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Application Note

AN-CoolMOS-09

200W SMPS Demonstration Board II

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Power Conversion

N e v e r s t o p t h i n k i n g

This application note describes the 200W SMPS Demonstration Board with Infineon power products like CoolMOS, OptiMOS, TDA16888, SiC Schottky diode thinQ!, small signal N- & P-channel MOSFETs.

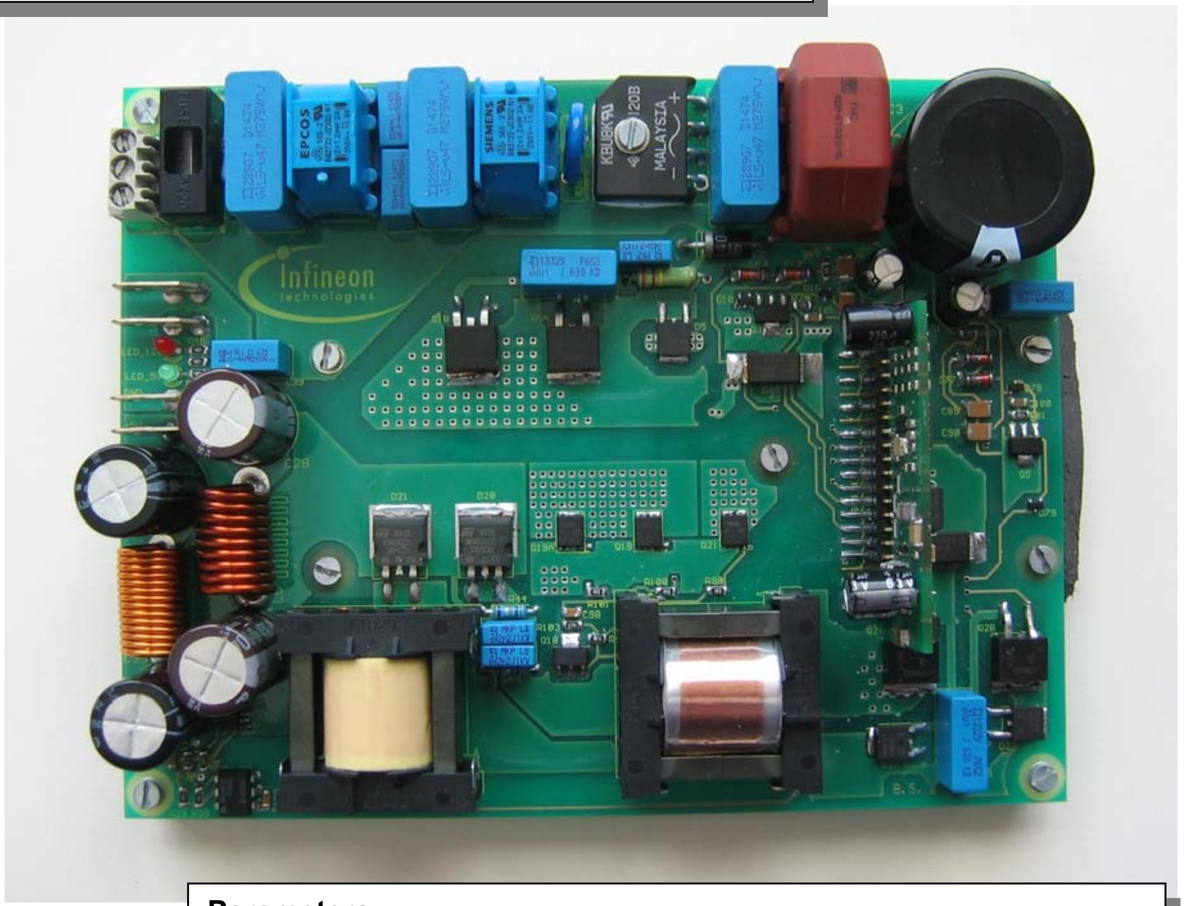
Table of Contents

Danger!
This demonstration board works with mortally high voltage. Do not touch it or any other connected equipment while powered. Be aware that the board could carry high voltage for at least 5 minutes after disconnecting from mains.
The unit can heat up to a high temperature. Risk of burning is given when touching.
Assure yourself when working with this unit that no danger or risk can occur to the user or any other person!
Do not run the main board without properly inserted control board!

1 Features / Parameters

Features:

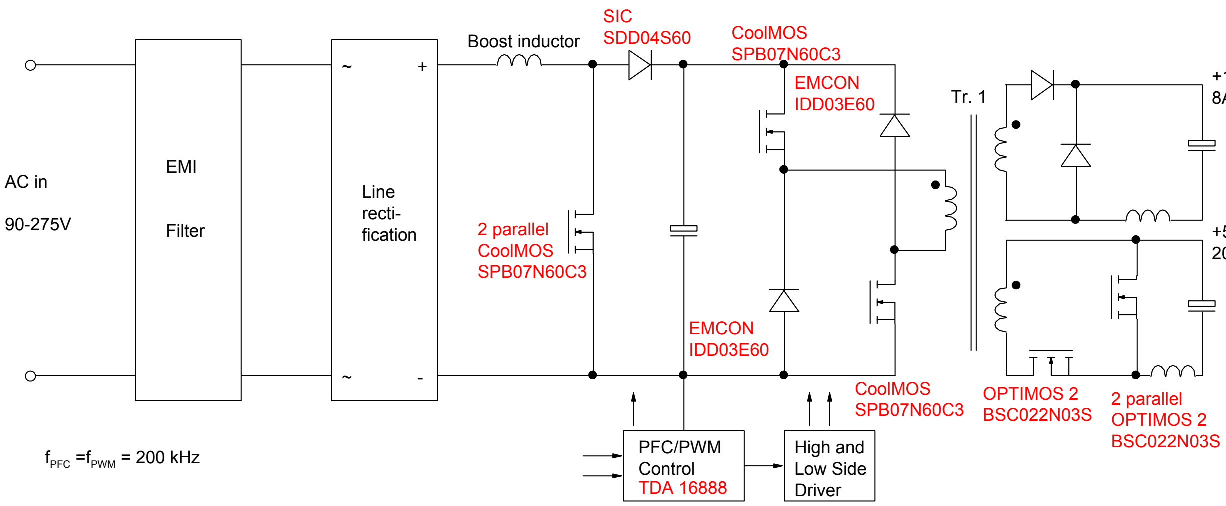
- Infineon & EPCOS components on board
- Third generation of CoolMOS C3 as PFC, PWM switches
- Silicon Carbide (SiC) Schottky diode thinQ! as PFC diode
- OptiMOS2 as synchronous rectification switches
- PFC and PWM controller in one IC
- High efficiency
- No external heat sink required
- No minimum output load required
- Output over load protected
- Output short circuit protected



Parameters:

- wide input voltage range 90-265V
- output power 200W
- output voltages
- 5V / 20A max (load resistance = 0.25Ohm)
- 12V / 8.3A max (load resistance = 1.45Ohm)
- active Power Factor Correction boost converter operates at 200kHz
- hard switching two transistor forward converter operates at 200kHz
- synchronous rectification for 5V output operates at 200kHz

