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AN4314
Application note

25 W wide-range high power factor buck-boost converter demonstration board using the L6564H

Introduction

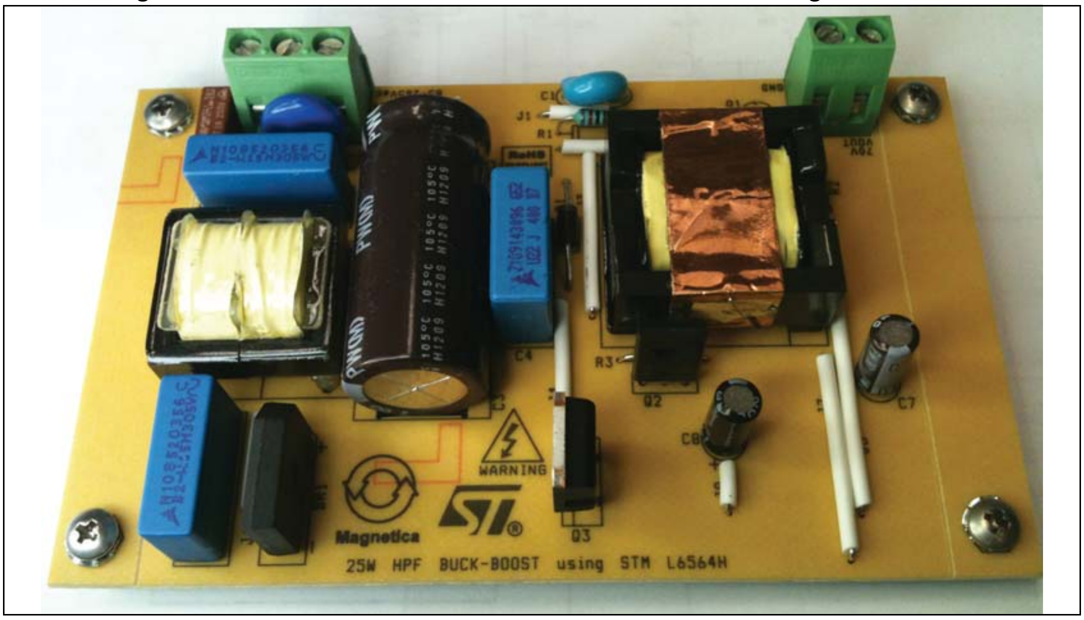
This application note describes a wide-range non-isolated 25 W regulated LED driver with high power factor. The EVL6564H-25W-BB demonstration board is well-suited to the Japanese market due to the broad use of standard 100 V_{ac} lighting applications and also 200 V_{ac} tubes in building automation systems.

The EVL6564H-25W-BB demonstration board has been designed in order to obtain the highest possible power factor over the entire input mains voltage, remaining compliant to EN55022 Class-B and keeping the average output current in a tight band with different LED characteristics.

The board is based on ST's L6564H power factor controller and the SEA05L CC-CV controller for LED current regulation in a non-isolated flyback configuration.

The form factor has been designed to fit into a standard LED driver case, facilitating the replacement of the incandescent flood lamps up to 80-100 W power.

Figure 1. EVL6564H-25W-BB demonstration board using the L6564H



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1 Main characteristics and circuit

The main characteristics of this single-stage LED driver demonstration board are given in the table below.

Table 1. Main characteristics and circuit

Parameter	Value
Line voltage range	85 to 265 V_{AC}
Line frequency (fL)	47-63 Hz
LED string voltage drop	70 V ±10 % (23-LED p.n. X42182) [6]
LED nominal current	350 mA ±3 %
LED current ripple pk-pk	100 mA
Rated output power	25 W
Power factor	> 0.9
Efficiency	> 89 @ 230 V
Maximum ambient temperature	50 °C
Conducted EMI	In accordance with EN55022 Class-B
Protections	Preventing overvoltage, load disconnection and short-circuit

The main feature of the converter is that the input current is almost in phase with the mains voltage; therefore the power factor is close to unity. This is achieved by the L6564H controller, which shapes the input current as a sine wave in phase with the mains voltage. An external high-voltage startup circuitry is not needed because it is already embedded in the IC.

The power supply utilizes a typical non-isolated buck-boost converter topology with a simple inductor to transfer energy to the LED load.

The converter is connected after the mains rectifier and the capacitor filter, which in this case is quite small, to avoid damage to the shape of the input current. The buck-boost switch is represented by the power MOSFET Q3 and driven by the L6564H.

At startup, a 0.85 mA internal current source of the L6564H charges the V_{CC} capacitor (C8), until the voltage on the V_{cc} pin reaches the startup threshold, then it is shut down.

The T1 auxiliary winding (pins 6-7), the charge pump (C14, R16, D4) and the BJT voltage regulator (Q2, DZ2, R3) generate a constant V_{CC} voltage that powers the L6564H during normal TM operation.

R37 is also connected to the auxiliary winding to provide the transformer demagnetization signal to the L6564H ZCD pin, turning on the MOSFET at any switching cycle. The MOSFET used is the STI8N65M5, a new MDmesh™ V, low-cost, low on-resistance, 710 V device housed in an I^2PAK package [5], and without any heatsink.

The multilayer inductor, using a standard ferrite size EF-25, is manufactured by Magnetica.

The resistors R27 and R26 sense the current flowing into the inductor primary side. Once the signal at the current sense pin has reached the level programmed by the internal multiplier of the L6564H, the MOSFET turns off.

The divider R13, R14, R15 and R30 provides the L6564H multiplier pin with instantaneous voltage information which is used to modulate the current flowing into the inductor.

To maintain a constant (average) output current, some kind of regulation is required and for this reason, on the output side, an error amplifier (inside the SEA05L) senses the LED current on sense resistors R6, R7, and it drives the input of the internal error amplifier of the L6564H. As a consequence, the PWM comparator is modulated too.

The inductor T1 is charged by Q3 when it is turned on, and it discharges into the output capacitor C3 and into the LED load when Q3 turns off.

Due to the topology, the LED string load is connected to a floating output so the loop is closed through a current mirror formed by two high-voltage BJTs (Q4, Q5). For the constant current regulation an SEA05L CC-CV has been used. The current loop regulates the LED current at a nominal level of 350 mA, the nominal voltage drop of the LED string is 70 V_{dc} with a tolerance of 10 %. Normally the voltage loop does not operate in the range 63 V - 77 V_{dc}, but it works in case the LED string opens to protect the output bulk capacitor C3 from overvoltage. The R8, R9 divider senses the output voltage and regulates the output voltage to around 84 V_{dc}.

In case one of the loops fails and the output voltage is no longer regulated, a protection preventing an open loop is performed using the PFC_OK pin, the L6564H sensing the increase of the auxiliary winding voltage.

The board is equipped with an input EMI pi-filter stage (C2-L1-C6) connected after the input connector. An input fuse and a varistor (VR1) are also provided at the input of the board, protecting from short-circuits and improving immunity against input voltage fast transients.

In order to prevent a short-circuit of the output stage, an external, low-cost circuit (composed of Q6, Q9, Q8, R23, R24, R32, R20, D3, D8, R40) disables the L6564H using the PFC_OK pin. The circuit is composed of a buffer stage (Q6, R23) connected to the feedback loop. When Q9 is off, a current through the R32 resistor connected to VCC_PROT will charge the C7 capacitor up to a voltage level imposed by the sum of two diode voltage drops (D7 + D3). At that voltage level, the transistor Q8 will switch on and it pulls the PFC_OK pin to ground, disabling the L6564H controller. Removing the short, the C7 capacitor will discharge through R40 connected to the Gate Drive pin during the MOSFET off-time (low state).

The time constant R32 with C7 is set in order to mask the transition time during startup. In fact during this time phase, when the loop is still open, the feedback signal is still low and it could activate the protection unnecessarily.

The board has been designed using the procedure described in AN1059 [*1*] used to design a standard high-power factor flyback. This application note has been used as a reference for calculating this demonstration board, since the buck-boost topology can be considered as a simple flyback with a unity transformer turn ratio and with the output voltage corresponding to the reflected voltage of the flyback.

A description of the dimensioning of the output capacitor and the LED current ripple definition appears in *Section 2* as it is not included in AN1059 [*1*].

2 LED current ripple definition

In a typical LED application the definition of ripple current must be carefully considered. We have defined a current ripple lower than 100 mA pk-pk, corresponding to about 30 % of the average LED current. This parameter depends only on two factors, one is linked to the load and the other to the converter as follows:

- the dynamic resistance of the LED string R_{Dtot}
- the output capacitor value of the converter C_o

The following formula describes the relation between the current ripple and the previous two factors:

Equation 1

$$I_{ripple} \propto \frac{I_{OUT}}{\sqrt{1+(4 \cdot \pi \cdot f_l \cdot R_{Dtot} \cdot C_O)^2}}$$

First, note that the value of the output capacitor will depend on the load so it is important to know the final application of the converter.

Second, the form factor of the converter will depend on the output capacitor size and, as a consequence, on the output current ripple specification.

In this application a 680 μF capacitor has been selected in order to maintain the current ripple below 100 mA.

