I would be grateful for a professional translation or correction of the following text. Please E-Mail to **D**elta **L**ima **2** **Y**ankie **E**cho **O**scar **@** **Q**ueen **R**omeo **P**apa **4** **U**niform .**D**elta **E**cho

250 W S.M.P.S. with Power FETs

Safety Instructions

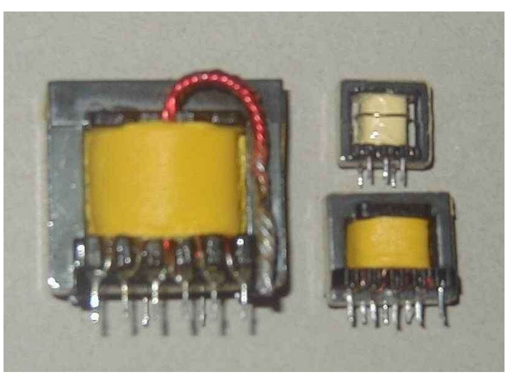
Caution mortal danger: The following circuit operates at a mains voltage of 230 Vac. Because of rectification some of the components conduct dc voltage of more than 322 V. Work has to be carried out only if the circuit is disconnected from the mains and de-energized. Note that capacitors located to the primary side can be charged with high voltage for several seconds even after switching of the mains voltage.

Experiments with the PC power supply encouraged me to an "advancement " design. The new power supply is also a forward converter with a half-bridge topology. The difference to the modified PC power supply consists in the following items: Two power FETs instead of bipolar transistors used as power switches, a synchronous rectifier on the secondary side instead of power diodes, the lack of a driver stage (current-proportional control) and a more simple over-current and over-voltage monitor. With the magnetic components (output transformer, driver transformer, chokes...) stripped from a PC power supply, the new power supply delivers a max. power output of 250 W, whereby the efficiency amounts up to 90 %. The power supply can handle 20 % over-load for a short duration.

Magnetic components from a PC power supply

The magnetic components of PC power supplies for AT boards do not indicate large differences. They are usually designed for a switching frequency of 25... 40 kHz and a power output of 200... 240 W. The transformers on the S.M.P.S circuit boards are to be found often in a small or somewhat larger size. I am not able to say, whether the larger size brings more power or if it is only an older design. For the new power supply I preferred the larger transformers, because of more space for additional turns available at all three transformers. The smaller transformers are completely filled with copper and isolation material and therefore only conditionally suitable for a modification.

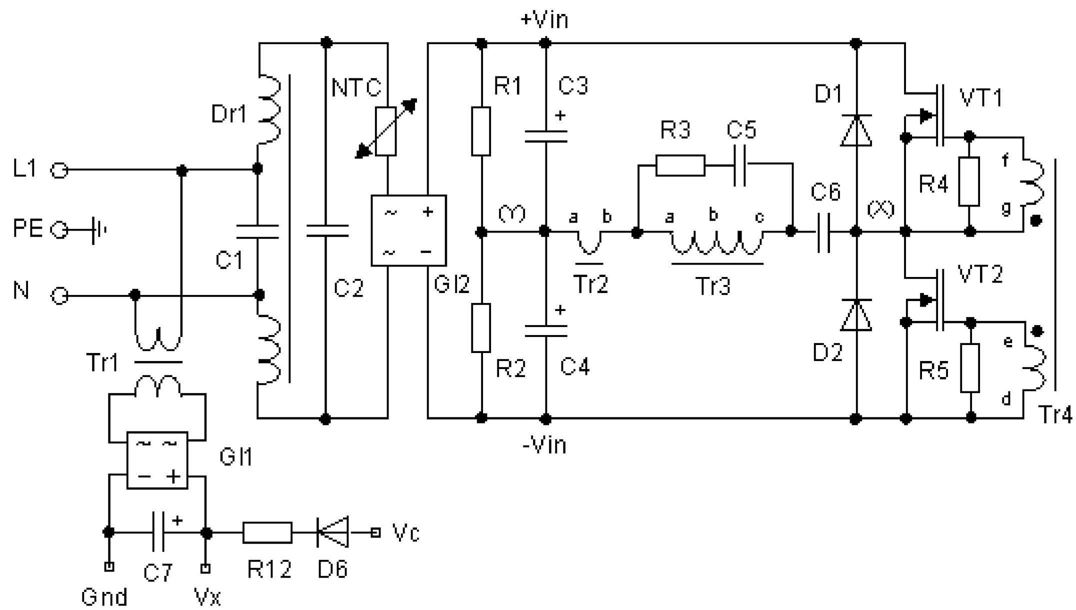
Fig. 1: Transformers from the PC power supply



