANY
98	3	SW1, SW2, SW3	0.05A/24VDC	SW PUSHBUTTON: Switch Tactile SPST	TE Connectivity ALCOSWITCH SWITCHES	FSM4JSMATR
99	1	SW4	0.05A/12VDC	SPST: Tactile Switches	WURTH ELECTRONICS	732-7047-1-ND
100	3	SW5, SW6, SW7	12 VDC	SW KEY-SPDT: Slide Switches	EAO	09.03290.01
101	1	T1	760 μ H	PFC Transformer	WURTH ELECTRONICS	750343861r02
102	1	T2	0-10V	Isolation Transformer	WURTH ELECTRONICS	750510642r00
103	1	T3	2.5mH	Flyback Transformer	AQ Magnetica Italy	1155.0005

8 References

The following reference documents are freely available on www.st.com.

1. AN2928 – Modified buck converter for LED applications
2. AN3009 – How to design a transition mode PFC pre-regulator using the L6564
3. AN4776 – General-purpose timer cookbook

Revision history

Table 10. Document revision history

Date	Version	Changes
15-Nov-2018	1	Initial release.

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