3 Electrical diagram and bill of material

Figure 2. EVL6564H-25W-BB demonstration board: electrical schematic

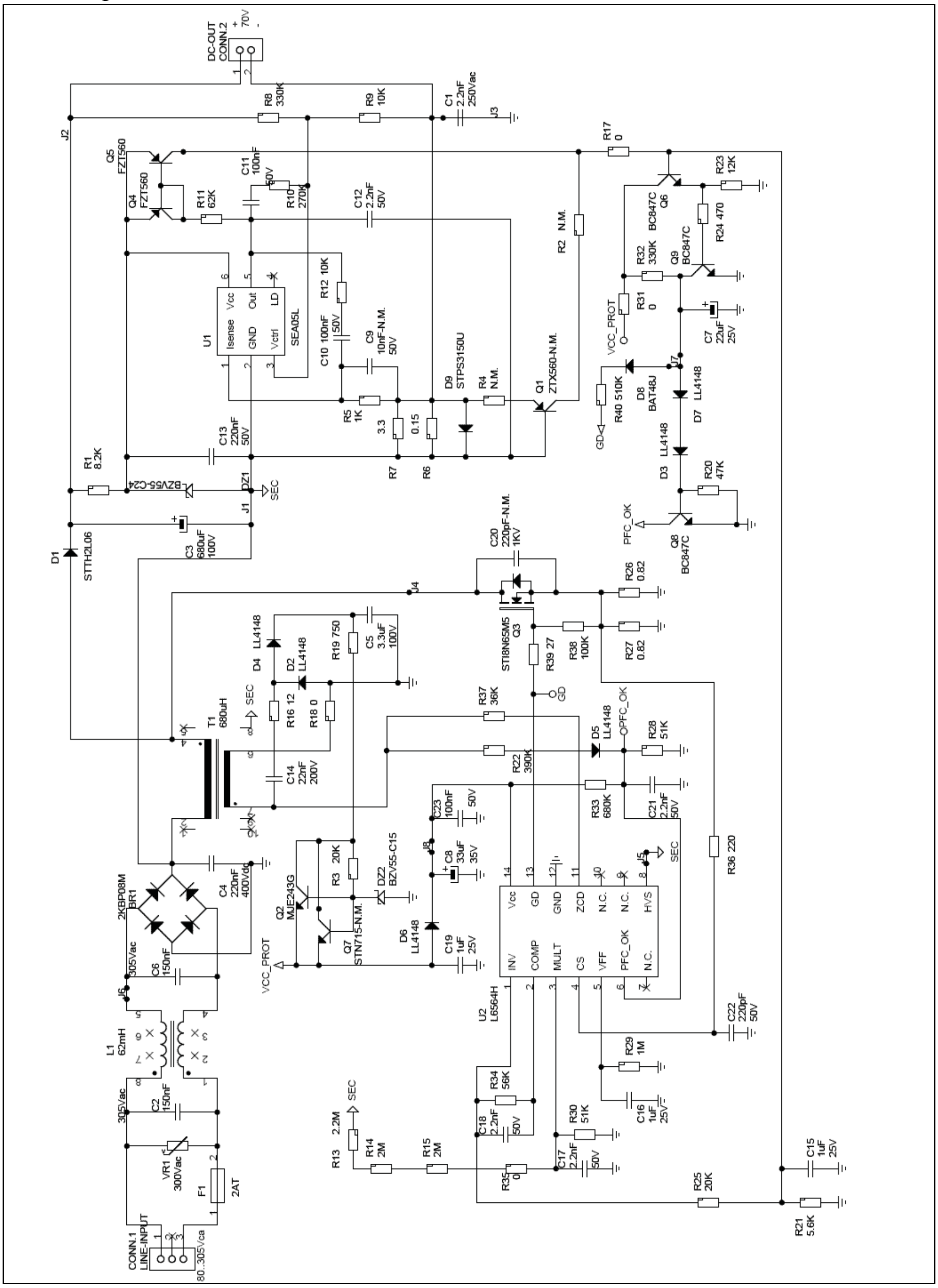


Table 2. Bill of material

Ref.	Part N.	Type	Supplier
BR1	2KBP08M	Bridge rect. 2 A 800 V	Vishay
Conn.1	Line-input	Connector MKDS 1.5/3-5.08-PS.5.08	Phoenix contact
Conn.2	DC-OUT	Connector MKDS 1.5/2-5.08-PS.5.08	Phoenix contact
C1	2.2 nF	Ceramic capacitor X1/Y2+-20%-P.7,5 mm	Murata
C2	150 nF	Capacitor MKP+-20%-PS15-X2	Epcos
C6	150 nF	Capacitor MKP+-20%-PS15-X2	Epcos
C3	680 uF	Electrolytic capacitor V.105 °C-PW-8000h	Nichicon
C4	220 nF	Capacitor MKP+-5%-200 V_{ac}-PS15	Epcos
C5	3.3 uF	Ceramic capacitor X7S 10% EIA1210-SMD	Kemet
C7	22 uF	Electrolytic capacitor V.105 °C-2000h-PW	Nichicon
C8	33 uF	Electrolytic capacitor V.105 °C-10000h-YXM	Rubycon
C9	10 nF N.M.	Capacitor X7R 10% EIA0805-SMD	Murata
C10	100 nF	Ceramic capacitor X7R 10% EIA1206-SMD	Yageo
C11	100 nF	Ceramic capacitor X7R 10% EIA0805-SMD	Kemet
C23	100 nF	Ceramic capacitor X7R 10% EIA0805-SMD	Kemet
C12	2.2 nF	Capacitor X7R 10% EIA0805-SMD	Kemet
C17	2.2 nF	Capacitor X7R 10% EIA0805-SMD	Kemet
C18	2.2 nF	Capacitor X7R 10% EIA0805-SMD	Kemet
C21	2.2 nF	Capacitor X7R 10% EIA0805-SMD	Kemet
C13	220 nF	Ceramic capacitor Y5V -20+80% EIA0805-SMD	AVX
C14	22 nF	Ceramic capacitor X7R 5% EIA1206-SMD	Kemet
C15	1 μF	Ceramic capacitor X7R 10%-EIA0805-SMD	Murata
C16	1 μF	Ceramic capacitor X7R 10%-EIA0805-SMD	Murata
C19	1 μF	Ceramic capacitor X7R 5%-EIA0805-SMD	Kemet
C20	220 pF N.M.	Capacitor HV-U2J-5% EIA1206-SMD	Murata
C22	220 pF	Ceramic capacitor C0G 5% EIA0805-SMD	Kemet
DZ1	BZV55-C24	Zener-diode 5%-Sz 19.6 mV/K-SMD	NXP
DZ2	BZV55-C15	Zener-diode 5%-Sz 11.4 mV/K-SMD	NXP
D1	STTH2L06	Ultrafast-diode 85 ns	STMicroelectronics
D2	LL4148	Fast-diode 4 ns-SMD	Vishay
D3	LL4148	Fast-diode 4 ns-SMD	Vishay
D4	LL4148	Fast-diode 4 ns-SMD	Vishay
D5	LL4148	Fast-diode 4 ns-SMD	Vishay
D6	LL4148	Fast-diode 4 ns-SMD	Vishay
D7	LL4148	Fast-diode 4 ns-SMD	Vishay

Table 2. Bill of material (continued)

Ref.	Part N.	Type	Supplier
D8	BAT48J	Schottky-diode SMD-MK 48	STMicroelectronics
D9	STPS3150U	Schottky-diode V_f 0, 82 V @ 25 °C 3 A-SMD-MKG315	STMicroelectronics
F1	2AT	Fuse 2 A 250 V 8.5 x 4-392/TE05-TIME-LAG	Littelfuse
J1	PS10 mm	Wire jumper 0 Ω	-
J2	PS30 mm	Wire jumper 0 Ω	-
J3	PS23 mm	Wire jumper 0 Ω	-
J4	PS20 mm	Wire jumper 0 Ω	-
J5	PS29 mm	Wire jumper 0 Ω	-
J6	PS12 mm	Wire jumper 0 Ω	-
J7	PS24 mm	Wire jumper 0 Ω	-
J8	PS5 mm	Wire jumper 0 Ω	-
L1	62 mH	Common mode chokes-270 $V_{ac\ max}$	Magnetica
Q1	ZTX560-N.M.	BJT.PNP-hfe 50 to 300	Diode Inc.
Q2	MJE243G	BJT.NPN-hfe 40 to 180	ON
Q3	STI8N65M5	MOSFET-N-0.6 Ω-tr/tf 14/11 ns-trr 200 ns	STMicroelectronics
Q4	FZT560	BJT.PNP-SMD-hfe 50 to 300	Diode Inc.
Q5	FZT560	BJT.PNP-SMD-hfe 50 to 300	Diode Inc.
Q6	BC847C	BJT.NPN-hfe 420 to 800-SMD-MK1G	NXP
Q8	BC847C	BJT.NPN-hfe 420 to 800-SMD-MK1G	NXP
Q9	BC847C	BJT.NPN-hfe 420 to 800-SMD-MK1G	NXP
Q7	STN715-N.M.	BJT.NPN-SMD-hfe80-MK N715	STMicroelectronics
R1	8.2 K	Resistor 1%	TE-LR1F8K2
R2	N.M.	Resistor 1%	TE-LR1F8K2
R3	20 K	Resistor 1%	TE-LR1F20K
R4	N.M.	Resistor 1%-150$V_{ac/dc}$ -EIA0805-SMD	Vishay
R5	1 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R6	0.15	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	IRC-LRC
R7	3.3	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R8	330 K	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R9	10 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R10	270 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R11	62 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R12	10 K	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay

Table 2. Bill of material (continued)

Ref.	Part N.	Type	Supplier
R13	2.2 M	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R14	2 M	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R15	2 M	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R16	12	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R17	0	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R18	0	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R31	0	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R19	750	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R20	47 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
[(1)]C//R20	10 nF	Ceramic capacitor X7R 10% EIA0805-SMD	Kemet
R21	5.6 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R22	390 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R23	12 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R24	470	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R25	20 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R26	0.82	Resistor 1% EIA1210-SMD	Rohm
R27	0.82	Resistor 1% EIA1210-SMD	Rohm
R28	51 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R29	1 M	Resistor 1%-50 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R30	51 K	Resistor 1%-50 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R32	330 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R33	680 K	Resistor 1%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R34	56 K	Resistor 5% -150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R35	0	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R36	220	Resistor 5%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R37	36 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R38	100 K	Resistor 5%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
R39	27	Resistor 5%-200 $V_{ac/dc}$ -EIA1206-SMD	Vishay
R40	510 K	Resistor 1%-150 $V_{ac/dc}$ -EIA0805-SMD	Vishay
T1	680 uH	Lighting buck/boost inductor 40 kHz	Magnetica
U1	SEA05L	I.C.-CC/CV controller 3.5 to 36 V-V_{ac} 0.5%-I_{acc} 4%-MK S5L-SMD	STMicroelectronics
U2	L6564H	I.C.-PFC controller HVS-TM-SMD	STMicroelectronics
VR1	300 V_{ac}	VDR-300 V_{ac}-385 V_{dc}-47J-D12 mm	Epcos

1. Add a 10 nF capacitor in parallel to R20 (0805).

4 Performance and considerations with LED loads

The board has been designed to source 350 mA nominal value into a string of 23 LEDs of about 1 W power and a forward drop of 3.2 V typical at ambient temperature. The LEDS used to test the demonstration board have been furnished by Seoul Semiconductor (part number X42182) [6].