Mains rectifier and filter

This circuit section is uncomplicated. The current compensated choke Dr1 (mains filter) is followed by a NTC resistor for limiting the inrush current. Its cold resistance amounts to 5 ohms and after few minutes the warm resistance is less than one ohm. The 230 Vac rectifier is generously dimensioned with 4 A and hence no cooling is necessary. A criterion for the selection of the capacity of C3 and C4 is the height of the admissible ripple voltage Ubr and the number of mains voltage half waves to be bridged. For Ubr = 25 V and zero half waves two 470 uF capacitors in series are sufficient. This specification applies to maximum load during low mains voltage Umin = 230 Vac - 15%

Fig. 2: Filter, rectifier and power switches



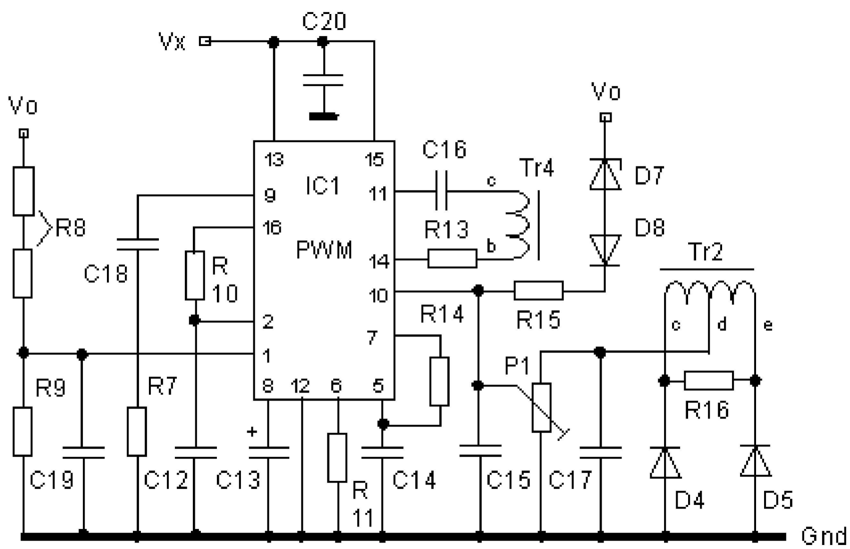
Power switches

As power switches FETs were used due to their short rise and fall times and the easy, component-saving driver circuit. If one is content with switching times of 100 ns, a small driver transformer and two gate resistances are sufficient for triggering the FETs. Re-dimensioning of the secondary winding for the supply of the gate voltage is not to be gone around unfortunately. The single turn and 2 x 8 turns must be removed from transformer Tr4. Instead of this 2 x 16 turns (bifilar) have to be applied. With a winding ratio of 16 : 26 and a 20 Vs control signal from IC1 the FETs gate voltage is up to 10 V high. With this voltage one achieves the indicated FETs Ron of 0,75 ohms and thus very small conduction losses. Dynamic (switching) losses at 50 kHz and the before mentioned switching times assume negligible. The PWM IC drives enough current for fast on /off switching the FETs. Increasing the switching frequency from before 33 kHz (PC power supply) to 50 kHz (new power supply) allows to transfer more energy via the transformer. You can not increase the latter with a given transformer whatever you like, since the transformer is usable for a certain frequency range only. Attempts showed that the transformer can cope with the factor 1.5 without problems (overheating).