2 General Description / Main Function



Block Diagram

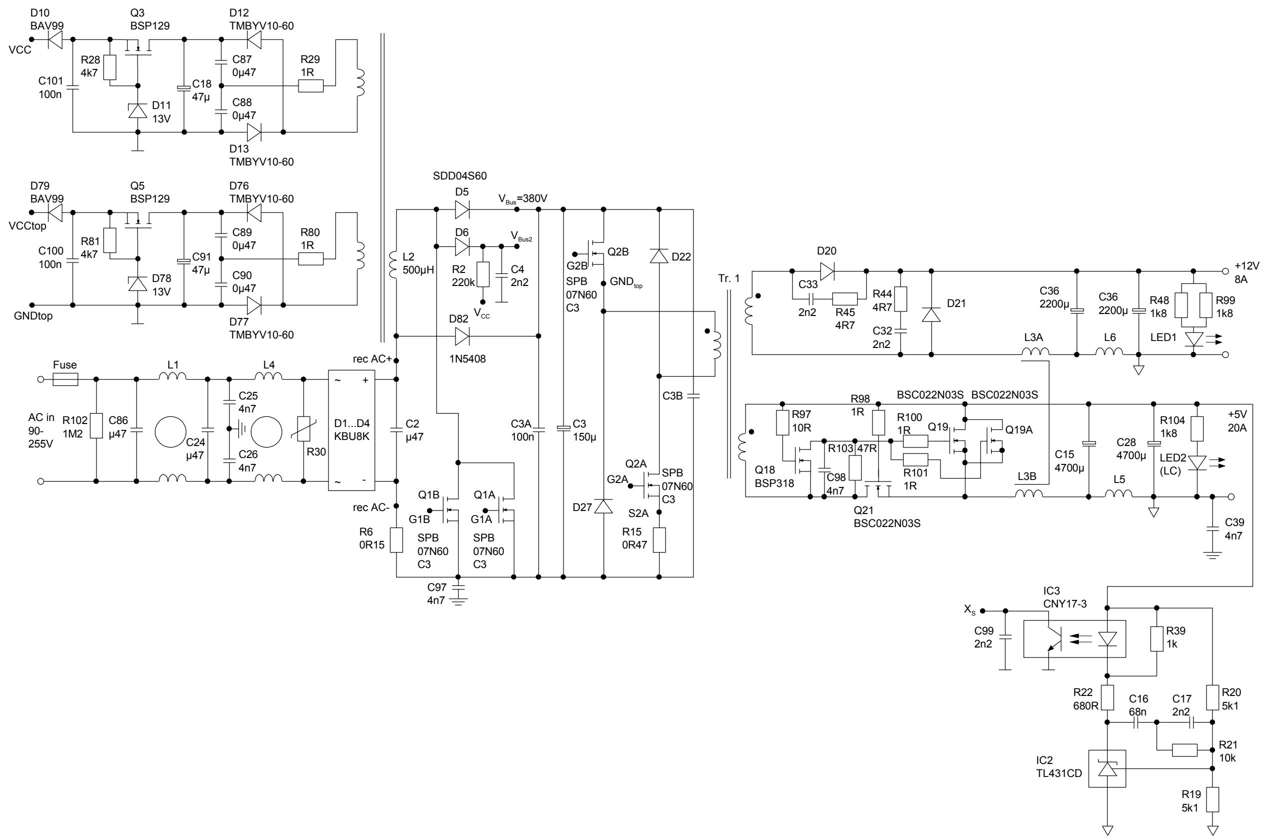
The SMPS Demoboard consists of two power stages, a AC-DC- converter for power factor correction (PFC section) and a PWM-controlled DC-DC-converter configured as a two-transistor forward topology (PWM section). The PFC stage is a step up (boost) converter which serves to provide a 380V DC-bus at its output while consuming sinusoidal line current (near a unity power factor) at the input. Another PFC related feature is the ability to supply the converter with a wide range input voltage (90-265VAC) without range switches to re-configure the rectifier assembly. The power semiconductors used are two CoolMOS SPB07N60C3 in parallel and a silicon carbide diode prototype SDD04S60 (4A/600V).
The two-transistor forward-converter provides isolation from the AC line. There are two output voltages, 5VDC and 12VDC. At the primary side the power semiconductors are two CoolMOS SPB07N60C3 and two EMCON diodes IDD03E60 (3A/600V). At the secondary side the rectification principle is different for each output. At the 12V-path there is a conventional rectification with Schottky diodes. The 5V output is realized as synchronous rectification using low voltage MOSFETS BSC022N03S.
One single integrated circuit, a TDA16888, provides control for both power stages, the PFC and PWM sections.

3 Construction / Heatsinks

A larger PCB (called “main board”) is the mechanical base of the SMPS. It carries the power semiconductors (in SMD lead frame technology) and the passive devices of the power stages. No additional heatsink is used. The copper layers of the board serve to distribute the dissipated energy with the help of a metal plate at the bottom of the board. A smaller PCB (called “control board”) carries the controlling circuitry and is plugged to the “main board” at its top.

4 Description of Functional Part Groups

4.1 Power Stages ("Main Board")



4.1.1 AC input/ EMI Filter

The input voltage of the SMPS is 90 to 265Vac (50/60Hz). A **Fuse** prevents greater damage in the case of catastrophic failure. The function of the line EMI Filter (**C86, L1, L4, C24...26, C2**) is to suppress the high frequency noise caused by the switching transitions of both power stages. Varistor **R30** serves to suppress high voltage line transients to protect the input. The line rectifier (**D1...4**) consists of standard silicon diodes.

4.1.2 PFC Converter

The PFC converter is a step up topology with continuous inductor current at full load. The switching frequency is 200kHz. The output voltage is approximately 380Vdc.
Main parts of the PFC are the boost inductor **L2**, switches **Q1A/Q1B**, boost diode **D5** and the bulk capacitor **C3**. **L2** is an iron powder toroidal core with a single layer of copper wire to keep stray capacitance small. **Q1A/Q1B** are CoolMOS SPB07N60C3 because of their high switching speed and their very low on-resistance (important at low input voltages→higher current, duty cycle). The only reason for paralleling is to get larger cooling areas for better heat distribution at the PCB. The boost diode is a 600V silicon carbide Schottky diode, which has an excellent switching characteristic (no charge storage). **D82**, a conventional silicon diode, is used to initially charge the bulk capacitor from the rectified AC voltage, avoiding high surge current in the unipolar SiC diode. The bulk capacitor **C3** serves to store energy to reduce the second harmonic voltage ripple and it must carry the switching frequency current. **C3A** keeps the commutation circuit short, it's a bypass for high frequency currents.

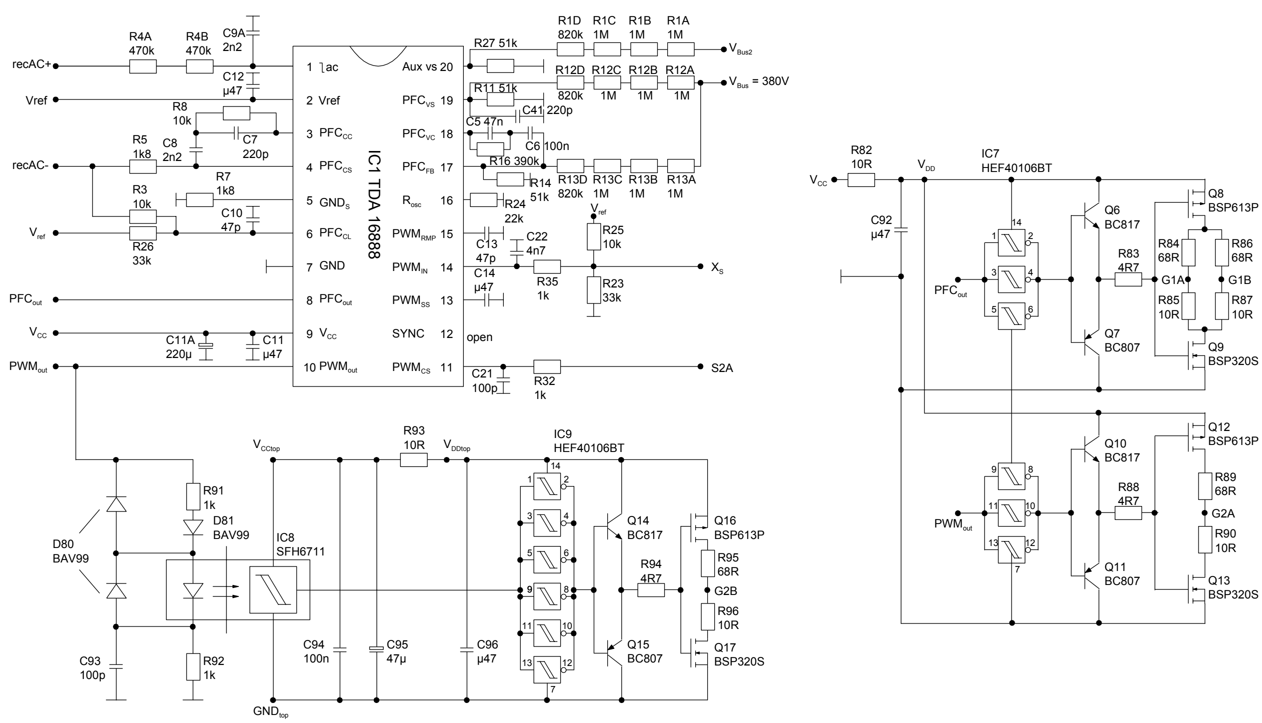
4.1.3 PWM Converter (Two Transistor Forward)