In order to reproduce the possible LED string drop variation due to thermal heating of a single LED, measurements have been done first by loading the SMPS with a string of 23 LEDs having a voltage drop of 71 V_{dc}, then loading 22 LEDs (68 V_{dc}) and finally 24 (75 V_{dc}). The behavior of the board has been checked also at the limit of the LED tolerance of the voltage drop, at -10 %, that is, 63 V_{dc} and +10 %, that is, 77 V_{dc} by using an active load.

Figure 3 represents the different load voltage drops of the LEDs, applied to the converter, at each point of the wide-range mains. This figure is necessary to understand the following *Figure 4*, *5*, *6* and *7*.

Figure 3. LED string voltage vs. line voltage

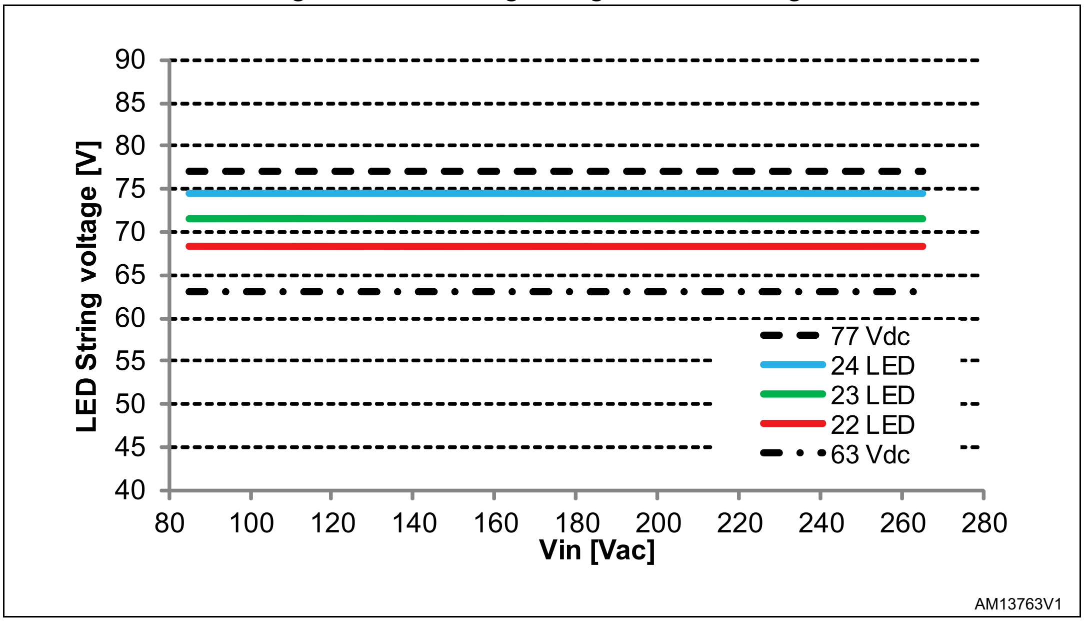


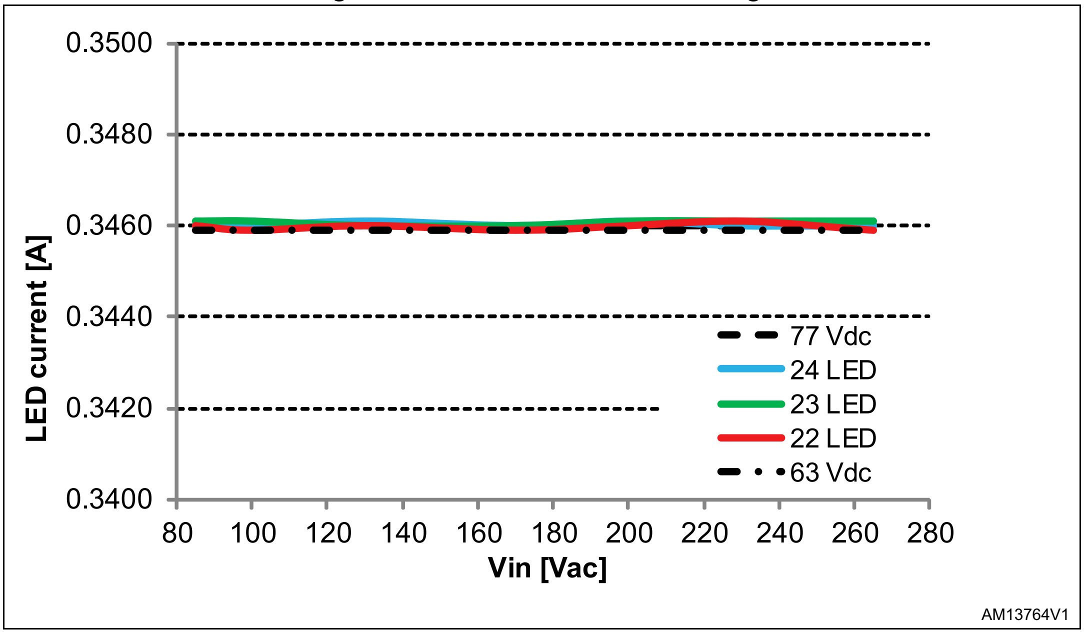
Figure 4 shows the LED string current versus the mains input voltage according to the load. The LED current has been set at 350 mA nominal, using *Equation 2* and considering the internal Vcsth of SEA05L (see datasheet):

Equation 2

$$R_{S\_SEA05L} = \frac{50mV}{350mA} = 0.14\Omega$$

The SEA05L perfectly regulates the current loop over the entire mains voltage and load range [-10 %, +10 %].

Figure 4. LED current vs. line voltage



Unlike boost topology, the buck-boost topology does not permit unity power factor even in an ideal case. From AN1059 [1], the ratio is defined as:

Equation 3

$$K_V = \frac{V_{PK}}{Vout}$$

The power factor is a function of K_v where V_{pk} is the input peak mains voltage and V_{out} is the nominal 70 V_{dc} LED voltage drop.

The current would normally be sinusoidal for K_v = 0 but will be distorted from an ideal sinusoid in proportion to the increase of K_V. Since K_v in this application varies according to the mains [85-265] V_{ac} in the range [1.7-5.3], a different PF versus input line voltage has been measured.

The PF is then affected by the current phase shift caused by the CX capacitor of the input EMI. A common-mode choke with high leakage value has been selected in order to increase the power of the EMI filter but at the same time reducing the two CX capacitors.

The test results of the following *Figure 5* and *Figure 6* show the PF and THD versus line voltage. The power factor remains above 0.9 up to the European range even considering the minimum tolerance value of the LED voltage drop (-10 %).

Considering the LED voltage drop variation, the PF remains above 0.9 until 250 V_{ac}.