Control circuit

After switching on the 230 Vac mains voltage an auxiliary voltage is available from the small 50 Hz transformer Tr1 for starting up the PWM controller SG3525. The P acting operation amplifiers in the SG3525 compares a portion of the 13,8 output voltage (actual value) with the internal +5,1 V reference voltage (set value) and forms from it the correction variable for the pulse width modulator. The modulator sends alternate control pulses via its two outputs to the transformer Tr4. The pulse duration is reciprocal to the correcting variable. Increased loading to the +13.8 V output makes for wider pulses, lighter loading causes narrower pulses. The switching frequency of the power switches is 50 kHz. For higher frequencies the FETs are usable but not the magnetic components that were taken over by the PC power supply. The oscillator frequency is determined by the components attached to pin 5 and 6. R14 determines the dead time, which is absolutely necessary to avoid two switching transistors conduct at the same time. Due to the not present storage time for FETs a very small value could be set. With 1 us deadtime and 20 us period duration the FETs can theoretically lead current for 95 % of the time and thus deliver energy to the output. Charging C13 after switching on causes a soft start with narrow pulse first and wider control pulses afterwards. Terminal (a) of the driver transformer Tr4 remains free. Only one half (26 t) of the primary turns (b - c) and the 16 turns of the secondary winding are sufficient to form the necessary ratio of 0,6.

Fig. 3: PWM control and monitoring



Monitoring functions

Two protection circuits are included in the new power supply. The transformer Tr2 is used as current detector and produces at R16 a voltage that is proportional to the current flow through the power switches. If the voltage at the shutdown pin 10 exceeds the limit value adjustable with P1, the control IC switches off immediately and restarts after a short duration. The reason for this is usually a too high current at the secondary side of the power transformer, caused by a short-circuit or an overload to the output. The load and the circuit itself are likewise protected from overvoltage at the Vo output. The SG3525 switches off at Vo > 15 V. Note: Both protection circuits are ineffective if the slider of P1 is adjusted to Gnd potential.

Synchronous rectifier

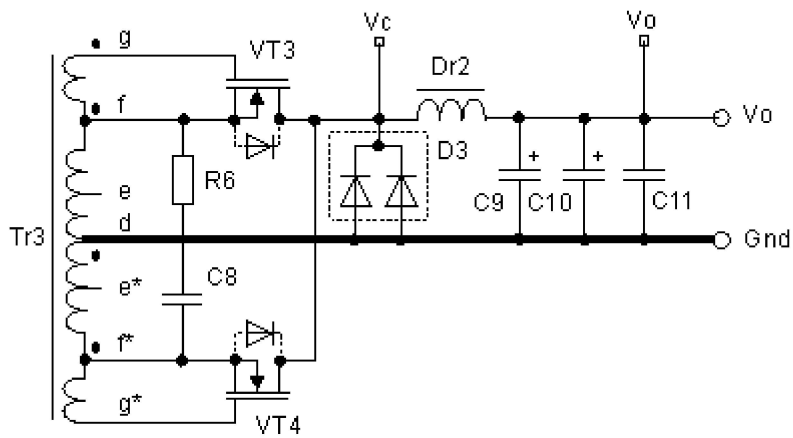
One must deal with a power dissipation up to 17 W at 18 A output current when using a rectifier with fast recovery diodes. With a 30 A / 45 V Schottky diode the looses are 12 W nevertheless. This rate forms the highest proportion referring of the total losses. The losses at the mains rectifier, power switches, transformers and the output choke are together below this value.

An improvement brings here a semi synchronous rectifier with two low impedance power FETs. FETs with a low Ron of e.g. 15 mOhm have only a voltage drop of 0,3 V at 18 A during the conduction phase. Good Schottky diodes are rated at 0,6 V. In the literature however with push-pull topology such circuits are advised against. As reason it is indicated that the choke current flows in opposite direction (revers mode) through the parasitical body diodes of the FETs as long as they are in the off state. High switching losses occur due to the storage charge of the body diodes which has to be removed first during the transition to the normal operation. This looses destroy the benefits achieved during the conduction phase.

The following circuit avoids this disadvantage, since the body diodes do not operate in the reverse mode. The free wheeling diode D3 takes over choke current since it has a substantially smaller forward on voltage Uf compared to the FETs body diode. D3 is from Schottky type and is arranged before the choke Dr2. The diode does not have a storage charge and thus switching on/off is extremely fast combined with low losses. It was removed once for by way of trial. The FETs heat sink warmed up thereupon by around +10 °C, although the body diode of the used IRFZ44 has already a very good trr (reverse recovery time) of 47 ns.

