AN4599
Application note

STEVAL-ISA132V1 24 V 300 W peak power resonant converter

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Introduction

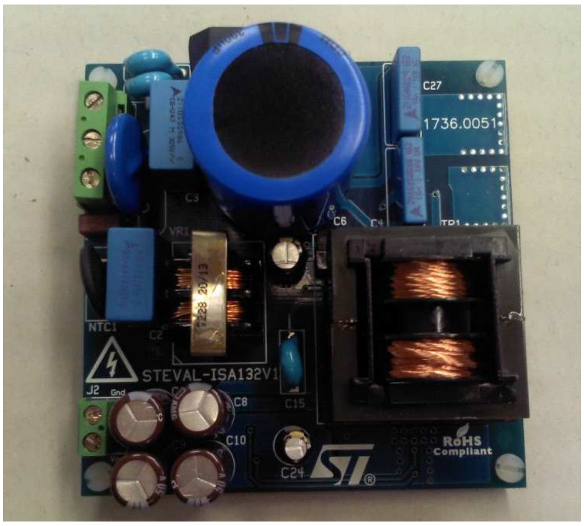
This application note describes the features of the STEVAL-ISA132V1 evaluation board at 24 V, 300 W peak power conversion.

The architecture is based on a single-stage LLC resonant converter without PFC using the new L6699 resonant controller.

The L6699 integrates some very innovative functions such as self-adjusting adaptive dead time, anti-capacitive mode protection and a proprietary "safe-start" procedure which prevents hard switching at start-up.

Thanks to the chipset used, the main features of this power supply are:
- very high efficiency under high-load and low-load conditions
- safe start up procedure to avoid hard switching
- hard switching prevention under overload and low-load conditions
- burst mode under low-load conditions with smooth restart to prevent audible noise
- the demo board can deliver more than 300 W peak power for a limited time thanks to the NTC thermal protection positioned near the output diodes.
- continuous power at 30°C ambient temperature is 170 W.
- the MOSFET and diode power devices are in D²PAK packages

Figure 1. STEVAL-ISA132V1 300 W peak power SMP evaluation board



Contents

1 Main features

The main features of the SMPS are:

- input mains range: from 190 to 264 V_{AC} - frequency 50 Hz
- output voltage: 24 V 5%
- no-load consumption: < 0.6 W
- efficiency @ 230 Vac > 92%
- EMI: Within EN55022 Class-B limits conducted precompliance
- safety: Meets EN60950-1
- dimensions: 90 x 90 mm, 50 mm component maximum height
- weight 220 gr

The circuit consists of a single stage LLC resonant converter.

The MOSFET and diode power components are in D^2PAK packages.

The L6699 integrates all the functions necessary to control the resonant converter with a 50 % fixed duty cycle and working with variable frequency.

2 Circuit description

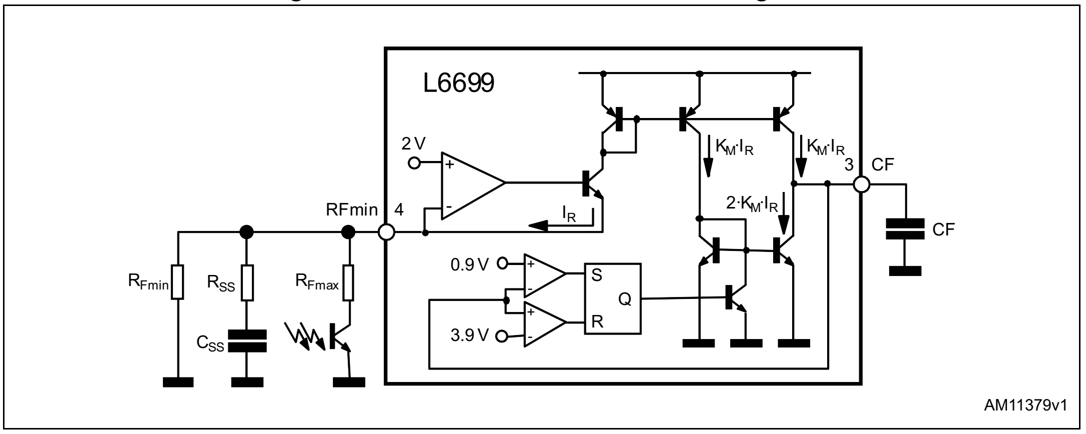
2.1 Start-up sequence

D12, D4, R7, C13 in *Figure 13* form the start-up circuit.

When the V_{CC} voltage reaches L6699 V_{CCon}, the system begins the start-up sequence and changes the switching frequency from f_{start} to the operative frequency.

2.2 Oscillator setting

Figure 2. Oscillator's internal block diagram



The oscillator is programmed externally by means of a capacitor connected from pin 3 (CF) to ground that is alternately charged and discharged by the current defined with the network connected to pin 4 (RF_{min}).

The pin provides an accurate 2 V reference with approximately 2 mA source capability; the higher the current sourced by the pin, the higher the oscillator frequency.

The *Figure 2* block diagram shows a simplified internal circuit explaining the operation.

Table 1. Recommended values for CF as a function of the start-up frequency f_{start}

f_{start} [kHz]	CF [pF]	f_{start} [kHz]	CF [pF]
150	680	230 - 240	180
160	560	250	150
170	470	260	120
180	390	270	100
190 - 200	330	280	82
210	270	290	68
210	220	300	56

Procedure to set oscillator components:

- nominate the start frequency (do not exceed 300 kHz f_{start})
- find the corresponding value of CF in *Table 1*
- with a chosen f_{start} of 156 kHz, the corresponding CF is 560 pF in *Table 1*
- choose the minimum frequency and determine RF_{min} using the equation:

Equation 1

$$Fmin = \frac{1}{3 * CF * RFmin}$$

The chosen F_{min} is 49.6 kHz, CF is 560 pF and thus RF_{min} = 12 kΩ

Determine R_{SS} using equation:

Equation 2

$$Fstart = 1/(3 * CF * \left(\frac{RFmin * Rss}{RFmin + Rss}\right))$$

For the chosen F_{start} of 156 kHz, CF = 560 pF, RF_{min} = 12 kΩ and consequently R_{SS} = 5.6 kΩ

Verify the following relationships:

Equation 3

$$Rss = RFmin/(\frac{Fstart}{Fmin} - 1)$$

Choose F_{max} and determine RF_{max} using the formula:

Equation 4

$$RFmax = \frac{3 * RFmin}{8 * \frac{Fmax}{Fmin} - 1}$$

For a chosen F_{max} of 150 kHz, RF_{max} = 2 kΩ

Calculate the C_{SS} using the formula C_{SS} = 3 * 0.001 / R_{SS}

In the application, it may be necessary to increase this value to optimize start-up procedure by minimizing the inrush current and charging current of the output capacitor.