Figure 5. Power factor vs. line voltage

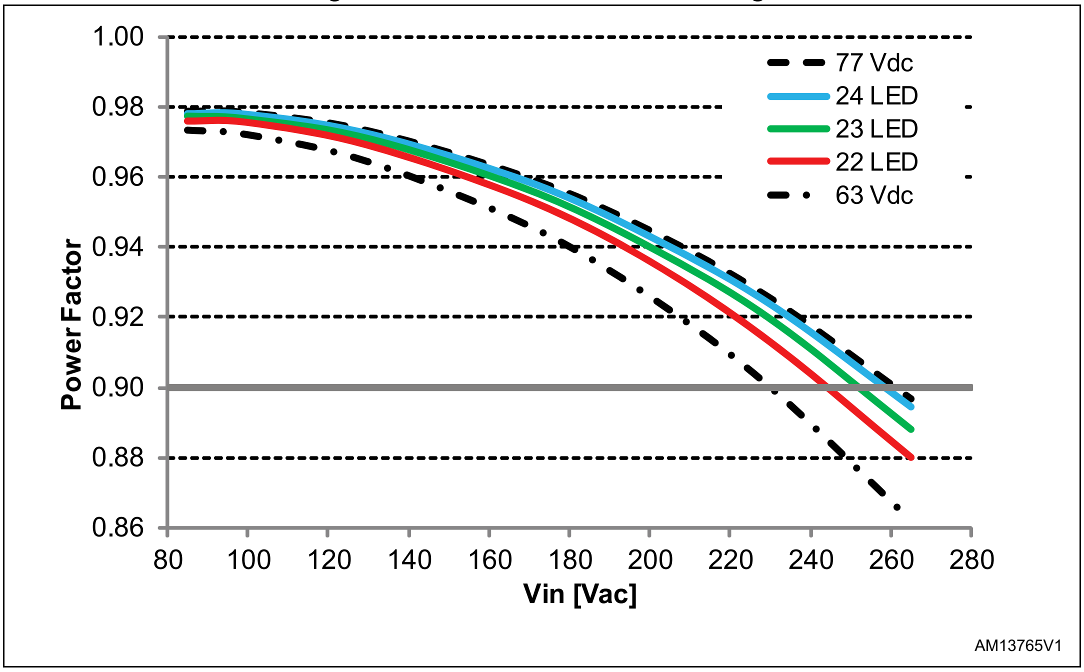
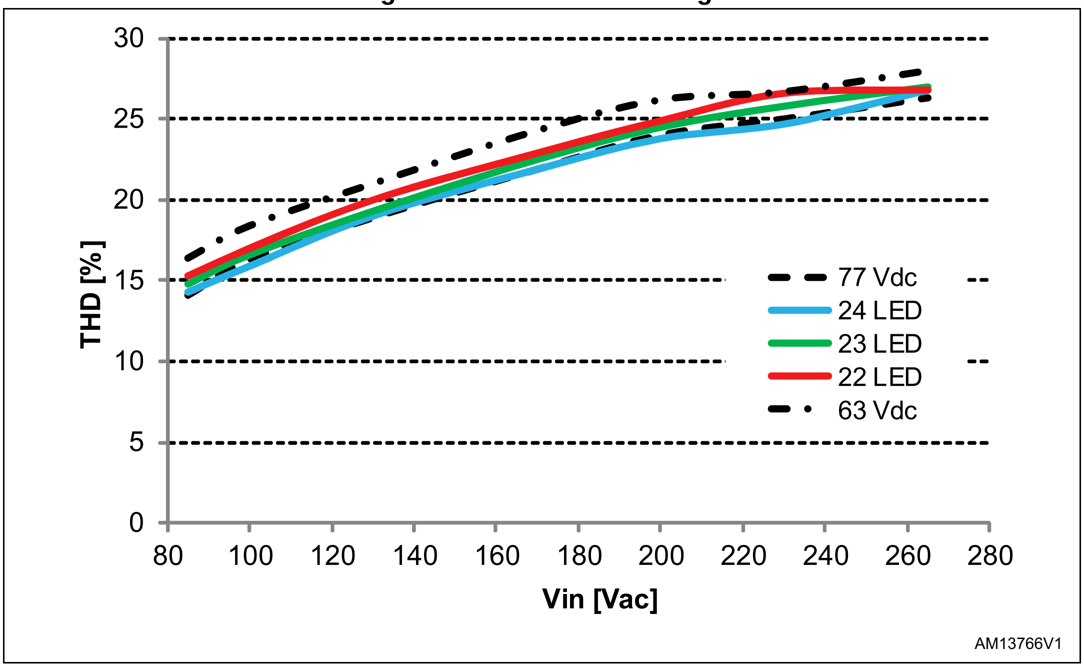
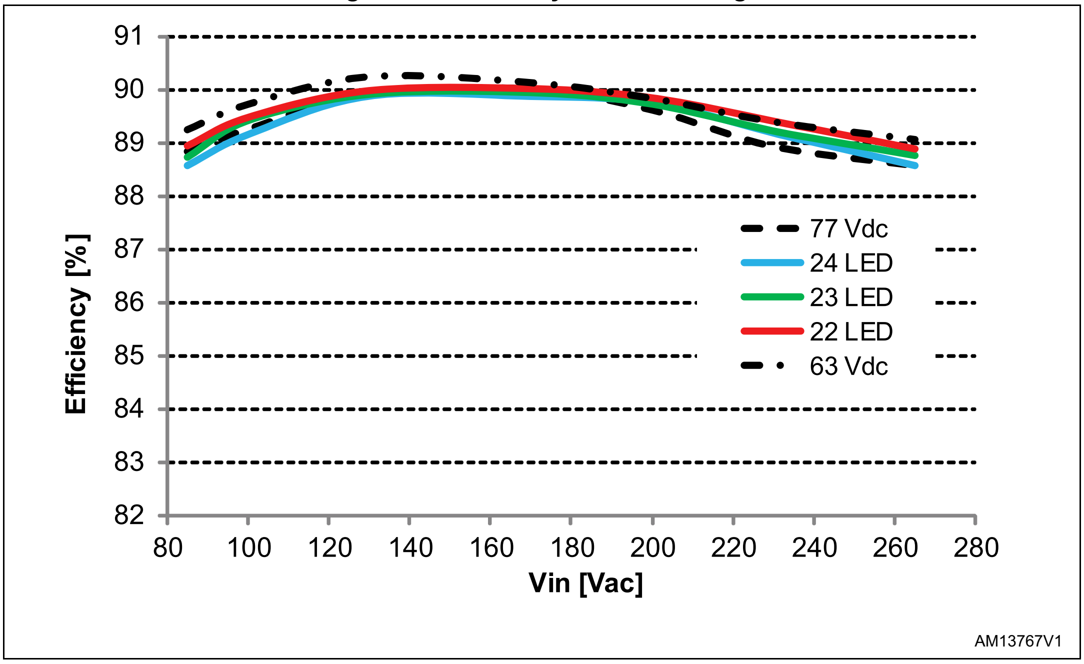


Figure 6. THD vs. line voltage



Finally the efficiency of the converter has been measured showing a curve varying between 89 % and 90 %.

Figure 7. Efficiency vs. line voltage



The voltage drop between the emitter and collector of the V_{cc} voltage regulator Q2 of the self-supply network increases with the input line voltage. The power losses on this BJT can be calculated as:

Equation 4

$$P_{losses} = V_{ce} \cdot I_{pump}$$

The current consumption of the L6564H and driving circuitry is 5 mA and the Q2 voltage drop can reach 70 V at high mains, so the power losses are around 350 mW, that is, 1.5 % of the total output power.

We can note that the losses at an input voltage above 200 V_{ac} become significant, causing a slight decrease of efficiency as visible in the diagram.

5 PFC waveforms

5.1 Input and output current and voltage waveforms

The waveforms of the input current and drain voltage at the nominal input voltage mains (100 V_{ac}/50 Hz or 230 V_{ac}/50 Hz) and 23-LED load condition are illustrated in *Figure 8* and *Figure 9*.

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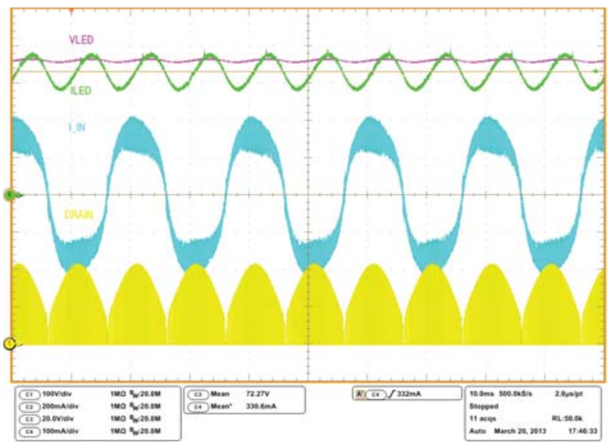
Figure 8. Input current waveform at 100 V_{ac} - 50 Hz



CH1: DRAIN
CH2: Input PFC Current
CH3: LED current
CH4: LED voltage drop

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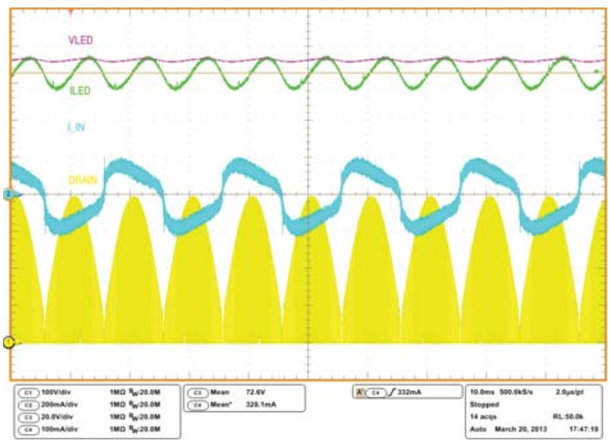
Figure 9. input current waveform at 230 V_{ac} - 50 Hz



CH1: DRAIN
CH2: Input PFC Current
CH3: LED current
CH4: LED voltage drop

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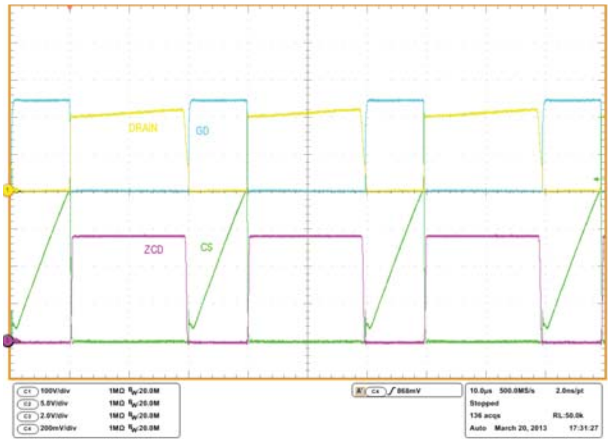
Note that the regulated LED current remains constant over the entire input mains voltage and with the variation of the LED voltage drop.
Drain voltage is modulated by the sinusoidal shape of the input rectified mains voltage. It increases with the input line voltage.

As described in *Section 4*, the PFC input current has more distortion at high mains, but it remains well below the harmonic limits of the international regulations. The LED current ripple amplitude (CH3) is below 100 mA pk-pk according to the calculation and the LED current is at the same level at both input voltages.

5.2 Transition mode operation

The ZCD pin, GD and CS pin have also been checked in order to show transition mode operation *Figure 10* and *Figure 11*.

Figure 10. TM operation at 100 V_{ac} - 0.35 A - fsw = 35 kHz



CH1: DRAIN
CH2: GD
CH3: ZCD
CH4: CS

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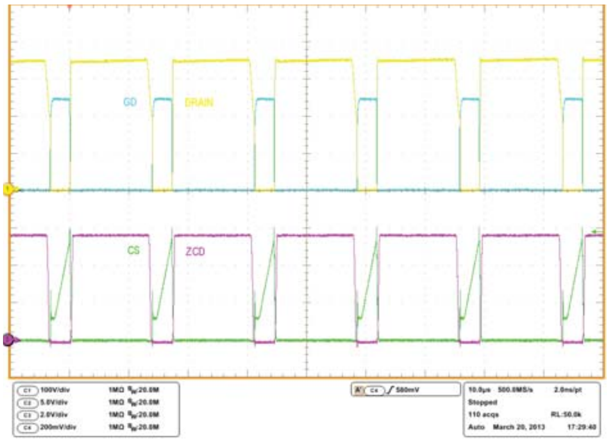
Figure 11. TM operation at 230 V_{ac} - 0.35 A- fsw = 50 kHz



CH1: DRAIN
CH2: GD
CH3: ZCD
CH4: CS

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An inductor value of 680 μH has been selected in order to get the converter to operate at very low frequency (35 kHz at 100 V_{ac}), minimizing the EMI filter and optimizing the power factor.