With a typical duty cycle of 57 % the losses in the two FETs make together 3.6 W. The free wheeling diode D3 is conducting for the remaining time and produces 4.6 W. Less than 8.2 W can only be attained, if one replaces the free wheeling diode also by a FET. Since triggering this FET is more complex than from VT3 and VT4, I did without this measure. A second reason is that with mains undervoltage or high output current the switch-on time of VT3/4 and not the switch-on time of D3 rise.

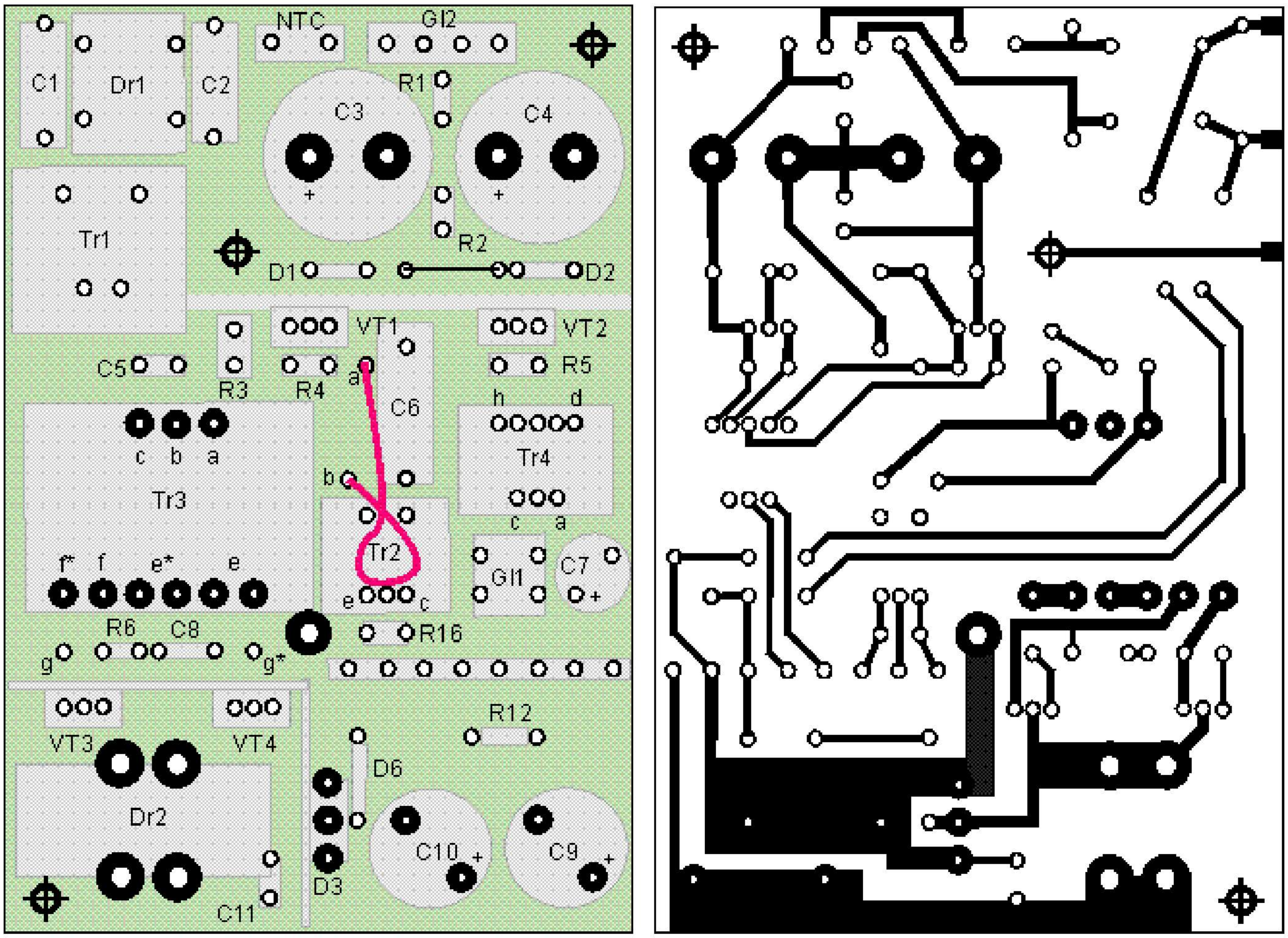
Fig. 4: Synchronous rectifier



Construction and alignment

For the power supply assembly a glass epoxy circuit board with the dimensions 82 x 122 mm is needed. One should not use another material. It applies to fasten relatively heavy components and realize copper tracks that are able to carry high current. The components for regulation and monitoring are mounted on a small strip board. Sorry, but I was too lazy to design a PCB layout for this circuit part.