Good performance is achieved with C_{SS} = 4.7 µF.

With reference to the schematic in *Figure 13*:

- RF_{min} = R18 = 12 kΩ
- RF_{max} = R19 = 3.3 kΩ
- R_{SS} = R15 = 5.6 kΩ
- CF = C22 = 560 pF
- C_{SS} = C26 = 4.7 µF

2.3 Burst mode operation at no load or very light load

To reduce the average switching frequency, the L6699 can operate in burst mode with a series of a few switching cycles in between relatively long idle periods with both MOSFETs in the off state.

The resulting average value of the residual magnetizing current and corresponding loss is reduced considerably, thus facilitating converter compliance with energy saving specifications.

L6699 can be operated in burst mode via pin 5 (STBY): if the voltage applied to this pin falls below 1.26 V, the IC enters the low-consumption idle state, where both gate drive outputs are low and the oscillator is stopped; the IC resumes normal operation when the voltage on pin exceeds 1.26 V + 30 mV.

To implement burst mode operation, the voltage applied to the STBY pin needs to be associated with the feedback loop.

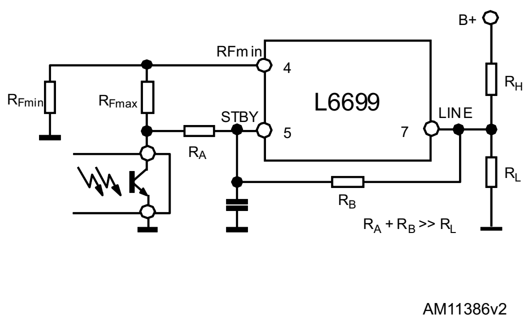
The resonant converter switching frequency and hence burst mode activation strongly depends on the variation of the input voltage.

Use the circuit in *Figure 3* when the input voltage range is quite large.

Due to the high non-linear relationship between the switching frequency and input voltage, it is more practical to empirically determine the correct magnitude for $R_A/(R_A+R_B)$ correction and RF_{max} to obtain an almost constant burst mode threshold in all input voltage ranges.

In this application, we obtained a good compromise with R_A = 56 kΩ, R_B = 150 kΩ and RF_{max} = 3.3 kΩ.

Figure 3. Wide input voltage range schematic



With reference to the schematic in *Figure 13*:

- R_A = R26 = 56 kΩ
- R_B = R6 = 150 kΩ
- R_H = R1 + R5 = 3 MΩ
- R_L = R8 = 27 kΩ

2.4 Brown out

Referring to *Figure 13*, the Line pin is connected to the high voltage input bus with a resistor divider: R1, R5 and R8.

The partition is slightly influenced by resistors R6 and R26.

A voltage below 1.25 V shuts down the IC and consequently lowers consumption and discharges the soft start capacitor.

IC operation is enabled when the voltage exceeds 1.25 V – the comparator is provided with current hysteresis: an internal 13 µA current generator remains on while the voltage applied at the Line pin is below 1.25 V.

Test results:

Decreasing V_{IN} shut down is 100 V_{AC}

2.5 Overload and short circuit protection

Referenced to *Figure 4*.

In the L6699, the current sense input ISEN (pin 6) monitors the current flowing in the resonant tank to perform multiple tasks:

1. primary overcurrent protection
2. hard-switching cycle prevention at start up
3. hard-switching cycle prevention during operation

The ISEN pin is able to withstand negative voltages in order to observe the voltage and current of the resonant tank.

ISEN is internally connected to the input of a first comparator referenced to V_{ISENX} (0.8 V typ.) and a second comparator referenced to 1.5 V.

If the voltage applied to ISEN exceeds 0.8 V, the first comparator is tripped which in turn activates an internal switch for 5 µs, thus discharging the soft-start capacitor C_{SS}.

This increases oscillator frequency, limiting the energy transfer.

The circuit shown in *Figure 4* operates as a capacitive current divider.

Cs is typically selected with a value around C_r/100 and the sense resistor is selected as: $R_S=0.77/I_{crpkx}*(1+C_r/C_s)$.

The OCP limits primary to secondary energy flow in case of overload or short circuit, but the output current in the secondary winding and in the rectifiers can still rise to dangerous levels.

To prevent any damage and reduce power loss, the converter must be forced to operate intermittently.

The DELAY pin manages the timing of the overcurrent protection.

A resistor and a capacitor are connected from this pin and GND to set the maximum duration of an overcurrent condition before the IC stops switching and the delay after which the IC restarts switching.

Every time the voltage on the ISEN pin exceeds 0.8 V, the capacitor on the DELAY pin is charged by 350 µA and is slowly discharged by the external resistor.

If the voltage on the DELAY pin riches 2 V, the soft start capacitor is completely discharged to push the switching frequency to its maximum value and a 350 µA current source is kept on.

When the voltage on the DELAY pin exceeds 3.5 V, the IC stops switching and internal 350 µA generator is turned off, causing the voltage on the pin to decay because of the external resistor.

The IC enters soft-restart when the voltage drops below 0.3 V.

In this way, the converter under short-circuit or overload condition works intermittently with very low input average power.

If the ISEN pin voltage exceeds 1.5 V, the L6699 is immediately stopped and the 350 µA current source is kept ON until the DELAY pin voltage reaches 3.5 V, at which time the generator is turned OFF and the voltage on the pin decays because of the external resistor; also in this case the IC enters soft-restart when the voltage drops below 0.3 V

Is not easy to find a relationship that links charging time to the CDELAY value, so it is more practical to determine CDELAY experimentally.

To give an approximate indication:

- the time to reach 2 V on the DELAY pin is 100 ms every 1 µF;
- the time from 2 V to 3.5 V is about 4.3*CDELAY;
- the time to discharge CDELAY pin from 3.5 V to 0.3 V is about 2.4*RDELAY*CDELAY.

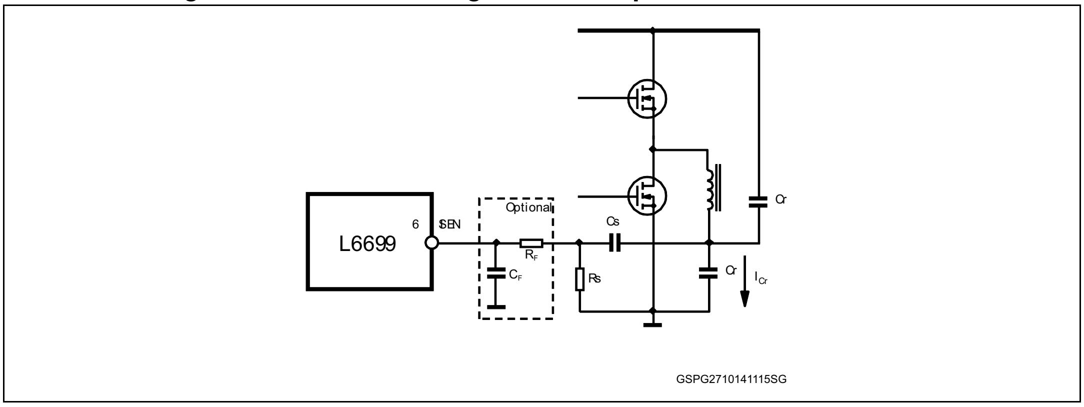
Referring to *Figure 13*, the resistor and capacitor on the DELAY pin are C21 = 470 nF and R29 = 330 kΩ.