The PWM converter is a two transistor forward topology. The operating frequency of 200 kHz is same as at the PFC section. Main parts at the primary side are **Q2A/Q2B** and **D22/D27.** When the forward transistors **Q2A/Q2B** are switched on simultaneously, energy is transferred to the output through the transformer. The transistors are chosen as CoolMOS SPB07N60C3 because of their high switching speed. **D22/D27** are EMCON diodes. They serve to clamp the flyback voltages from the transformer leakage inductance, during reset of the transformer magnetization, in every turn off cycle. The transformer **Tr.1** provides galvanic isolation of the output from the line and adapts the output voltages from the voltage of the bulk capacitor. The transformer consists of a ETD29/N97-core by EPCOS with tape windings. The windings are interleaved to reduce leakage inductance and winding losses. Main parts at the secondary are **D20/D21, L3A, L6** and **C36/C37** (12V-output) and **Q19/Q21, L3B, L5** and **C15, C28** (5V-output). **D20/D21** are 45-volts standard Schottky diodes, which handle the current in both sequences, when the transistors are on in series rectifier mode or as freewheeling path if the transistors are off.

4.1.4 Synchronous Rectification

At the 5V-path there is used a synchronous rectifier with 30V-MOSFETs BSC022N03S featuring the Super-SO8-package. It uses control waveforms generated by the secondary side of the transformer. Two MOSFETs in parallel, **Q19** and **Q19A** handle the freewheeling current in the "low" PWM state, and one MOSFET, **Q21**, handles the series rectifier circuitry. The freewheeling synchronous rectifiers are turned on in the absence of the PWM pulse output, driven through the body diode of **Q18** during the primary transformer reset interval. When the primary switches turn on, the gate of **Q18** (previously biased negative), driven through **R97** connected to the dot transformer winding, starts switching positive.

4.2 Controlling Circuitry ("Control Board")



4.2.1 General Description of the Combi-IC TDA16888

The TDA 16888 comprises the complete control for power factor controlled switched mode power supplies. With its PFC and PWM section being internally synchronized, it is suitable for two stage off-line converters with worldwide input voltage range. It is designed to reduce system costs by less external parts count.

Special PFC features include:

- Dual loop control (average current and voltage sensing)
- Additional operation mode as auxiliary power supply
- Fast, soft switching totem pole gate drive (1A)
- Leading edge pulse width modulation
- Peak current limitation
- Overvoltage protection

Special PWM features include:

- Improved current mode control
- Fast, soft switching totem pole gate drive (1A)
- Soft-start management
- Trailing edge pulse width modulation
- 50% maximum duty cycle to prevent transformer saturation
- Individually adjustable Power Management

4.2.2 PFC Control

The TDA 16888 provides active power factor control in average current control mode. The “heart” of the PFC section is an analog multiplier. It creates the current programming signal for the current amplifier OP2 by multiplying the rectified line voltage with the output of the voltage amplifier so that the current programming signal has the shape of the input voltage and an average amplitude which controls the output voltage.
At the Demoboard the external circuitry of the voltage amplifier (voltage sensing, compensating) consists of **R13, R14, R16, C5,** and **C6.** The resistor **R4** serves to monitor the actual rectified line voltage. **R5, R7, R8, C7,** and **C8** are the components belonging to the current amplifier, the inductor current is monitored as a voltage drop at **R6** (located at “main board”). **R3, R26** determine the PFC current limit (approx. 6,5A). **R11, R12** fix the overvoltage thresholds.

4.2.3 PWM Control

The TDA 16888 provides an improved current mode control containing effective slope compensation as well as enhanced spike suppression. The converter primary side switch current is monitored as voltage drop at **R15** (located at “main board”). The amplified and “cleaned” current signal sensed at PWMCS (11), measurable at PWMRMP (15), together with the output voltage control loop feedback signal at PWMIN (14), are both inputs of the PWM comparator C8. Together they determine the actual duty cycle. **C14** provides soft start of the PWM section. The components of the output voltage control loop are located at the secondary side of the converter (on the “main board”). The feedback signal is transferred across the isolation barrier via a low cost optocoupler, **IC3.**

4.2.4 Auxiliary Power Supply /Gate Drive Circuitry

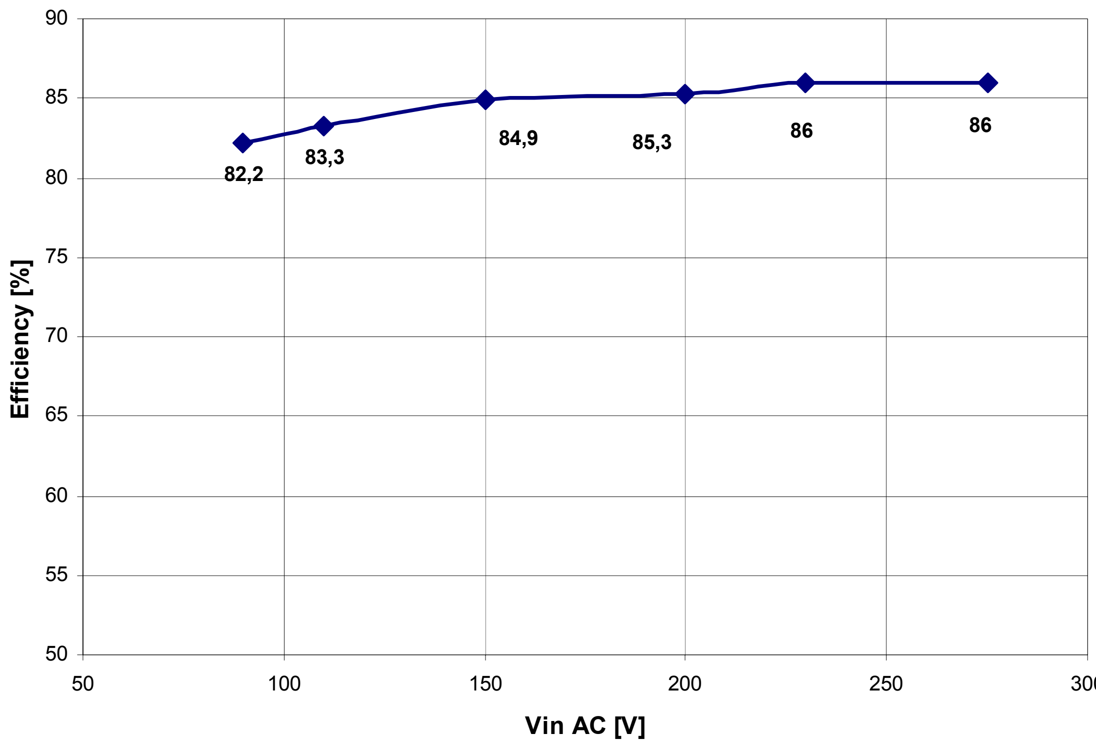
The supply voltage of the control circuitry is generated by an additional winding of the PFC choke **L2**. This cost-efficient technique is featured by the TDA 16888 because of a special control loop, which ensures a continuous generation of auxiliary power even at no load condition and sudden load drops.
Because of the very high operating frequency the PFC section power transistors (**Q1A, Q1B**) and the low side power transistor (**Q2A**) of the PWM stage are driven by discrete high speed, high current driver stages using small signal bipolar transistors and MOSFETs. That’s why the original gate drive signals at PFCOUT/ PWMOUT are schmitt-trigerred and used as inputs of the discrete drivers. The gate drive signal of the high side power transistor (**Q2B**) is transferred via a high-speed optocoupler, **IC8** (SFH 6711), and amplified as described before. The floating supply voltage for the high side driver circuitry is generated by another separate winding of **L2.**