Turn-on of the MOSFET depends on the ZCD triggering signal during its falling edge, turn-off depends on the CS signal and its comparison with the internal feedback signal (MULT x COMP).

5.3 Startup

With a 33 μF capacitor on the V_{CC} pin, the L6564H turns on typically in less than 600 ms and the LED light appears 100 ms later. The turn-on time of the device depends on the value of the V_{CC} capacitor and the charging current of the HVS, according to the following equation (L6564H datasheet [3]):

Equation 5

$$T_{start-up} = C_{VCC} \cdot \frac{V_{turn-on}}{I_{charge}}$$

After turn-on the L6564H starts switching, absorbing energy from the V_{CC} capacitor. During normal operation the external charge pump provides energy to supply the IC. The power delivered by the charge pump depends on the input mains voltage, the LED voltage drop and on the primary-to-auxiliary turn ratio (n = 4.34):

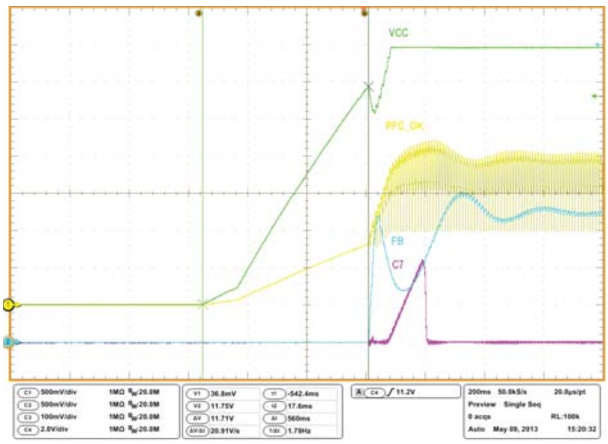
Equation 6

$$V_{AUX\_TON} = -\frac{VAC_{IN}}{n} \qquad V_{AUX\_TOFF} = \frac{V_{OUT}}{n}$$

The self-supplied circuitry has two worst-case conditions, one is when the circuit is operating at minimum input mains voltage (85 V_{ac}), and the second one is a lower voltage drop tolerance (63 V_{dc}) of the LEDs. Design has to take into account both worst case conditions contemporaneously.

The voltage regulator (Q2, DZ2, R3) regulates the V_{CC} voltage at about 14 V_{dc}. After the L6564H starts switching, the output capacitor voltage rises up until it reaches the nominal voltage drop of the LEDs. *Figure 12* and *Figure 13* show the startup phase at the two nominal conditions.

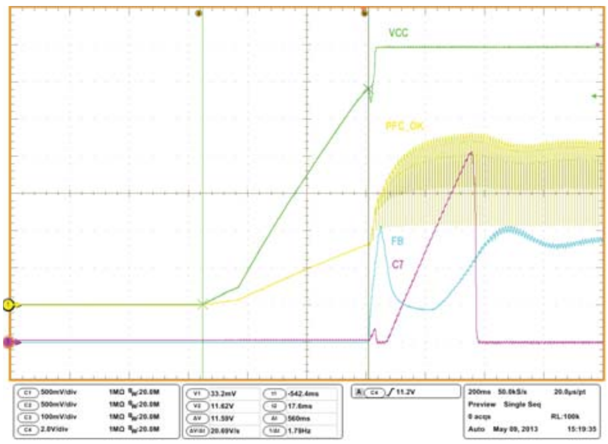
Figure 12. Startup at 100 V_{ac} - 0.35 A



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13772V1

Figure 13. Startup at 230 V_{ac} - 0.35 A



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

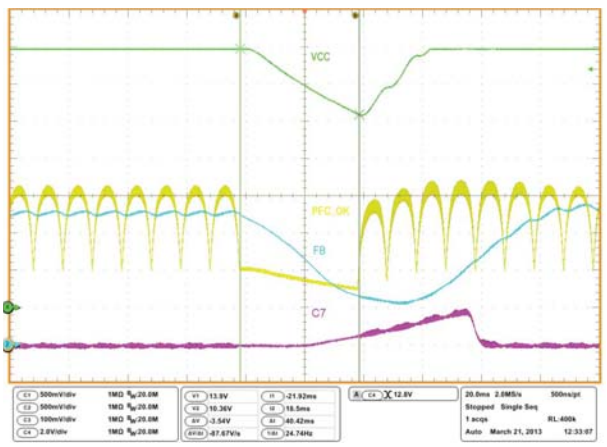
AM13773V1

Note that during startup, the loop is still open and the feedback signal (CH2-sensed on R17) is still low. The time constant - R32 with C7 - (see CH3- voltage on C7 capacitor) is set in order to mask this transition time, preventing the activation of the protection unnecessarily.

5.4 Line sags and fast on-off

The circuit behavior during a mains sags sequence has been tested, varying the OFF time period of the line. *Figure 14* and *Figure 15* show the behavior during two missed cycles of 20 ms each (line is at 50 Hz).

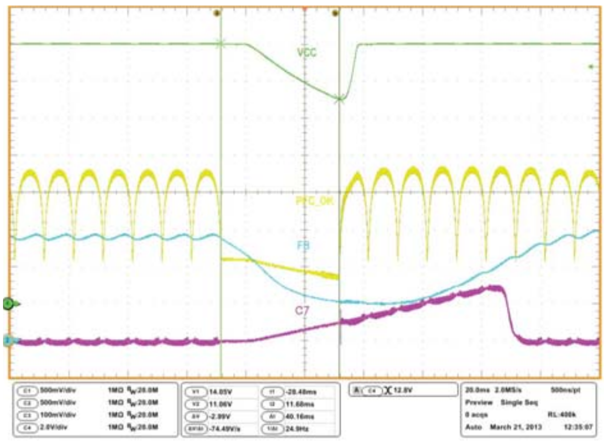
Figure 14. TOFF = 40 ms at 100 V_{ac} / 50 Hz - 0.35 A



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13774V1

Figure 15. TOFF = 40 ms at 230 V_{ac} / 50 Hz - 0.35 A

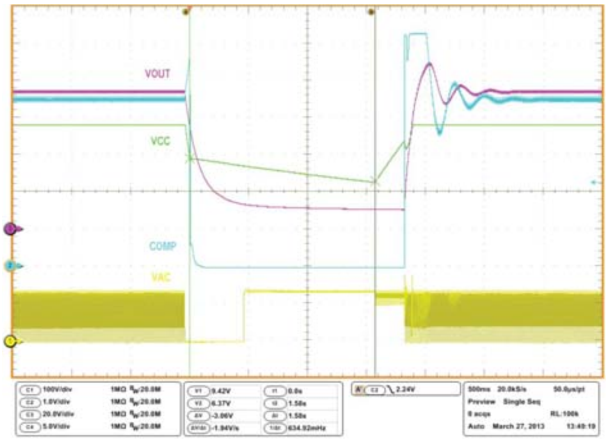


CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13775V1

If V_{CC} doesn't discharge until its turn-off level during the missed cycles, the converter restarts immediately. During the missed cycles, the protection on the PFC_OK pin is correctly inactivated.

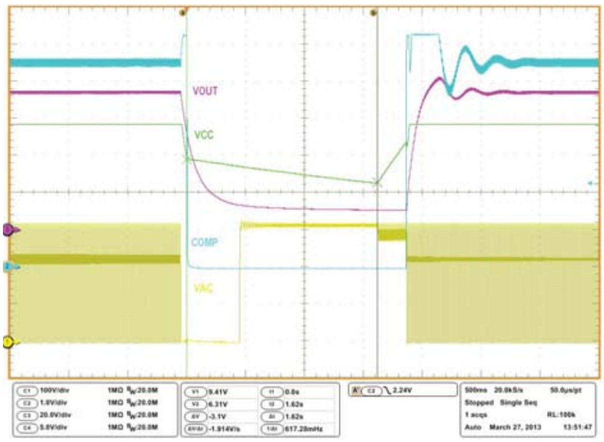
Figure 16. TOFF = 500 ms at 100 V_{ac}/50 Hz - 0.35 A



CH1: VAC
CH2: COMP
CH3: Vout
CH4: Vcc

AM13776V1

Figure 17. TOFF = 500 ms at 230 V_{ac}/50 Hz - 0.35 A



CH1: VAC
CH2: COMP
CH3: Vout
CH4: Vcc

AM13777V1

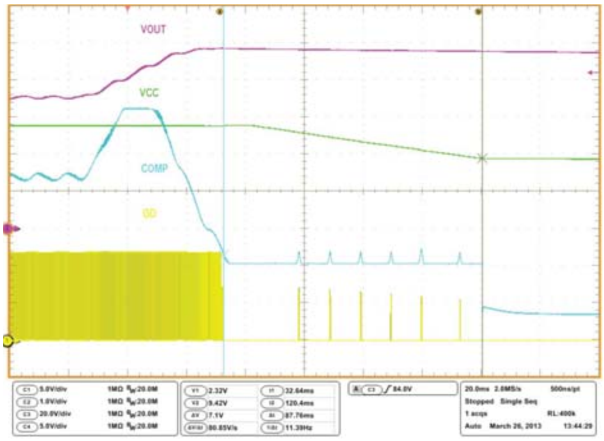
Figure 16 and *Figure 17* show the circuit behavior during a mains interruption of 500 ms, as in the case of a fast on-off-on cycle.

If the OFF time increases, V_{CC} discharges until turn-off level, the HVS generator shuts down and it is re-enabled only when the V_{CC} voltage reaches the restart threshold. This is the cause of the delay in the appearance of the LED light when the OFF time period of the line is compared to a manual button switch ON and OFF (T > 500 ms).