The protection times are:

- approx. 50 ms: slowly increase frequency
- approx. 1.8 µs force frequency to f_{start}
- about 370 ns: switching is stopped

If the overload is less than 50 ms, the system functions as a power limiter without shutdown.

Figure 4. Current sensing lossless capacitive current divider



2.6 Thermal protection

To render the application unbreakable, it was necessary to apply thermal protection near the output diodes, the warmest area on the power (PWR) supply.

A thermal resistor NTC2 in partition with the R2 resistance is processed by a TSM103W, used as comparator with high hysteresis.

When the output diodes reach 120 °C, the output of TSM103W drives Q3 to drain the current from the optocoupler. The PWR supply shuts off and stays off as long as TSM103W is supplied.

3 Power components

Q1 and Q2 are STB13N60M2 series MOSFETs featuring MDmesh™ M2 technology.

They are suitable for resonant types, and are highly rugged to withstand hard switching; they reduce losses from switching turn-off commutation and reduce the current consumption due to Qg.

The D3 and D5 STPS20H100CG diodes are optimized to balance leakage current and voltage drop; they are avalanche rated with a high-junction temperature capacity of 175 °C.

4 Magnetic components

Figure 5. Transformer (Code 05801 Class Code 1860.0044 Magnetica)

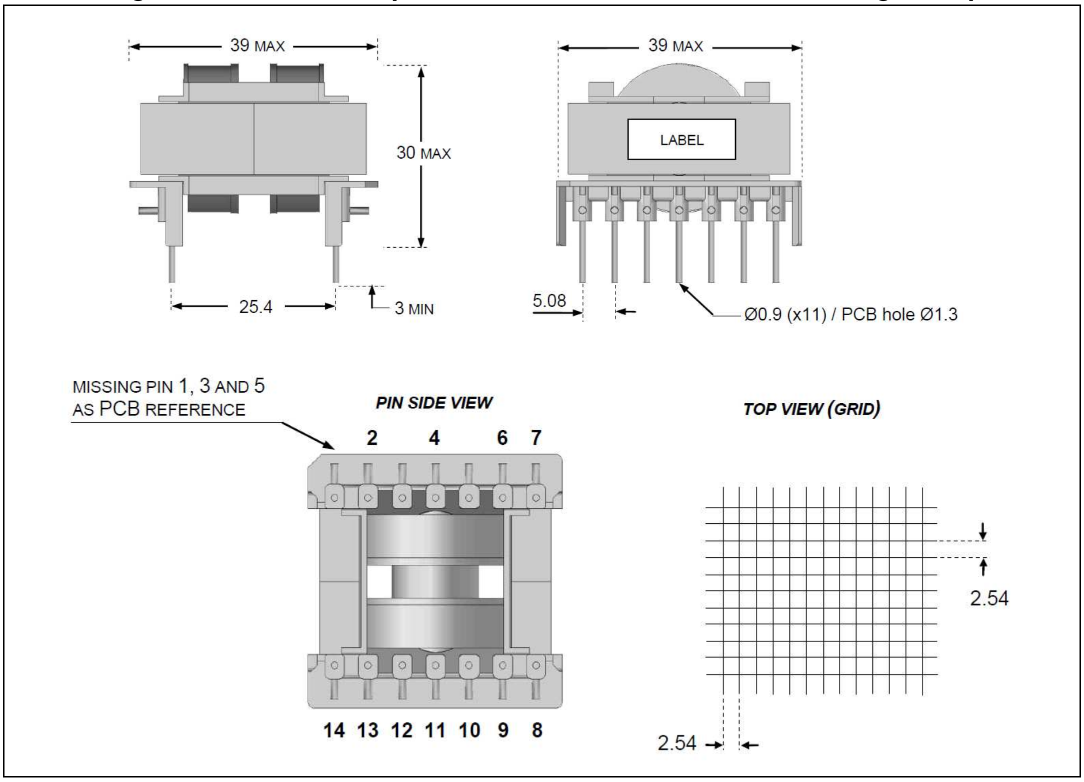
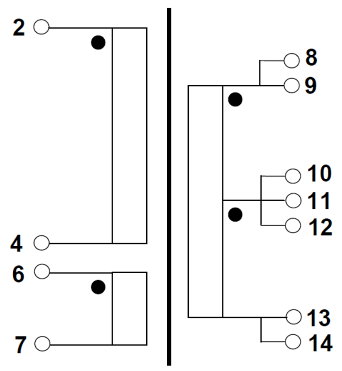


Table 2. Pin functions

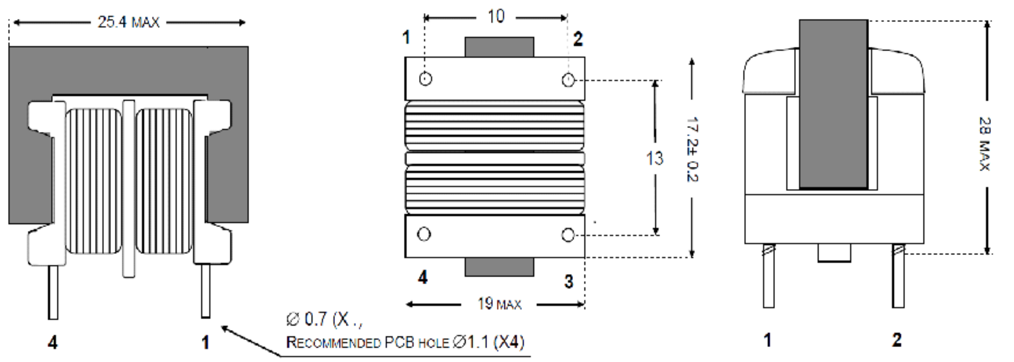
<table>
<tr><th>Pin n°</th><th>Function</th><th>Pin n°</th><th colspan="2">Function</th></tr>
<tr><td>1</td><td>Not connected</td><td>8_A</td><td rowspan="2">Secondary A</td><td rowspan="7">200 W $_{MAX}$
24 V 8.3 A</td></tr>
<tr><td>2</td><td>Primary Drain/source</td><td>9_A</td></tr>
<tr><td>3</td><td>Not present</td><td>10_B</td><td rowspan="3">Ground secondary</td></tr>
<tr><td>4</td><td>Primary with CR</td><td>11_B</td></tr>
<tr><td>5</td><td>Not present</td><td>12_B</td></tr>
<tr><td>6</td><td>Auxiliary (12 V 50 mA)</td><td>13_C</td><td rowspan="2">Secondary B</td></tr>
<tr><td>7</td><td>Auxiliary ground (12 V 50 mA)</td><td>14_C</td></tr>
</table>