5 Power Losses / Efficiency

Measured power losses at nearly full load and different input voltages:

Vinac/V	Pin/W	Pout/W	V12v/V	I12v/A	V5v/V	I5v/A	η/%
90	225	185,0	10,25	7,2	5,03	22,1	82,2
110	222	185,0	10,25	7,2	5,03	22,1	83,3
150	218	185,0	10,25	7,2	5,03	22,1	84,9
200	217	185,0	10,25	7,2	5,03	22,1	85,3
230	215	185,0	10,25	7,2	5,03	22,1	86,0
275	215	185,0	10,25	7,2	5,03	22,1	86,0

The best efficiency appears at high input voltage, the worst at the lowest. The reason is the variation of the line current. Higher input currents result in increased conduction losses at the input rectifier, EMI Filter, PFC choke and PFC current sense resistor. The RMS value of the PFC transistor current is much higher at low line conditions, when the switches have to carry higher peak currents. Furthermore, the transistors switch at twice the effective duty cycle in order to provide a higher step up rate for the PFC stage. The higher current values also cause increased switching losses of the PFC stage. The behavior of the PWM stage doesn't depend on the input voltage, due to the pre-regulated bulk bus from the output of the PFC stage.



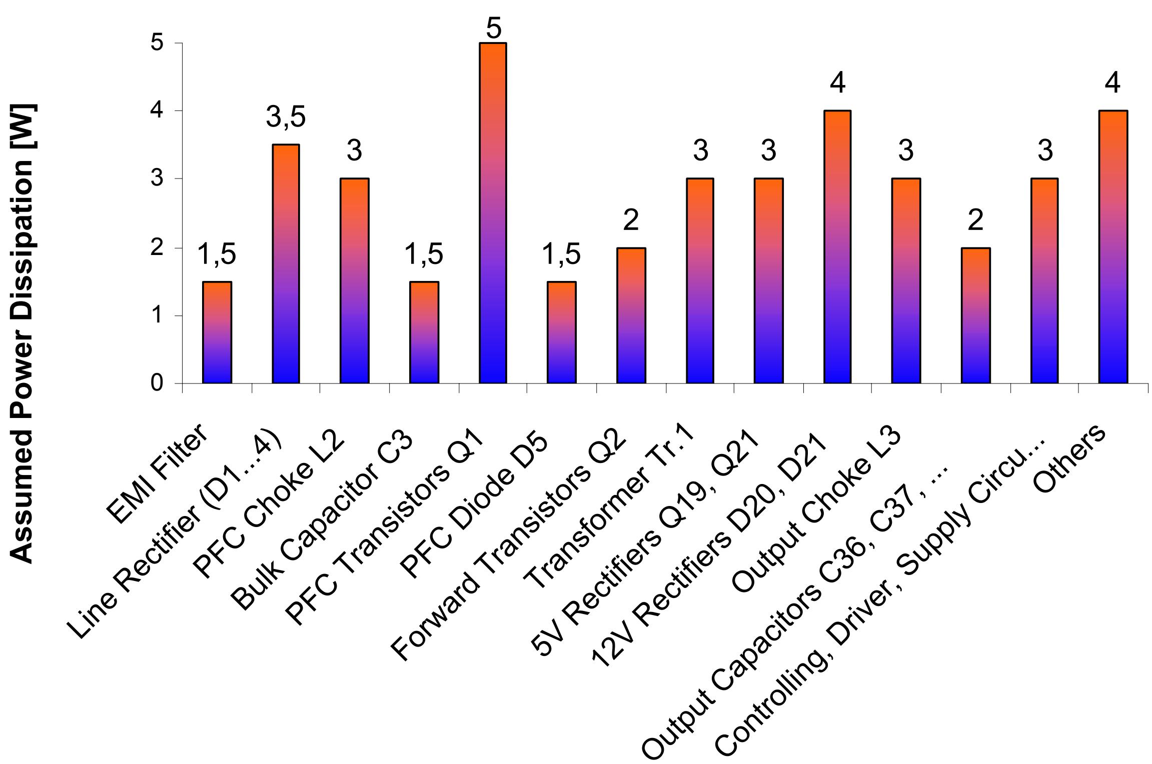
6 Power Loss Sources

The highest power dissipation appears at full load and low line condition.

Operation point:
Vin AC = 90V
Pin = 225W
Pout = 185W
⇒Ploss = 40W

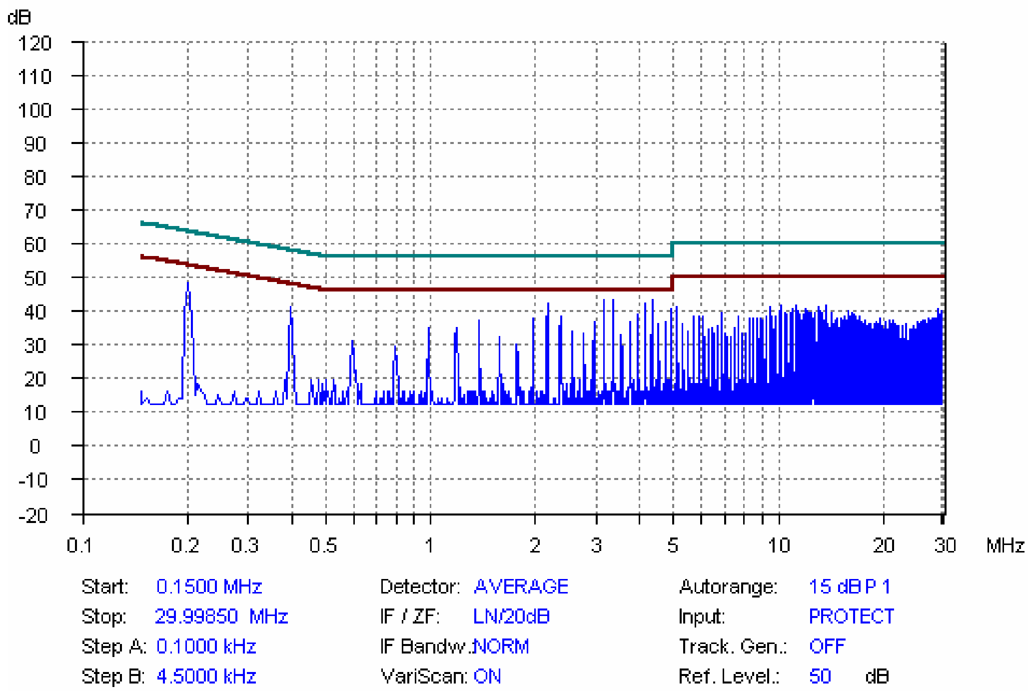
The distribution of the power losses is calculated or assumed by the help of measured device temperatures.