5.5 Load disconnection

During load disconnection, the output voltage is controlled by the voltage loop and the converter works in auto-restart. *Figure 18* and *Figure 20* represent the load disconnection transition at 100 V_{ac}/50 Hz and 230 V_{ac}/50 Hz. *Figure 19* and *Figure 21* show the behavior during the no-load condition.

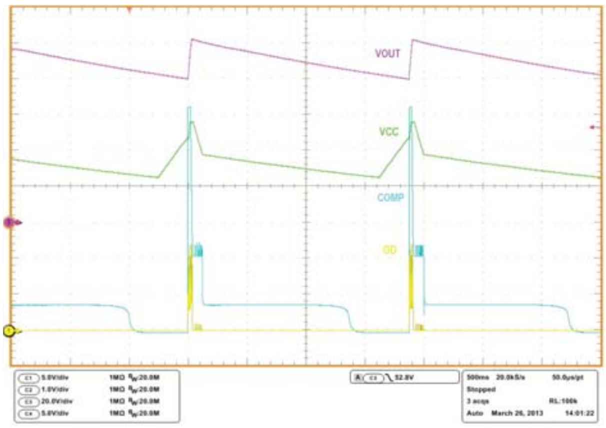
Figure 18. Load disconnection transition at 100 V_{ac}/50 Hz



CH1: GD
CH2: COMP
CH3: Vout
CH4: Vcc

AM13778V1

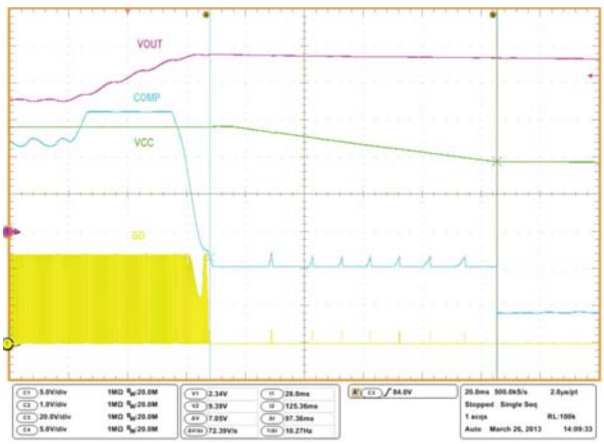
Figure 19. No load at 100 V_{ac}/50 Hz



CH1: GD
CH2: COMP
CH3: Vout
CH4: Vcc

AM13779V1

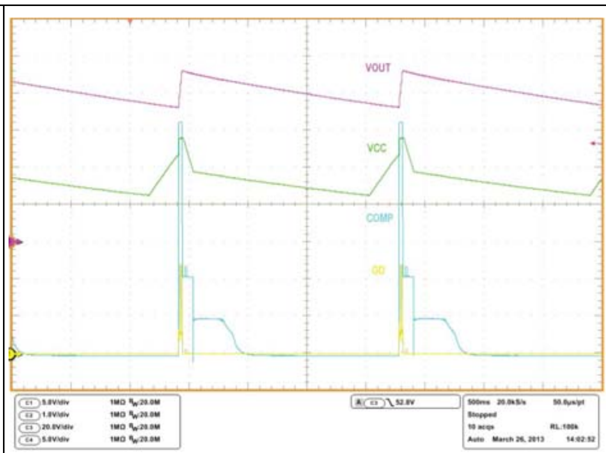
Figure 20. Load disconnection transition at 230 V_{ac}/50 Hz



CH1: GD
CH2: COMP
CH3: Vout
CH4: Vcc

AM13780V1

Figure 21. No load at 230 V_{ac}/50 Hz



CH1: GD
CH2: COMP
CH3: Vout
CH4: Vcc

AM13781V1

When the load is disconnected, first the current loop tries to compensate the low current sensed on R6 and R7 and increases the output of U1 (pin 5). As a consequence, the COMP pin increases too, but as the output voltage reaches about 85 V_{dc}, the voltage loop operates, and the output of U1 is forced to decrease. The overlap of these two effects can be seen on the COMP pin (CH2). As this signal falls, it triggers the burst mode. During this operation the output voltage of the converter decreases, V_{CC} voltage reaches its turn-off level and the L6564H shuts down. Only when V_{CC} voltage reaches the V_{CC}-restart threshold does the HVS generator pump current into the V_{CC} capacitor and the L6564H restarts switching.

The intervention of the voltage loop can be set using:

Equation 7

$$V_{OVP} = 2.5V \cdot \frac{R_8 + R_9}{R_8}$$

considering that the internal reference of the SEA05L is 2.5 V typ. [4].

The speed of the voltage loop can be increased by fine-tuning the C11, R10 network. A high value of C15 slows down the voltage loop reaction, but it filters the output capacitor voltage ripple, affecting the power factor. In this design a compromise has been found.

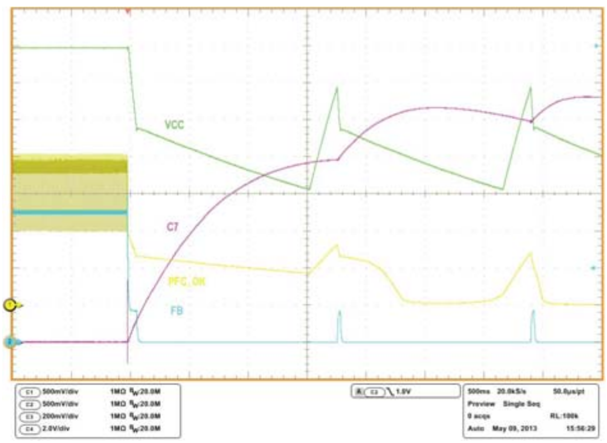
5.6 Short-circuit

During a short of the output connector, all the energy stored in the output electrolytic capacitor C3 is discharged into the output side loop, and no current will flow into the external LEDs, preventing their failure. The SEA05L CC-CV controller is no longer supplied and it cannot regulate the loop. A peak high current of 60 A has been measured during 100 ns flowing from the output capacitor into the output side loop. In order to protect the sense resistor of the cc-cv controller, a Schottky diode D9 of 80 A surge current (see STPS3150U datasheet [7]) has been added in the demonstration board.

After this initial transient the short-circuit protection, described above, senses the feedback signal and disables the L6564H from the PFC_OK pin (see disable function of the L6564H [3]).

The behavior of the protection has been tested with positive results over the entire input voltage range; only the two nominal conditions at 100 V_{ac} and 230 V_{ac} have been discussed in this application note.

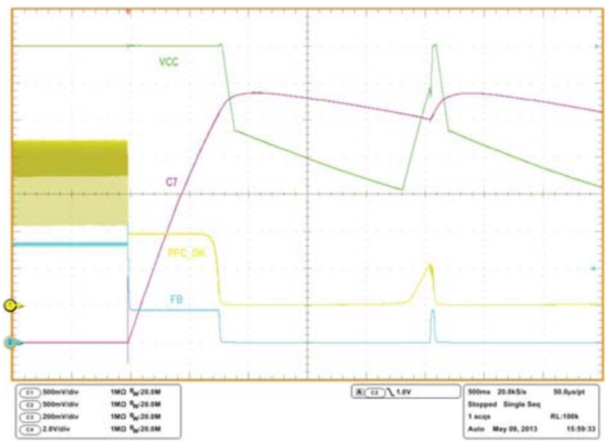
Figure 22. Short-circuit at 100 V_{ac}



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13782V1

Figure 23. Short-circuit at 230 V_{ac}



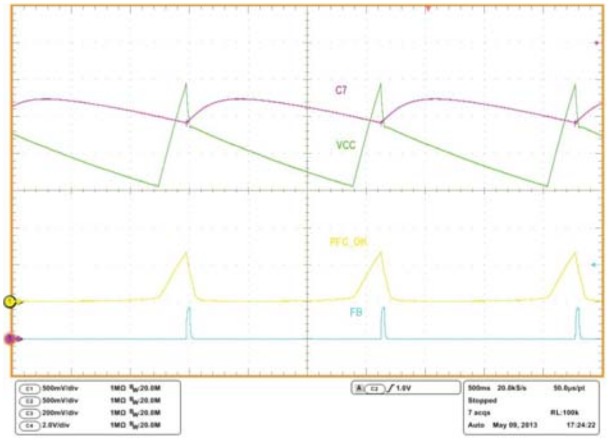
CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13783V1

Figure 22 and Figure 23 show that PFC_OK is pulled to GND when the voltage on the C7 capacitor reaches the value of 3 x Vbe (2 x Vf (LL4148) + BC847C Vbe).

Figure 24 and *Figure 25* show the resulting hiccup mode of the converter during shorts, when the protection is tripped.