Figure 6. Transformer electrical diagram and features



INDUCTANCE (MEASURE 1KHz, TA 20°C)	
PIN 2-4	520 uH ± 15%
PIN 6-7	5 uH ± 15%
PIN 8-11	11 uH ± 15%
PIN 10-13	11 uH ± 15%
PIN 12-14	11 uH ± 15%
PIN 9-11	11 uH ± 15%
RESISTANCE (D.C. MEASURE, TA 20°C)	
PIN 2-4	180 mΩ MAX
PIN 6-7	150 mΩ MAX
PIN 8-11	10 mΩ MAX
PIN 10-13	15 mΩ MAX
PIN 12-14	12 mΩ MAX
PIN 9-11	18 mΩ MAX
TURN RATIO (MEASURE 10KHz, TA 20°C)	
PIN 2-4 ⇔ 6-7	12.2 ± 10%
PIN 2-4 ⇔ 8-10	8.1 ± 10%
LEAKAGE INDUCTANCE (MEASURE 2-4, PIN 8÷14 IN S.C, F 10KHz, TA 20°C)	135 uH NOM
LEAKAGE INDUCTANCE (MEASURE 2-4, PIN 8÷14 IN S.C, F 100KHz, TA 20°C)	132 uH NOM
WORKING FREQUENCY (P_{MAX} 200W, TA 20°C)	47 KHZ MIN
RESONANCE FREQUENCY (TA 20°C)	93 KHZ NOM
OPERATING TEMPERATURE (P_{MAX} 200W, TA=25°C)	-10°C÷+45°C
PRIMARY TO SECONDARY INSULATION (F 50Hz, TEST DURATION 2", TA 20°C)	4KV
MAX DIMENSIONS	39x39x30 mm
WEIGHT	65 g APPROX

Figure 7. Common mode inductor (Code 07228 Class Code 2258.0001 Magnetica)



- inductance (1-2 = 4-3) 10.5 mH min
- (measured 1 kHz, T_A 20 °C)
- resistance (1-2 = 4-3) 240 m max
- (measured DC, T_A 20 °C)
- leakage inductance 0.53% nom
- (measured 1-2 and 4-3 in S.C, F 10 kHz, T_A 20 °C)
- operating current 1.8 A max
- (measured 1-2 and 4-3,T_A 20 °C)
- operating frequency 50–60 Hz
- (current 1.8 A Max, T_A 20 °C)
- insulation (1-2 4-3) 1500 V max
- (F 50 HZ, duration test 2", T_A 20 °C)
- ambient temperature range: –20 °C to +85 °C

- (I_R 1.8 A max, with self t_{rise} 45 °C)
- thermal CLASS B
- storage temperature range: –20 °C to +85 °C
- maximum dimensions: 25.4 x 19, H 28 mm, weight 18 g approx.

5 Functional and thermal test

Table 3. Functional and thermal test

	Test	190 Vac	230 Vac	265 Vac
Functional	Tstart (sec)	3.9	3	2.2
Functional	Pin no load (W)	1	0.6	0.5
Functional	η@load 6.5 A (%)	91	92	93
Functional	η@load 3.5 A (%)	91.5	92.5	93.5
Functional	Freq @ load6.5A (kHz	66	80	98
Functional	ILimit (A)	12	13.5	16
Thermal	Delay time thermal protection 200 W (sec)		45	
Thermal	Delay time thermal protection 250 W (sec)		32	

All the measurements are typical and performed at 30 °C ambient temperature.

Thermal testing is performed starting with a power of 100 W applied for 30 min.

6 Waveform

Figure 8. I_{RES} & V_{HB} load 6.5 A V_{IN} min.

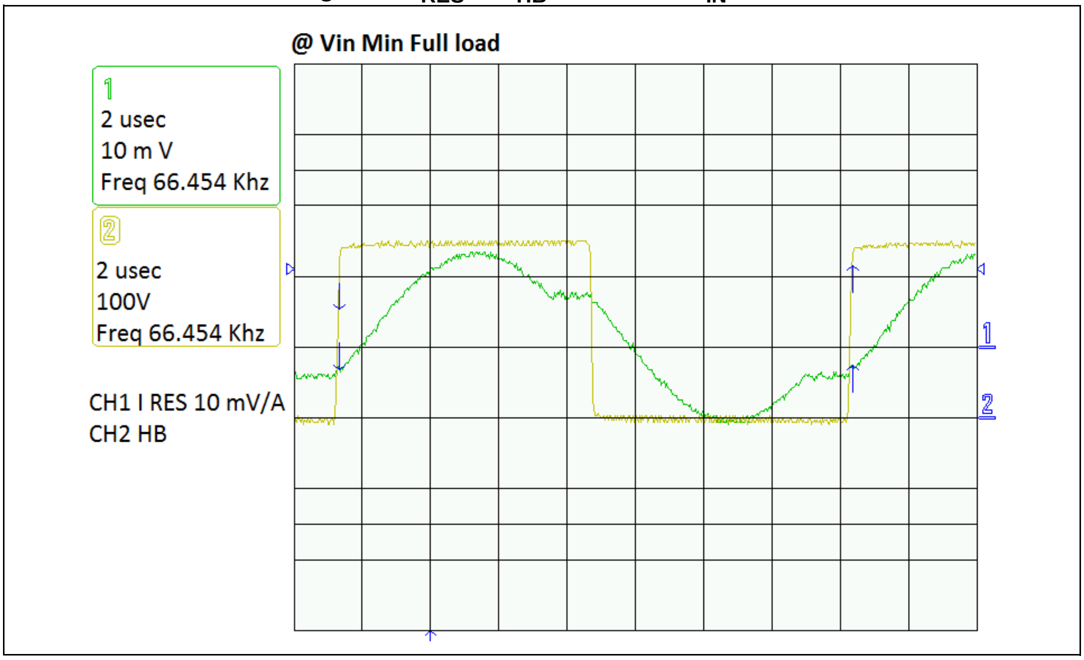


Figure 9. I_{RES} & V_{HB} load 6.5 A V_{IN} nom.