Power Loss Sources	Assumed Power Dissipation/ W
EMI Filter	1.5
Line Rectifier (**D1...4**)	3.5
PFC Choke **L2**	3
Bulk Capacitor **C3**	1.5
PFC Transistors **Q1**	5
PFC Diode **D5**	1.5
Forward Transistors **Q2**	2
Transformer **Tr.1**	3
5V Rectifiers **Q19, Q21**	3
12V Rectifiers **D20, D21**	4
Output Choke **L3**	3
Output Capacitors **C36, C37, C15, C28**	2
Controlling, Driver, Supply Circuitry	3
Others	4
$\sum$	40

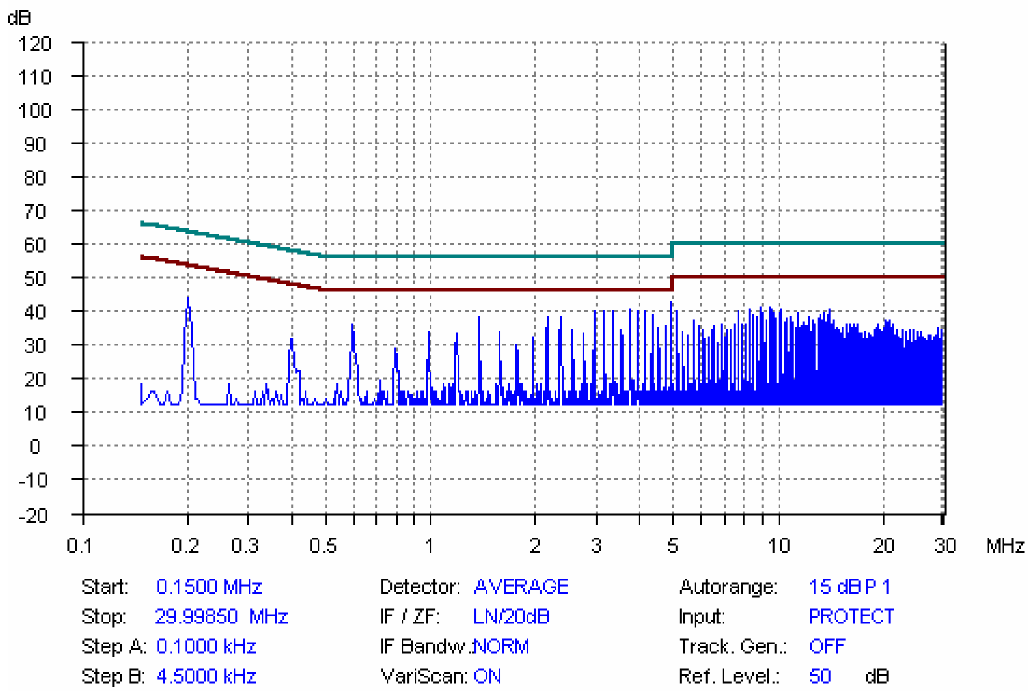


7 Conducted EMI Measurements

Measuring of conducted noise with an EMI-Receiver FMLK 1518 at a Line-Impedance Stabilization Network (LISN) NSLK 8128.
Conditions: VAC in = 230V, Pout = 181,4W, main board in a metal case.



Phase 1, Average



Phase 2, Average

As it can be seen from the figures above the measured EMI spectra are below the norm limit lines.

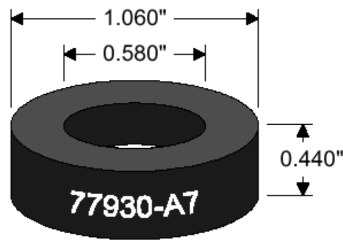
8 Construction of magnetic components

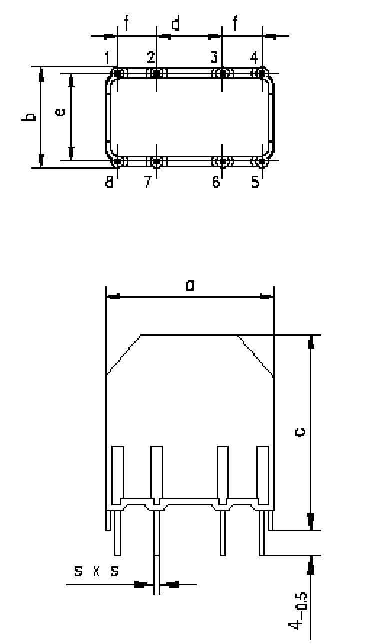
8.1 PFC choke

Core: MAGNETICS Ringcore 77930 - A7; L = 490 µH (Pin1 - Pin8)

1.060"OD × 0.580"ID × 0.440"HT (26.9mm × 14.7mm × 11.2mm)

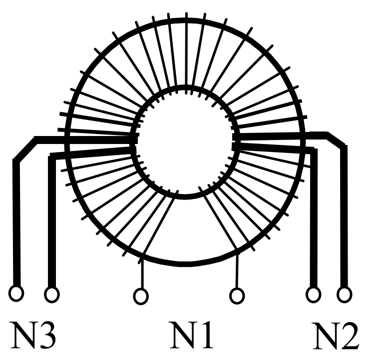
Part Number	Perm. (µ)	AL ± 8%
77932-A7	26	32
77894-A7	60	75
77935-A7	75	94
77934-A7	90	113
77930-A7	125	157





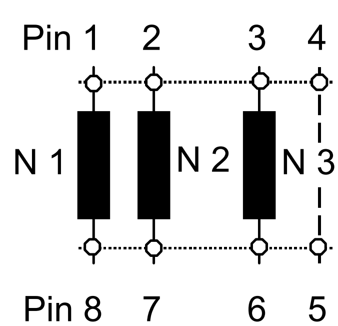
Physical Characteristics		
Window Area	308,000 c.mils	1.56 cm²
Cross Section	0.1014 in²	0.654 cm²
Path Length	2.50 in.	6.35 cm.
Volume	0.254 in³	4.15 cm³
Weight	0.056 lb.	25.5 gm.
Area Product	0.0245 in⁴	1.020 cm⁴

Core Dimensions (after finish)		
O.D. (max.)	1.090 in.	27.7 mm.
I.D. (min.)	0.555 in.	14.10 mm.
HT. (max.)	0.470 in.	11.94 mm.
Surface Area	3.83 in²	24.7 cm²



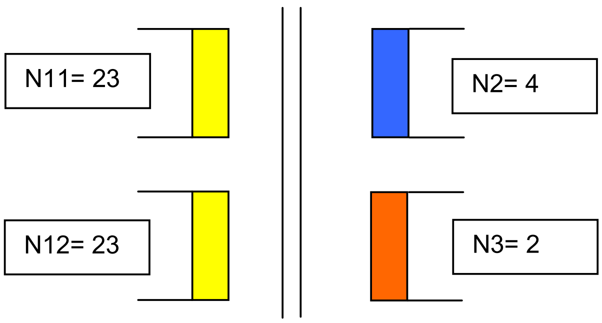
N1: 56 turns 0,5mm ∅
N2: 4 turns 0,2mm ∅
N3: 4 turns 0,2mm ∅

Hole arrangement
View in mounting direction



8.2 Main transformer

Core: ETD29/16/10, N97
without airgap
ratio: 23:2:1

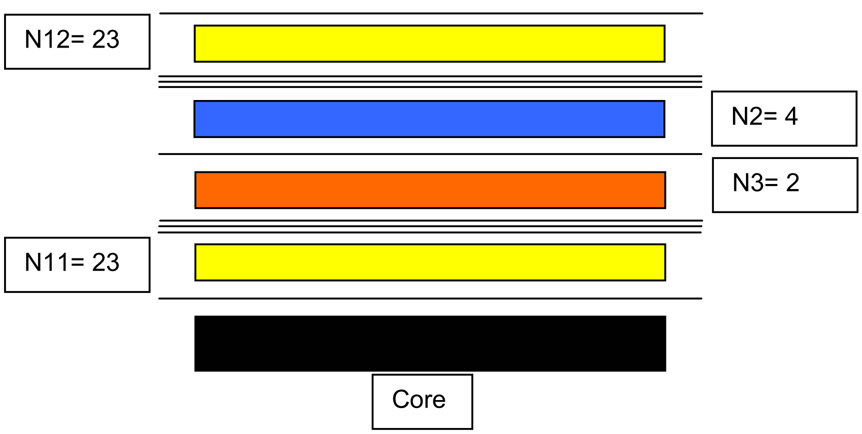


N11/ N12 are series connected (on PCB)

Windings:

Cu-tape
N1: 13,4 x 0,035 mm
N2: 13,4 x 0,070 mm
N3: 13,4 x 0,100 mm

Design: **interleaved**



8.3 Output filter choke

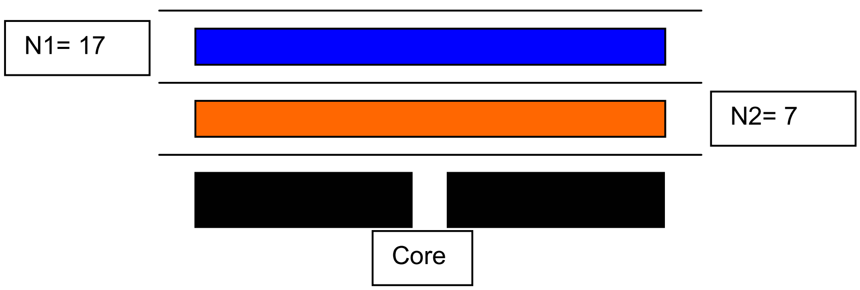
Core: ETD29/16/10, N97
Air gap (total): 1,5 mm → Al= 93,4nH

→Inductance: L1= 27µH
L2= 4,6µH

Windings:

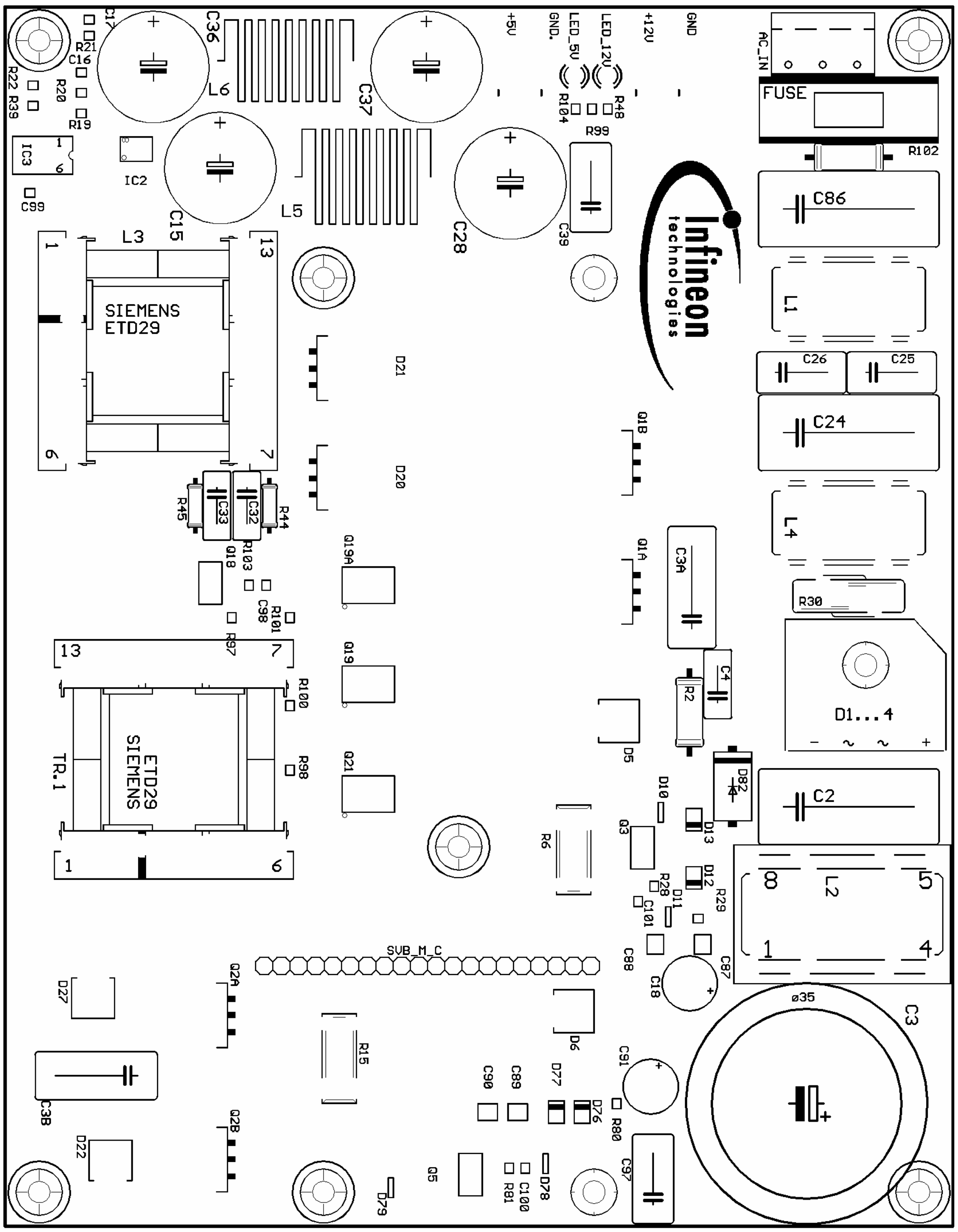
Cu-tape
N1: 15,4 x 0,050 mm
N2: 15,4 x 0,150 mm

Design:

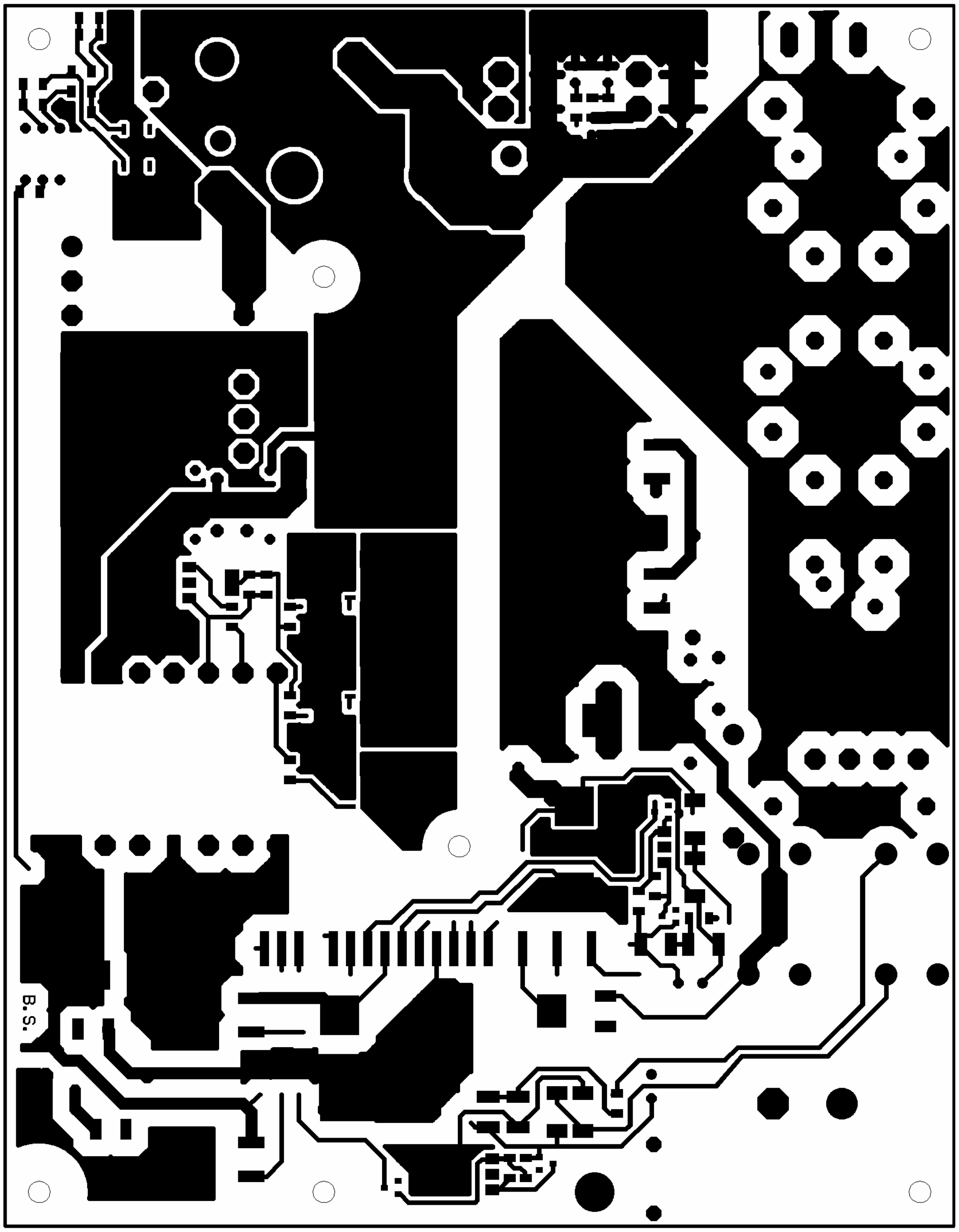


9 PCB Layout

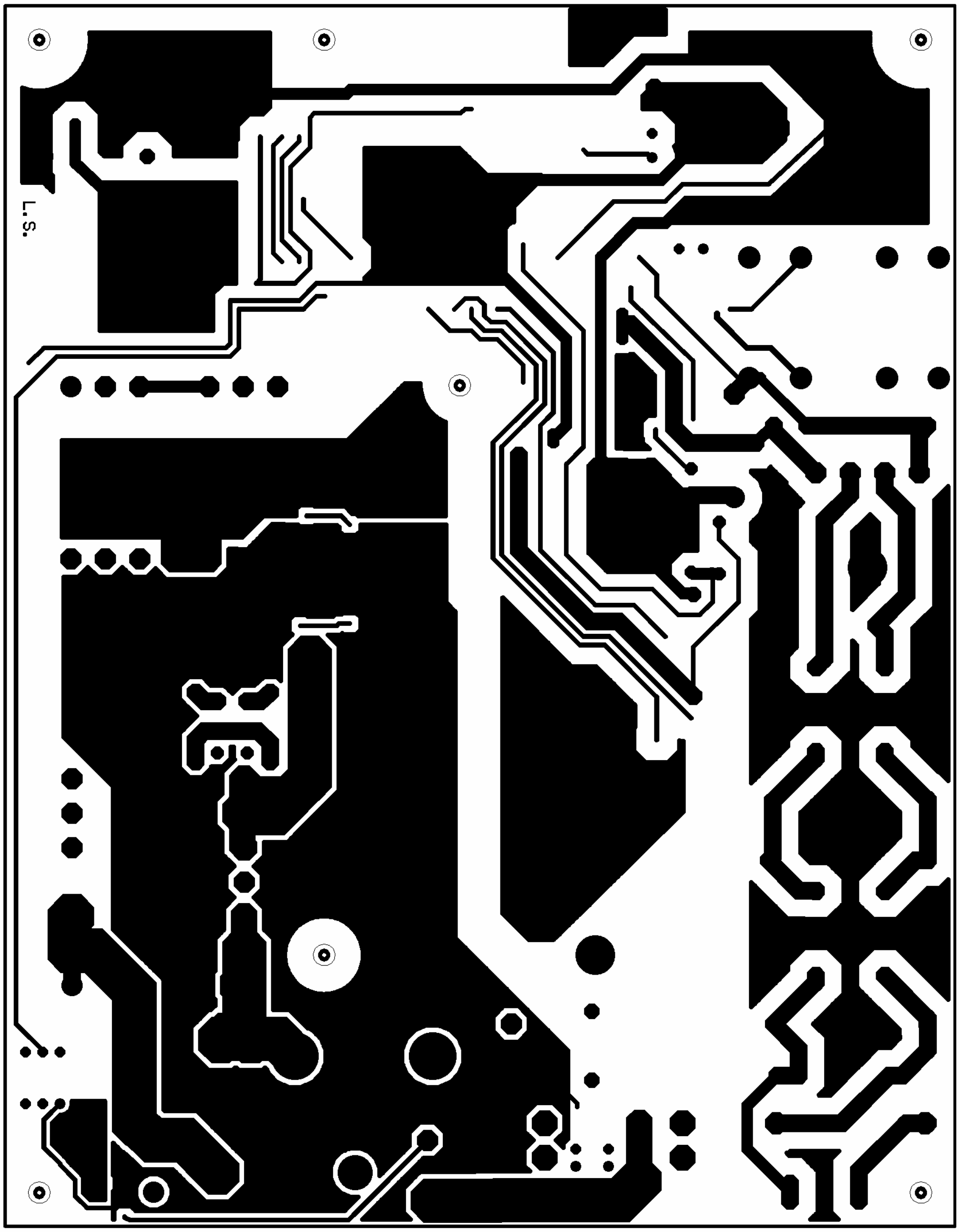
9.1 Main Board - Scaling 1:1



Main Board/ Top/ Components

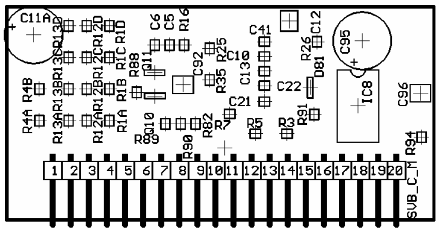


Main Board /Top / Copper

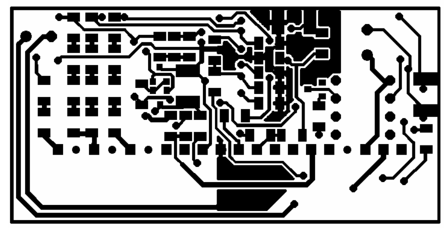


Main Board/ Bottom/ Bottom View/ Copper

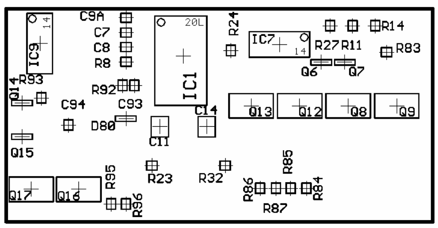
9.2 Control Board- Scaling 1:1



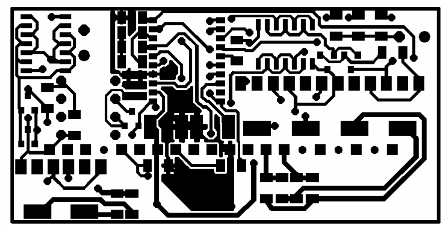
Control Board/ Top/ Components



Control Board/ Top/ Copper



Control Board/ Bottom/ Bottom View/ Components



Control Board/ Bottom/ Bottom View/ Copper

10 Bill of Materials

10.1 Main Board

Part	Value	Package	Position (mil)
+5V		FLSTL6,3	(500 3275)
+12V		FLSTL6,3	(500 4075)
AC_IN		KLEMME-3	(200 5150)
C2	u47/X2	C22,5B11	(4650 5300)
C3	150u/450V	EB35D	(6375 5053.74)
C3A	100n/630V	C15B7	(3375 4387.5)
C3B	100n/630V	C15B7	(6200 825)
C4	2n2/1kV	C7,5B4	(3937.5 4537.5)
C15	4m7/10V		(1050 1525)
C16	68n	1206	(700 200)
C17	2n2	1206	(500 200)
C18	47u/63V	E3,5-8	(5675 4375)
C24	u47/X2	C22,5B11	(2475 5300)
C25	4n7/Y	C10B6	(2125 5550)
C26	4n7/Y	C10B6	(2125 5025)
C28	4m7/10V		(1050 3275)
C32	2n2/1kV	C7,5B4	(2900 1800)
C33	2n2/1kV	C7,5B4	(2900 1625)