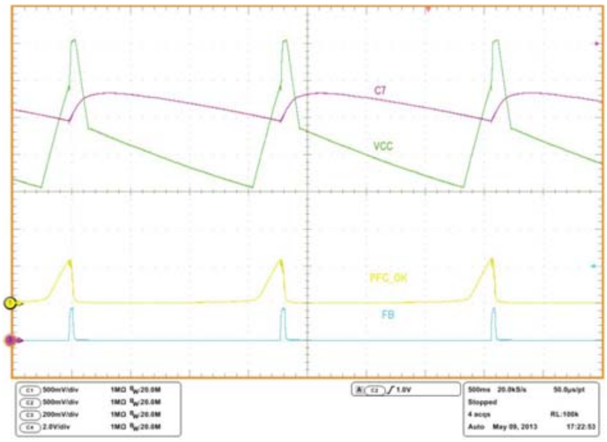
Figure 24. Overload behavior after a short-circuit at 100 V_{ac}



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13784V1

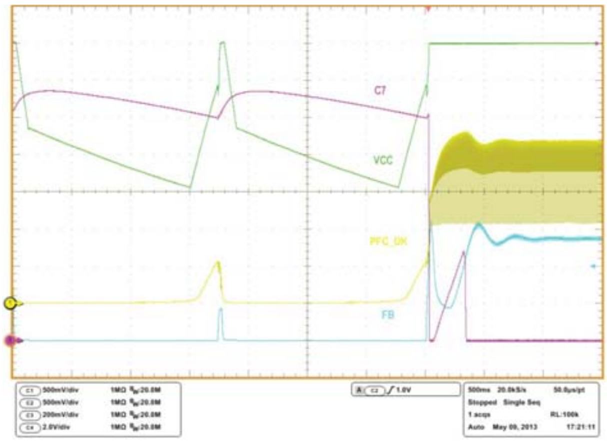
Figure 25. Overload behavior after a short-circuit at 230 V_{ac}



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13785V1

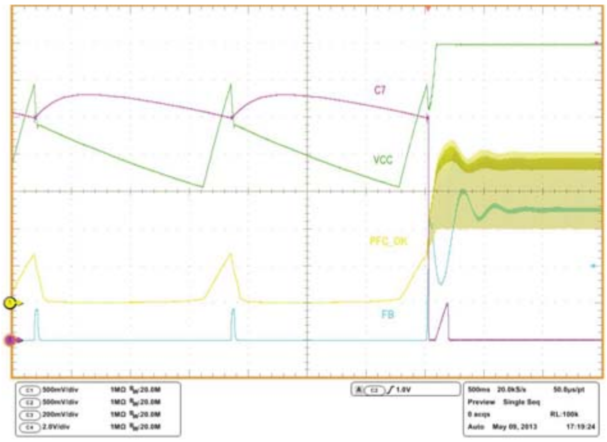
Figure 26. Short-circuit removal at 100 V_{ac}



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

AM13786V1

Figure 27. Short-circuit removal at 230 V_{ac}



CH1: PFC_OK
CH2: FB (sensed on R17)
CH3: C7 voltage
CH4: Vcc

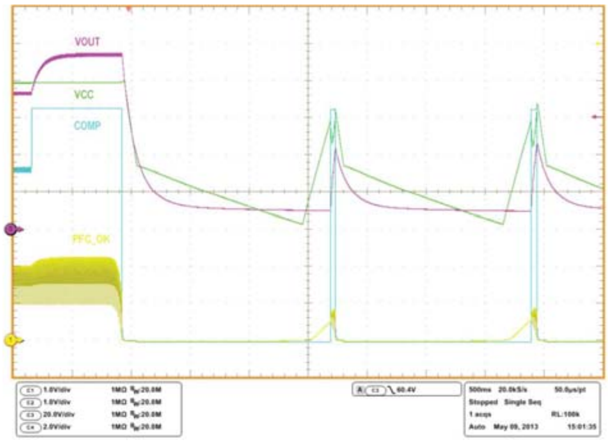
AM13787V1

Figure 26 and *Figure 27* show the behavior after the short removal. The startup sequence is activated.

5.7 Feedback failure protection (open loop)

A kind of protection that any power supply must have is one which prevents the failure of the feedback circuitry. If a failure occurs, for example degradation of one BJT (Q4 or Q5), the output voltage can increase, damaging the electrolytic capacitor and the LED load. *Figure 28* and *Figure 29* show the board behavior opening the loop by removing the resistor R17 (0 Ω).

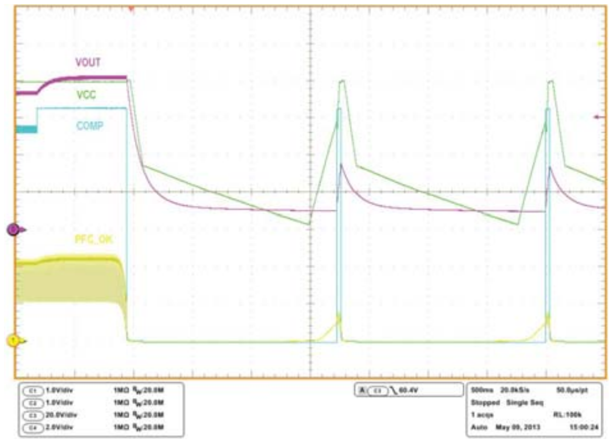
Figure 28. Feedback failure protection at 100 V_{ac}/50 Hz



CH1: PFC_OK
CH2: COMP
CH3: Vout
CH4: Vcc

AM13788V1

Figure 29. Feedback failure protection at 230 V_{ac}/50 Hz



CH1: PFC_OK
CH2: COMP
CH3: Vout
CH4: Vcc

AM13789V1

The feedback signal on C15 falls, activating the same external protection that pulls down the PFC_OK (CH1) pin below its disable threshold. The delay in triggering is due to the charging time of the capacitor C7 through R32. The output voltage (CH3) is limited.

6 Harmonic content measurement

One of the main purposes of this converter is the correction of input current distortion, decreasing the harmonic contents below the limits of the actual regulation. Therefore, the board has been tested according to the Japanese standard JEIDA-MITI Class-C and European standard EN61000-3-2 Class-C, at full load and both nominal input voltage mains.

Figure 30. EVL6564H-25W-BB at 100 V_{ac}/50 Hz compliance with JEIDA-MITI class-C limits at PF = 0.9801

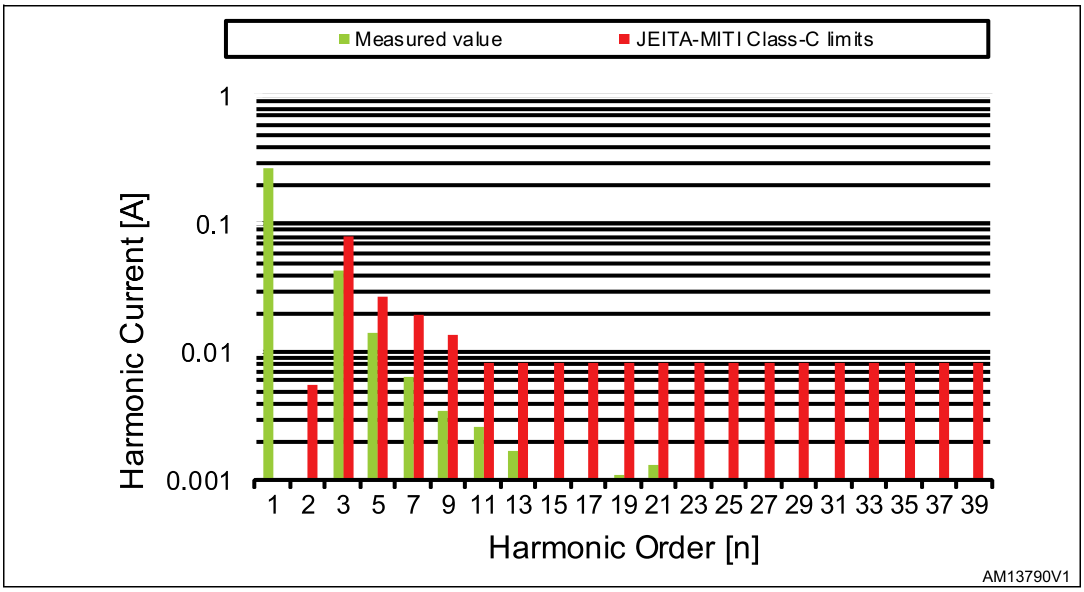
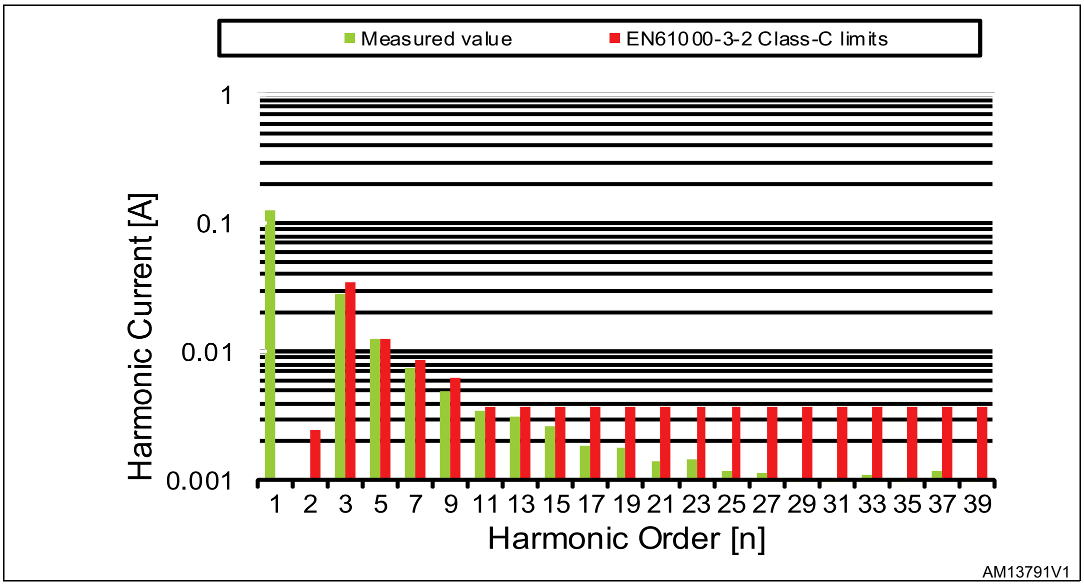


Figure 31. EVL6564H-25W-BB at 230 V_{ac}/50 Hz compliance with EN61000-3-2 class-C limits at PF = 0.9180



As shown in the figures that follow, the circuit is capable of reducing the harmonics well below the limits of both regulations.

7 Thermal measurements

To check the reliability of the design, thermal mapping using an IR camera was carried out. *Figure 32* and *Figure 33* show thermal measurements on the component side of the board at nominal input voltages and full load. Pointers show the relevant temperature of key components. *Table 3* provides the correlation between the measured points and components for both thermal maps. The ambient temperature during both measurements was 25 °C. According to these measurement results, all components on the board function within their temperature limits.