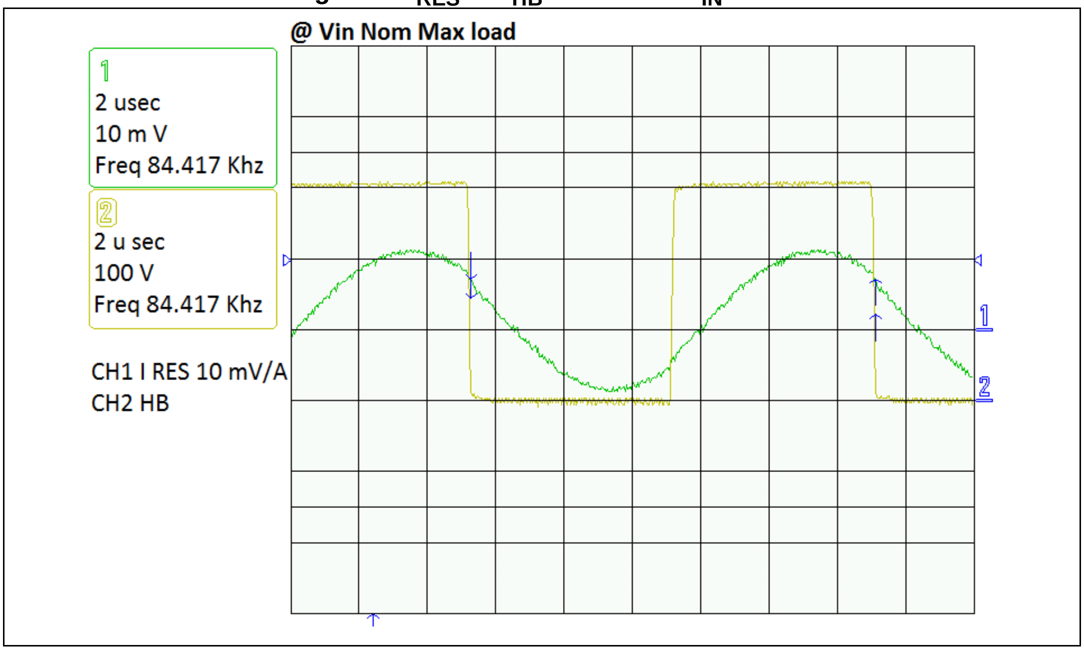


Figure 10. I_{RES} & V_{HB} load 6.5 A V_{IN} max

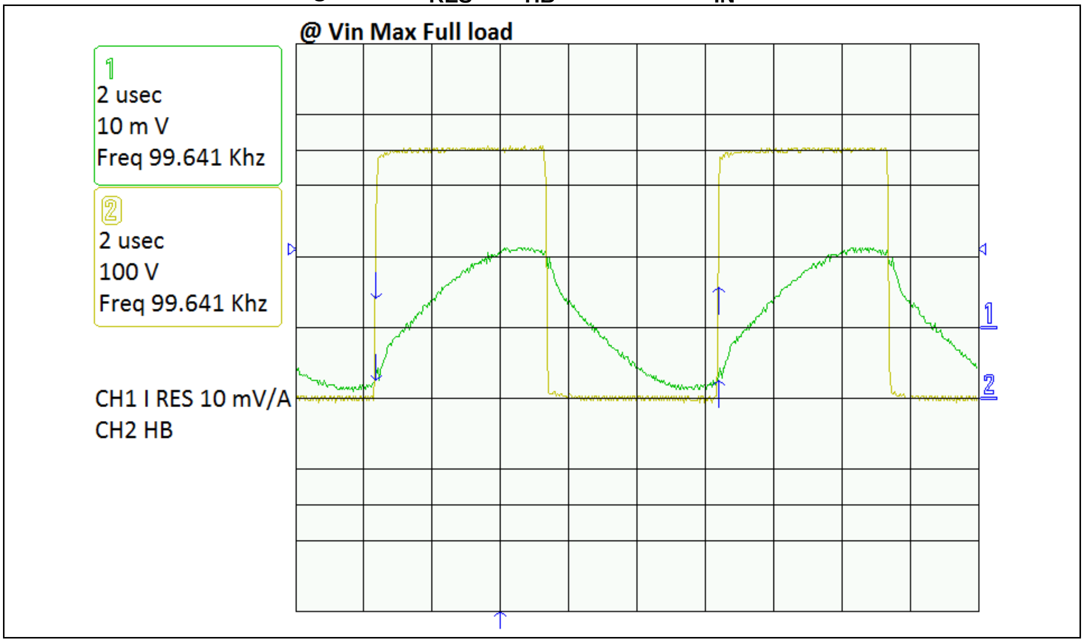