	Value	Package	Position (mil)
C36	2m2/25V		(362.5 1112.5)
C37	2m2/25V		(362.5 2762.5)
C39	4n7/Y	C10B6	(1050 3800)
C86	u47/X2	C22,5B11	(1175 5300)
C87	u47	1812	(5450 4450)
C88	u47	1812	(5450 4175)
C89	u47	1812	(6425 3375)
C90	u47	1812	(6425 3200)
C91	47u/63V	E3,5-8	(6275 4150)
C97	4n7/Y	C10B6	(6812.5 4162.5)
C98	4n7	1206	(3362.5 1912.5)
C99	2n2	1206	(1143.75 250)
C100	100n	1206	(6750 3418.75)
C101	100n	1206	(5200 4075)
D1...4	KBU8K	KBU-L	(4375 5400)
D5	SDD04S60	DPAK	(4150 3925)
D6	IDD03E60	DPAK	(5837.5 3700)
D10	BAV99	SOT-23	(4681.25 4206.25)
D11	BZX84C13	SOT-23	(5287.5 4250)
D12	TMBYV10-60	MELF	(5062.5 4400)
D13	TMBYV10-60	MELF	(4725 4400)
D20	MBRB2545	D2PAK	(2737.5 2325)
D21	MBRB2545	D2PAK	(2100 2325)
D22	IDD03E60	DPAK	(6575 650)
D27	IDD03E60	DPAK	(5875 642.52)
D76	TMBYV10-60	MELF	(6425 3750)
D77	TMBYV10-60	MELF	(6425 3600)
D78	BZX84C13	SOT-23	(6725 3537.5)
D79	BAV99	SOT-23	(6862.5 2637.5)
D82	1N5408	DO201-15	(4531.25 4625)
E$5		BO3,2-P	(6889.76 3818.9)
E$9		BO3,2-P	(1574.8 3818.9)
FUSE	4AT	SH22	(600 5300)
GND		FLSTL6,3	(500 4325)
GND.		FLSTL6,3	(500 3525)
IC2	TL431CD	SO-8	(250 600)
IC3	CNY17-3	DIL06	(987.5 475)
L1	2x1m2	82722J	(1700 5300)
L2	500u	INF-PFC	(5275 5262.5)
L3	36/6uH	RM14-12A	(2075 1000)
L4	2x1m2	82722J	(3000 5300)
L5	1u	INAIR20A	(1050 2400)
L6	1u	INAIR8A	(312.5 1937.5)

Part	Value	Package	Position (mil)
LED_5V	Green/LC	LED3	(400 3706.25)
LED_12V	Red	LED3	(400 3893.75)
Q1A	SPB07N60C3	D2PAK	(3400 3925)
Q1B	SPB07N60C3	D2PAK	(2650 3925)
Q2A	SPB07N60C3	D2PAK	(5862.5 1625)
Q2B	SPB07N60C3	D2PAK	(6700 1625)
Q3	BSP129	SOT-223	(4887.5 4100)
Q5	BSP129	SOT-223	(6787.5 3100)
Q18	BSP318	SOT-223	(3350 1587.5)
Q19	BSC022N03S	P-TDSON-8	(4012.5 2325)
Q19A	BSC022N03S	P-TDSON-8	(3375 2325)
Q21	BSC022N03S	P-TDSON-8	(4650 2325)
R2	220k/2W	0411/15	(4100 4375)
R6	0R15/1W	R-SMR	(4900 3700)
R15	R47	R-SMR	(6112.5 2337.5)
R19	5k1	1206	(450 500)
R20	5k1	1206	(700 650)
R21	10k	1206	(450 350)
R22	680R	1206	(700 500)
R28	4k7	1206	(5112.5 4168.75)
R29	1R	1206	(5300 4425)
R30	S14K275	S14K275	(3425 5300)
R39	1k	1206	(700 350)
R44	4R7/0,6W	0207/10	(2900 1925)
R45	4R7/0,6W	0207/10	(2900 1500)
R48	1k8	1206	(593.7 3897.98)
R80	1R	1206	(6375 3950)
R81	4k7	1206	(6750 3325)
R97	10R	1206	(3550 1712.5)
R98	1R	1206	(4387.5 2087.5)
R99	1k8	1206	(593.75 3806.25)
R100	1R	1206	(3750 2075)
R101	1R	1206	(3112.5 2075)
R102	1M2/Netz	0411/15	(875 5300)
R103	47R	1206	(3362.5 1812.5)
R104	1k8	1206	(593.75 3712.5)
S$63		BO3,2-P	(3825 5400)
SVB_M_C		1X20SMDI	(5575 2850)
TR.1		RM14-12A	(4550 1000)

10.2 Control Board

Part	Value	Package	Position (mil)
C5	47n	1206	(900 968.75)
C6	100n	1206	(818.75 968.75)
C7	220p	1206	(1699.36 1050)
C8	2n2	1206	(1699.36 968.75)
C9A	2n2	1206	(1699.36 1131.26)
C10	47p	1206	(1424.36 906.24)
C11	u47	1812	(1511.85 528.12)
C11A	220u/25V	E3,5-8	(150 1025)
C12	u47	1812	(1561.87 1103.13)
C13	47p	1206	(1424.37 825)
C14	u47	1812	(1252.48 528.12)
C21	100p	1206	(1424.37 656.25)
C22	4n7	1206	(1424.37 743.75)
C41	220p	1206	(1424.36 987.5)
C92	u47	1812	(975 749.36)
C93	100p	1206	(1653.13 756.25)
C94	100n	1206	(2018.75 537.5)
C95	47u/63V	E3,5-8	(1965.63 993.75)
C96	u47	1812	(2287.5 703.13)
D80	BAV99	SOT-23	(1700 571.87)
D81	BAV99	SOT-23	(1678.12 734.37)
IC1	TDA16888	SO-20L	(1380.61 918.75)
IC7	HEF40106BT	SO-14	(849.36 981.25)
IC8	SFH6711	DIL-08	(1943.11 631.25)
IC9	HEF40106BT	SO-14	(2175 988.14)
Q6	BC817	SOT-23	(618.75 884.38)
Q7	BC807	SOT-23	(487.5 884.38)
Q8	BSP613P	SOT-223	(468.11 643.75)
Q9	BSP320S	SOT-223	(199.36 643.75)
Q10	BC817	SOT-23	(818.75 687.5)
Q11	BC807	SOT-23	(818.76 815.63)
Q12	BSP613P	SOT-223	(736.86 643.75)
Q13	BSP320S	SOT-223	(1005.61 643.75)
Q14	BC817	SOT-23	(2275.01 659.37)
Q15	BC807	SOT-23	(2275 471.88)
Q16	BSP613P	SOT-223	(1961.86 181.25)
Q17	BSP320S	SOT-223	(2224.35 181.25)
R1A	1M	1206	(568.11 550)
R1B	1M	1206	(568.11 725)
R1C	1M	1206	(568.11 900)
R1D	820k	1206	(568.11 1075)

Part	Value	Package	Position (mil)
R3	10k	1206	(1549.36 478.13)
R4A	470k	1206	(180.61 550)
R4B	470k	1206	(180.61 725)
R5	1k8	1206	(1374.36 478.13)
R7	1k8	1206	(1233.74 587.5)
R8	10k	1206	(1699.36 887.5)
R11	51k	1206	(443.75 1087.5)
R12A	1M	1206	(443.11 550)
R12B	1M	1206	(443.11 725)
R12C	1M	1206	(443.11 900)
R12D	820k	1206	(443.11 1075)
R13A	1M	1206	(343.11 550)
R13B	1M	1206	(343.11 725)
R13C	1M	1206	(343.11 900)
R13D	820k	1206	(343.11 1075)
R14	51k	1206	(318.75 1087.5)
R16	390k	1206	(981.26 968.75)
R23	33k	1206	(1556.25 312.5)
R24	22k	1206	(1118.75 950)
R25	10k	1206	(1121.87 950)
R26	33k	1206	(1714.98 987.5)
R27	51k	1206	(568.76 1087.5)
R32	1k	1206	(1150 312.5)
R35	1k	1206	(1121.87 775)
R82	10R	1206	(1043.75 531.26)
R83	4R7	1206	(256.25 940.63)
R84	68R	1206	(700 187.5)
R85	10R	1206	(787.5 187.5)
R86	68RR	1206	(956.25 187.5)
R87	10R	1206	(868.75 187.5)
R88	4R7	1206	(718.75 706.25)
R89	68R	1206	(878.13 531.25)
R90	10R	1206	(962.5 531.25)
R91	1k	1206	(1700.01 584.38)
R92	1k	1206	(1718.76 756.25)
R93	10R	1206	(2168.75 687.5)
R94	4R7	1206	(2293.75 459.38)
R95	68R	1206	(1781.25 100)
R96	10R	1206	(1700 100)
SVB_C_M		1X20/90I	(1205.61 400)