Figure 32. Thermal map at 100 V_{ac}/50 Hz

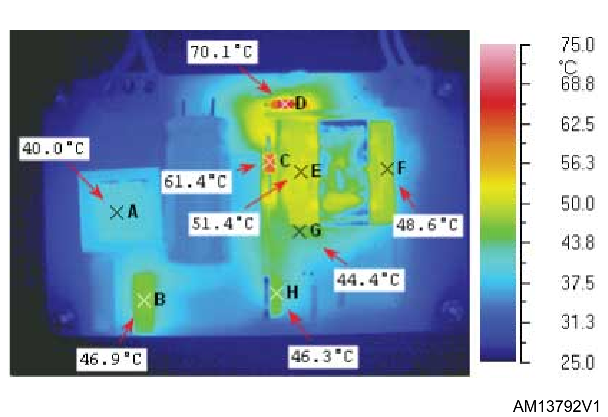


Figure 33. Thermal map at 230 V_{ac}/50 Hz

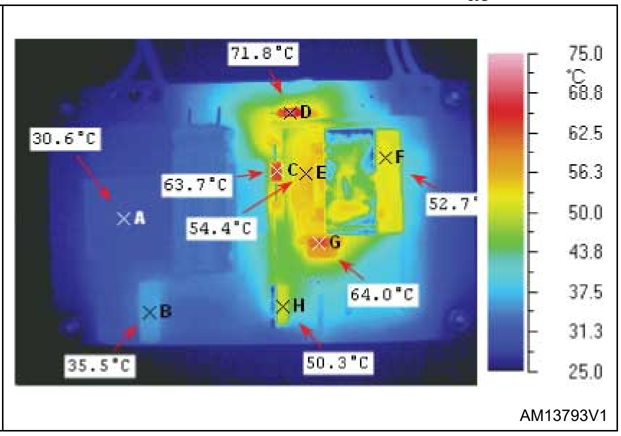


Table 3. Measured temperature at 100 V_{ac}/50 Hz and 230 V_{ac}/50 Hz

Point	Component	Temp. at 100 V_{ac} (°C)	Temp. at 230 V_{ac}(°C)
A	Common-mode choke	46.9	35.5
B	Diode bridge	46.9	35.5
C	Output diode D1	61.4	63.7
D	R1 (SEA05-FB bias)	70.1	71.8
E	Q3 inductor choke T1-L	51.4	54.4
F	Q3 inductor choke T1-R	48.6	52.7
G	BJT voltage regulator	44.4	64.0
H	MOSFET	46.3	50.3

8 Conducted emission pre-compliance test

The following graphs show the average measurements of the conducted noise with a 23-LED load and nominal mains voltages. The limits shown on the diagrams are those of EN55022 class-B, which is the most popular standard for European equipment. As visible, good margins with respect to the limits are present in all test conditions. Increasing the CX capacitor value of the EMI filter will improve the safety margin but will affect the PF. A compromise has been found in this design.

Figure 34. 100 V_{ac}/50 Hz - phase

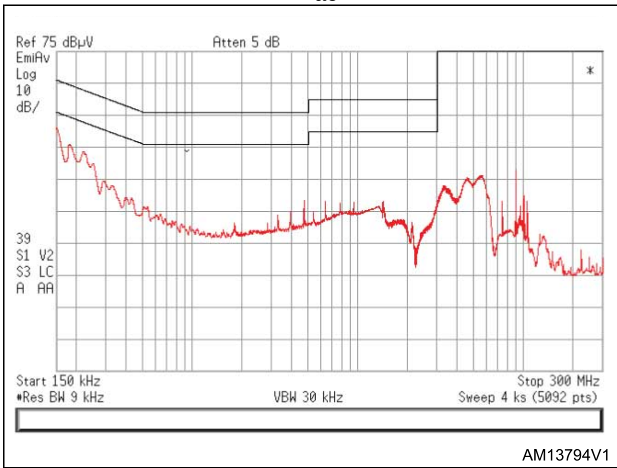


Figure 35. 100 V_{ac}/50 Hz - neutral

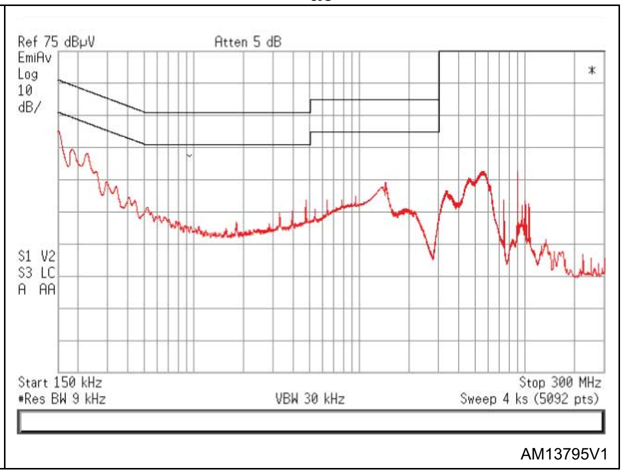


Figure 36. 230 V_{ac}/50 Hz - phase

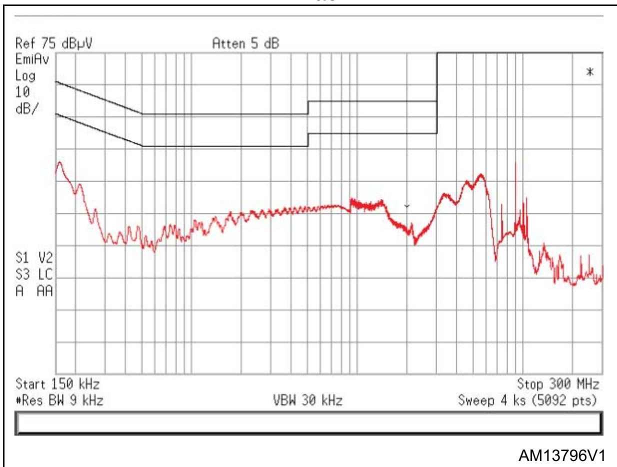
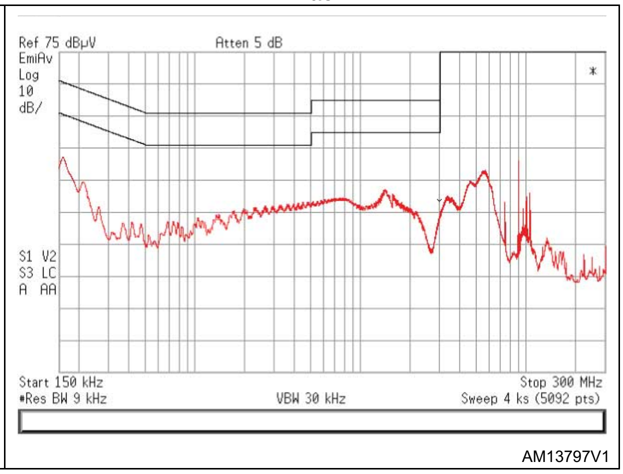


Figure 37. 230 V_{ac}/50 Hz - neutral



Note that a CY capacitor between the negative output pin of the converter and ground has been placed to filter common-mode noise flowing into the demonstration board.

A small filter capacitor between the SEA05L output (pin 5) and SEA05L GND (pin 2) has also been placed for the same reason.

The C20 capacitor between the drain and source of Q3 acts as a snubber and it has been foreseen to increase the safety margin.

9 PCB layout

Figure 38 and *Figure 39* show the layout of the PCB.

The demonstration board has been designed to fit in a typical LED driver case so the maximum height is 20 mm, maximum length is 90 mm and the maximum width is less than 65 mm.

Of course the form factor could be further reduced depending on the capacitor value. Here a very narrow current ripple has been defined as a specification, but accepting a higher value, the capacitor size could be further reduced.

Figure 38. Bottom layer

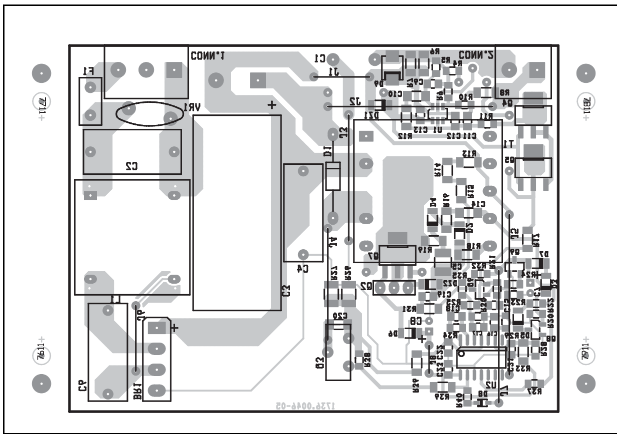
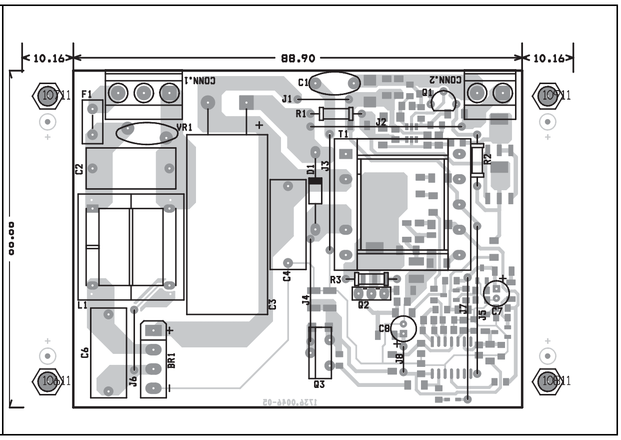


Figure 39. Top layer



10 References

1. AN1059 - Design equations of high-power-factor flyback converters based on the L6561
2. AN1060 - Flyback converters with the L6561 PFC controller
3. L6564H - datasheet
4. SEA05L - datasheet
5. STI8N65M5 - datasheet
6. X42182 LED - datasheet (Seoul Semiconductor)
7. STPS3150U - datasheet
8. STTH2L06 - datasheet

11 Revision history

Table 4. Document revision history

Date	Revision	Changes
18-Jul-2013	1	Initial release.
29-Jul-2013	2	Corrected rendition errors in Figures 14 to 29.