Figure 11. Startup @ 230 V_{AC}

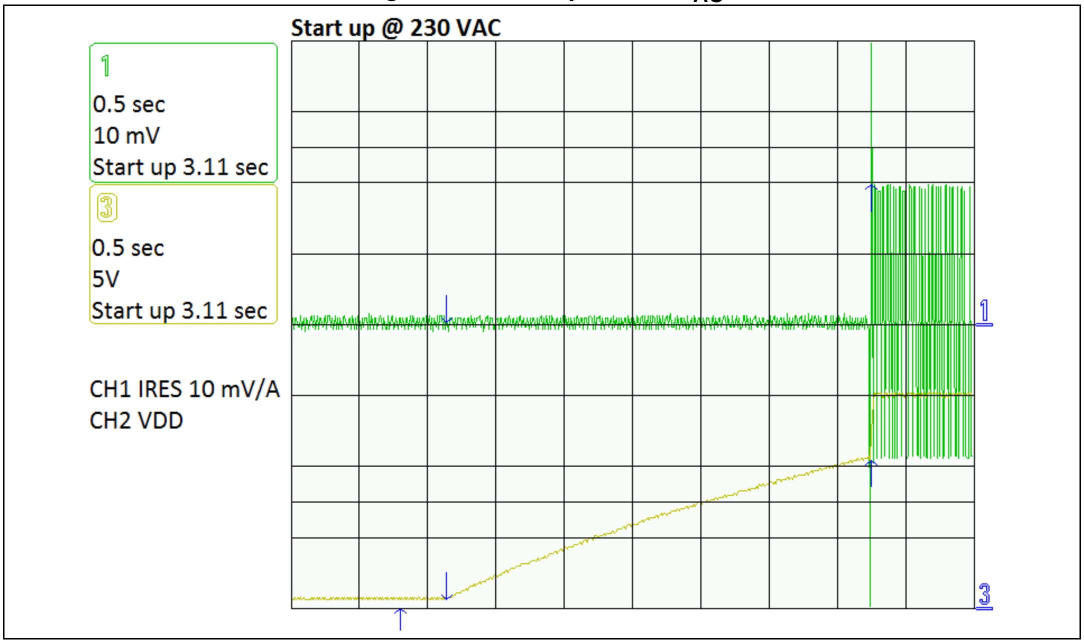
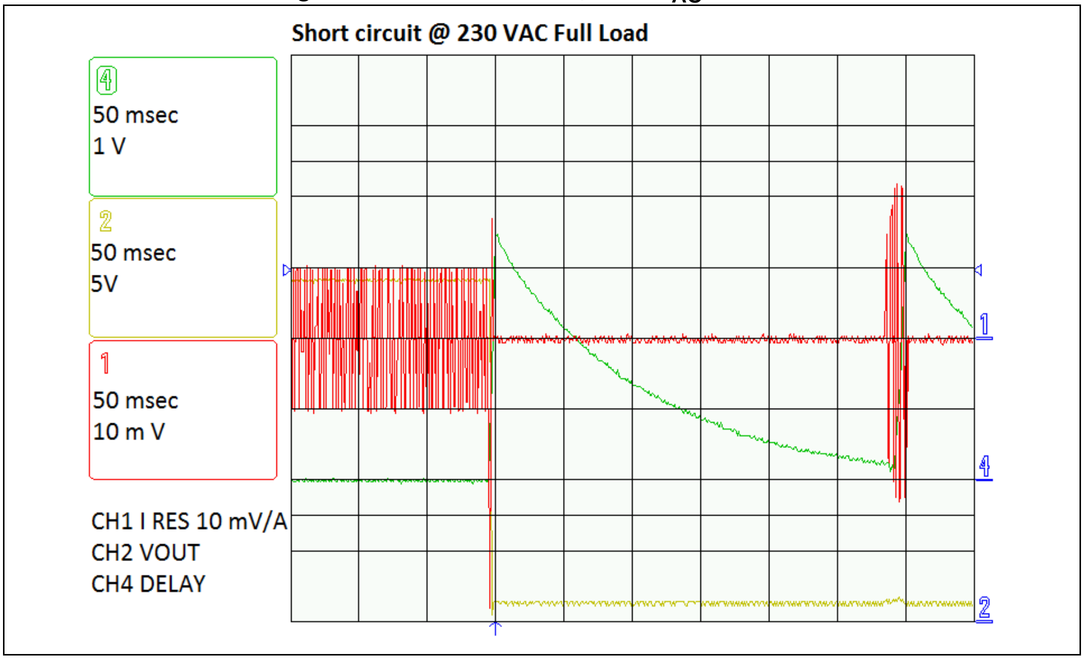
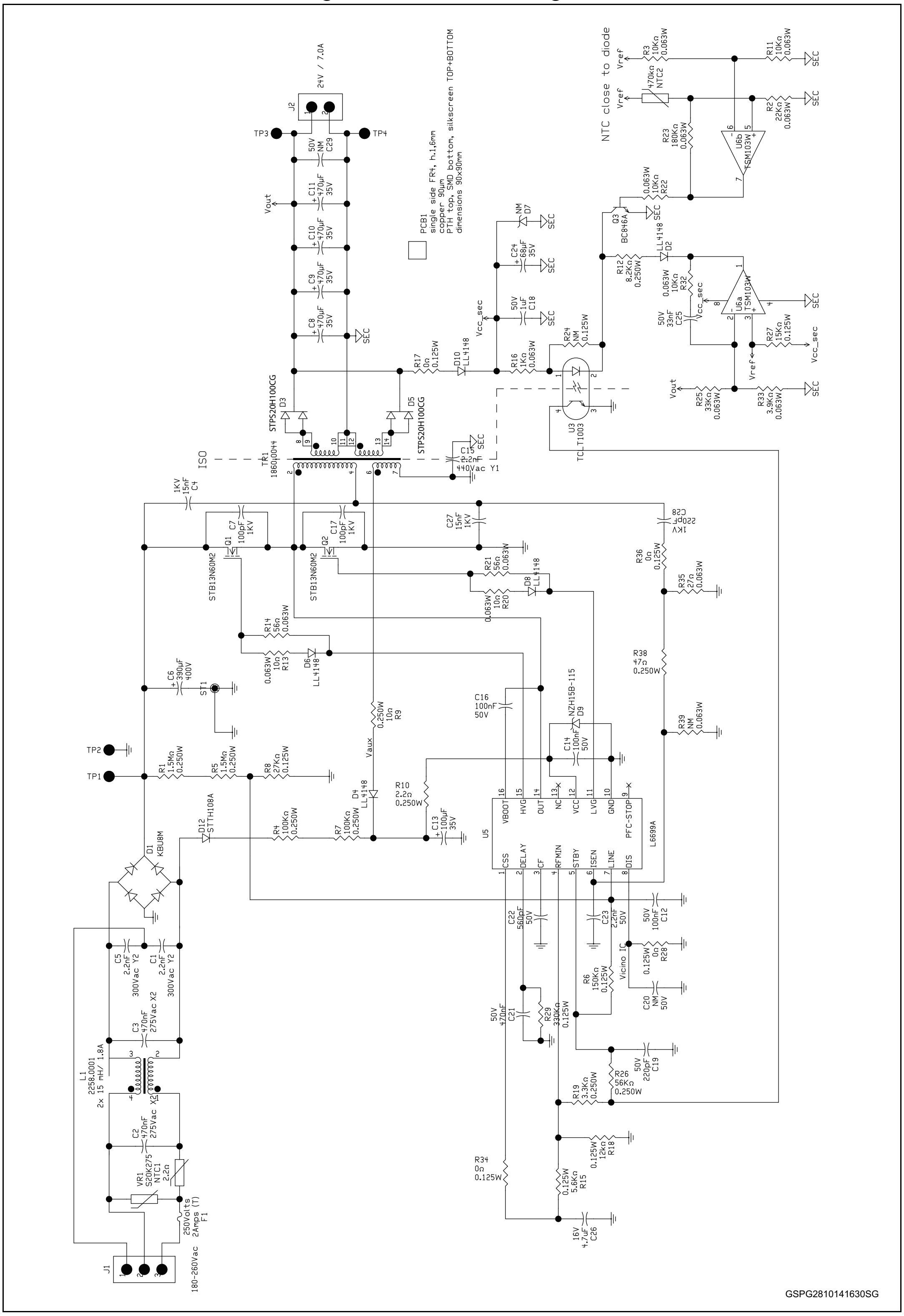


Figure 12. Short circuit @ 230 V_{AC} full load



7 Electrical diagram

Figure 13. Electrical diagram



8 Bill of material

Table 4. Bill of material

Type/Value	Modifier	Part number	Manuf.	Description	Qty	Reference IDs
NM	50V	Generic	Generic	Generic capacitor - 0805	1	C20
NM	50V	Generic	Generic	Generic capacitor - 1206	1	C29
100pF	1KV	Generic	Generic	Generic capacitor - 1206	2	C7, C17
220pF	1KV	Generic	Generic	Generic capacitor - 1206	1	C28
220pF	50V	Generic	Generic	Generic capacitor - 0805	1	C19
560pF	50V	Generic	Generic	Generic capacitor - 1206	1	C22
2.2nF	300Vac Y2	PHE850EA4220MA01R	KEMET	Generic capacitor - P10.0	2	C1, C5
2.2nF	300Vac Y1	Generic	KEMET	Generic capacitor - P10.0	2	C15
2.2nF	50V	Generic	Generic	Generic capacitor - 0805	1	C23
15nF	1.5KV	B32652A1153J	EPCOS	Generic capacitor - P15.0	2	C4, C27
33nF	50V	Generic	Generic	Generic capacitor - 0805	1	C25
100nF	50V	Generic	Generic	Generic capacitor - 0805	2	C12, C14
100nF	50V	Generic	Generic	Generic capacitor - 1206	1	C16
470nF	275Vac X2	Generic	Generic	Generic capacitor - P15.0	2	C2 C3
470nF	50V	Generic	Generic	Generic capacitor - 0805	1	C21
1µF	50V	Generic	Generic	Generic capacitor - 1206	1	C18
4.7µF	16V	Generic	Generic	Generic capacitor - 0805	1	C26
68µF	35V	Generic	Generic	Generic polarized capacitor -P3.5	1	C24
100µF	35V	Generic	Generic	Generic polarized capacitor -P3.5	1	C13
390µF	400V	Generic	Generic	Generic polarized capacitor -P10.0	1	C6
470µF	35V	Generic	Generic	Generic polarized capacitor -P5.0	4	C8, C9, C10, C11
KBU8M	-	Generic	Generic	Full-wave Bridge rectifier	1	D1
LL4148	-	Generic	Generic	Generic small signal diode - SOD80	5	D2, D4, D6, D8, D10
NM	-	Generic	Generic	Zener diode - SOD123	1	D7
NZH15B-115	15V	NZH15B-115	NXP	Zener diode - SOD123	1	D9
STPS20H100CG	20A - 100V	STPS20H100CG	ST	Dual common-cathode diode	2	D3, D5
STTH108A	1A - 800V	STTH108A	ST	Generic diode	1	D12
2Amps (T)	250Volts	39212000000	LITTLEFUSE	Fuse - P5.08	1	F1
SIP header	2-pin	796949-3	TE AMP	2-pin Single in-line connector - P5.08	1	J2

Table 4. Bill of material (continued)

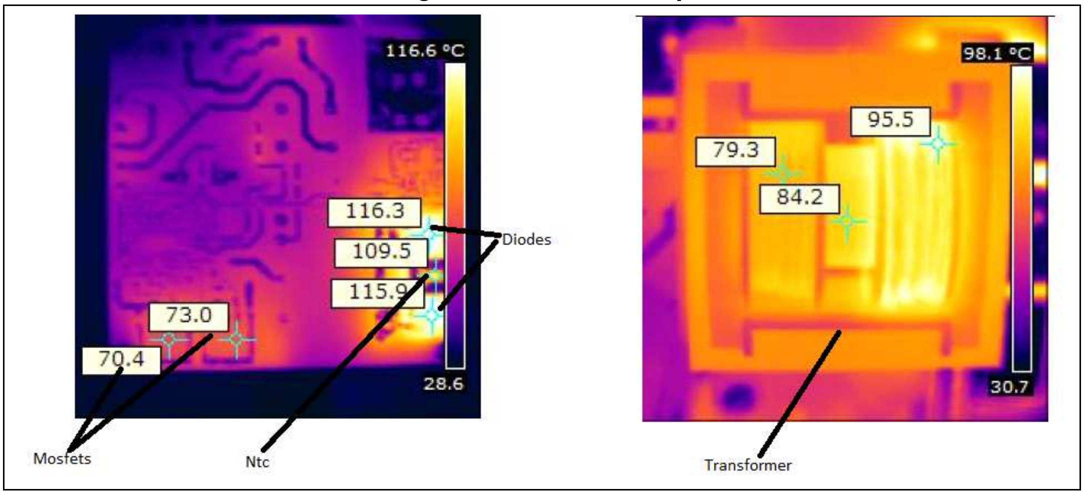
Type/Value	Modifier	Part number	Manuf.	Description	Qty	Reference IDs
SIP header	3-pin	282845-3	TE AMP	3-pin Single in-line connector - P7.62	1	J1
22580001	2x 15 mH/ 1.8A	22580001	MAGNETIC A	Common mode choke	1	L1
2.2 Ω	-	B57237S0229M0	EPCOS	Inrush NTC	1	NTC1
470 kΩ	0603	B57371V2474	EPCOS	NTC	1	NTC2
BC846A	SOT23-3	BC846A	NXP	NPN Generic	1	Q3
STB13N60M2	11A - 600V	STB13N60M2	ST	N-Channel MOS FET	2	Q1, Q2
0 Ω	0.125W	Generic	Generic	Generic resistor	4	R17, R28, R34, R36
NM	0.125W	Generic	Generic	Generic resistor	1	R24
2.2 Ω	0.250W	Generic	Generic	Generic resistor	1	R10
10 Ω	0.063W	Generic	Generic	Generic resistor	2	R13, R20
10 Ω	0.250W	Generic	Generic	Generic resistor	1	R9
27 Ω	0.063W	Generic	Generic	Generic resistor	1	R35
47 Ω	0.250W	Generic	Generic	Generic resistor	1	R38
56 Ω	0.063W	Generic	Generic	Generic resistor	2	R14, R21
1 kΩ	0.063W	Generic	Generic	Generic resistor	1	R16
3.3 kΩ	0.250W	Generic	Generic	Generic resistor	1	R19
3.9 kΩ	0.063W	Generic	Generic	Generic resistor	1	R33
5.6 kΩ	0.125W	Generic	Generic	Generic resistor	1	R15
8.2 kΩ	0.250W	Generic	Generic	Generic resistor	1	R12
10 kΩ	0.063W	Generic	Generic	Generic resistor	4	R3, R11, R22, R32
12 kΩ	0.125W	Generic	Generic	Generic resistor	1	R18
15 kΩ	0.125W	Generic	Generic	Generic resistor	1	R27
22 kΩ	0.063W	Generic	Generic	Generic resistor	1	R2
27 kΩ	0.125W	Generic	Generic	Generic resistor	1	R8
33 kΩ	0.063W	Generic	Generic	Generic resistor	1	R25
56 kΩ	0.250W	Generic	Generic	Generic resistor	1	R26
100 kΩ	0.250W	Generic	Generic	Generic resistor	2	R4, R7
150 kΩ	0.125W	Generic	Generic	Generic resistor	1	R6
180 kΩ	0.063W	Generic	Generic	Generic resistor	1	R23
330 kΩ	0.125W	Generic	Generic	Generic resistor	1	R29
1.5 MΩ	0.250W	Generic	Generic	Generic resistor	2	R1, R5
18600044	520µH/80kHz	18600044	MAGNETIC A	Resonant transformer	1	TR1
L6699D	-	L6699D	ST	Resonant PWM Control	1	U5
TCLT1003	-	TCLT1003	Vishay	Optocoupler	1	U3

Table 4. Bill of material (continued)

Type/Value	Modifier	Part number	Manuf.	Description	Qty	Reference IDs
TSM103W	-	TSM103W	ST	Generic	1	U6
S20K275	275Vac	B72220P3271K101	EPCOS	Varistor	1	VR1

9 Thermal measures

Figure 14. Thermal map



230 V_{AC} Load 7 A steady thermal after 2 h T_{amb} 30° C

summary

- Trasfo Copper 95.5 °C
- Trasfo Core 84.2 °C
- secondary diodes 118.8 °C
- primary MOSFETs 73.6 °C
- common mode choke 69.4 °C

10 EMC precompliance test

Figure 15. EMC test 150 W

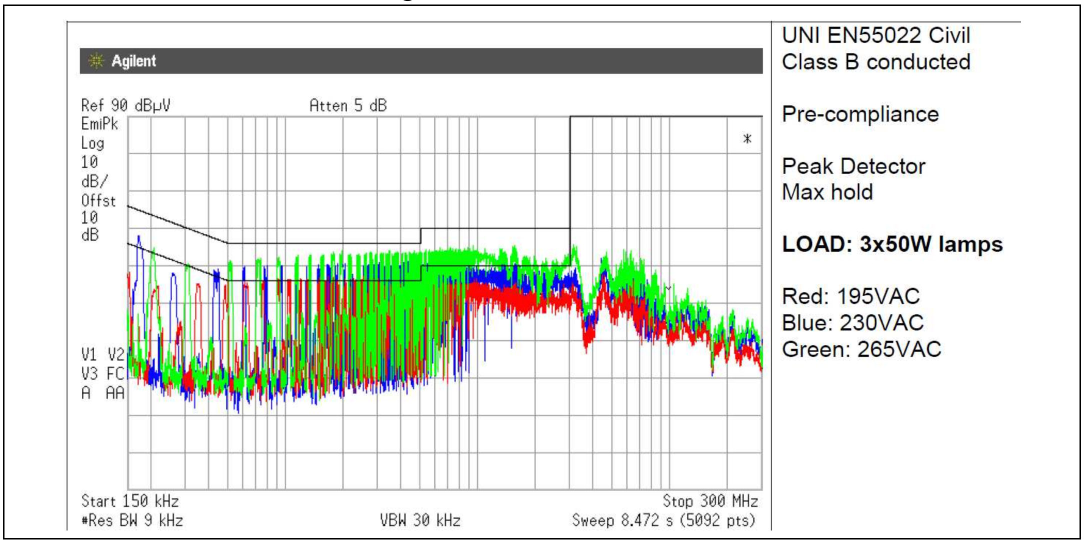
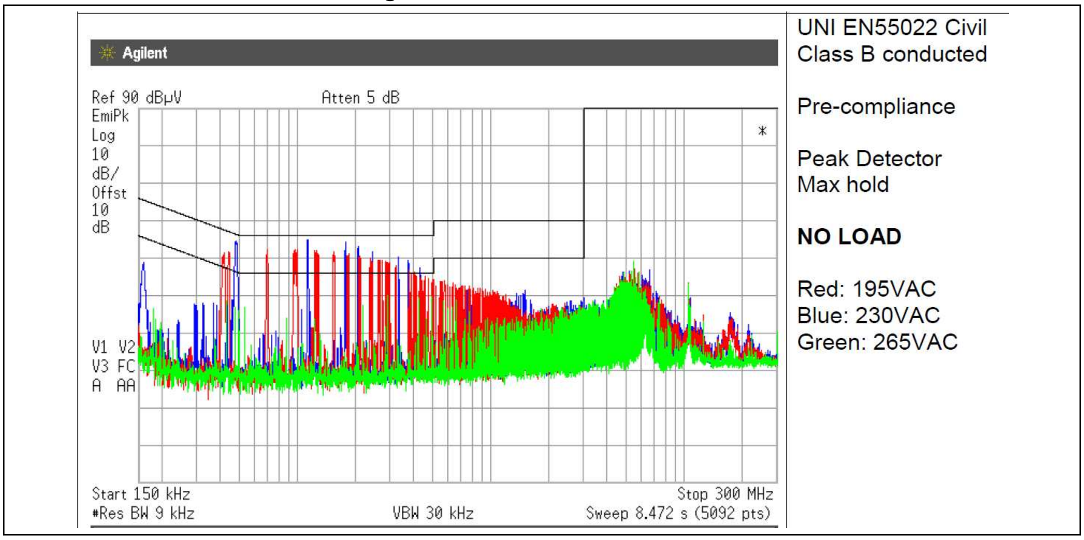


Figure 16. EMC Test No Load



11 Conclusion and remarks

This power supply is a high performance, low cost solution for any application requiring high peak power for a limited time. These are usually industrial applications and don't require PFC stage, such as vending machines, automatic gates, textile machinery etc.

Some features of this power supply can be enhanced with further circuitry. For example, low consumption with no load can be optimized by adding high voltage start up and a more complex compensation for burst mode versus voltage input variation.

It is possible to change the output voltage by changing the R25, R33 voltage divider and the transformer.

Transformer codes for different V_{OUT} are:

- 15 V - 18 V 300 W Peak Transformer MAGNETICA code 1860.0133
- 24 V 300 W Peak Transformer MAGNETICA code 1860.0044
- 28 V - 30 V 300 W Peak Transformer MAGNETICA code 1860.0102
- 36 V 300 W Peak Transformer MAGNETICA code 1860.0134

For voltage output greater than 35 V, limit the voltage at the TSM103W supply V_{CC} sec.

12 Revision history

Table 5. Document revision history

Date	Revision	Changes
03-Feb-2015	1	Initial release.
29-May-2015	2	Updated: - *Figure 13: Electrical diagram* - D3 and D5 part numbers on *Table 4*
28-Jun-2015	3	Updated: C4, C27 modifier value on *Table 4*