Fig.5: PCB layout (1:1) and assembly



For the interconnection of the components for regulation and monitoring a 40 x 45 mm small strip-board is sufficient. The copper tracks (pink) are to be removed in the indicated places. A wood or a metal drill with a diameter from 3 to 4 mm is suited best tool for this work. Cable links are drawn in as broken lines. They are forgotten fast with the assembly. The same applies to the horizontal ground potential bar within the upper area of the strip-board that distributes Gnd potential onto the vertical copper tracks.

Fig.6: View to the strip-board soldering side (2:1)

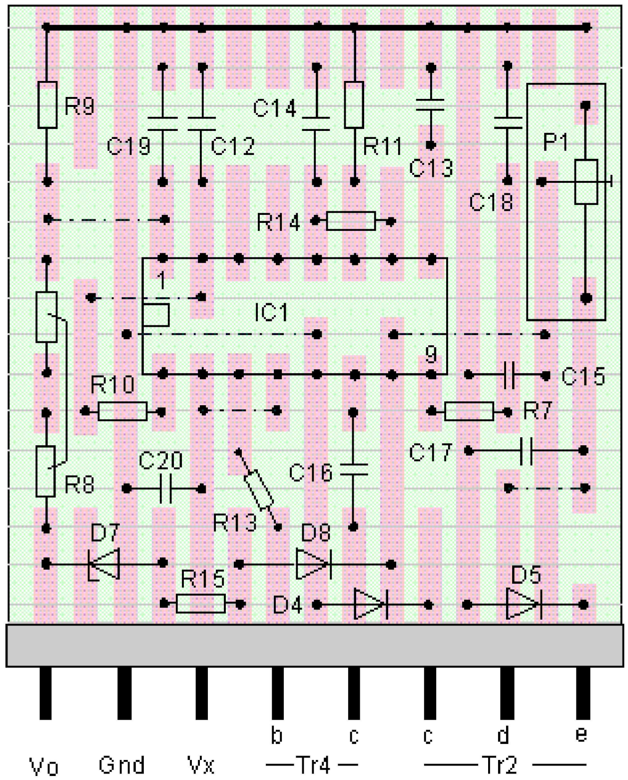
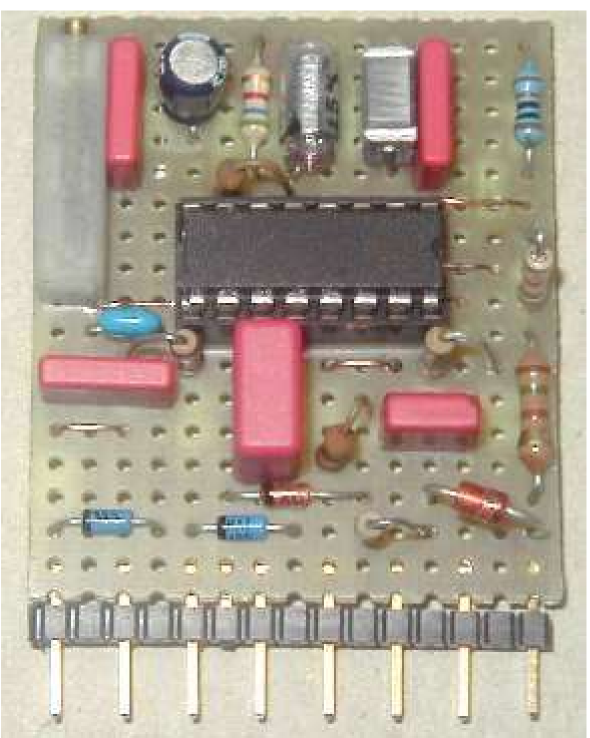


Fig. 7: View to the strip-board component side (2:1)

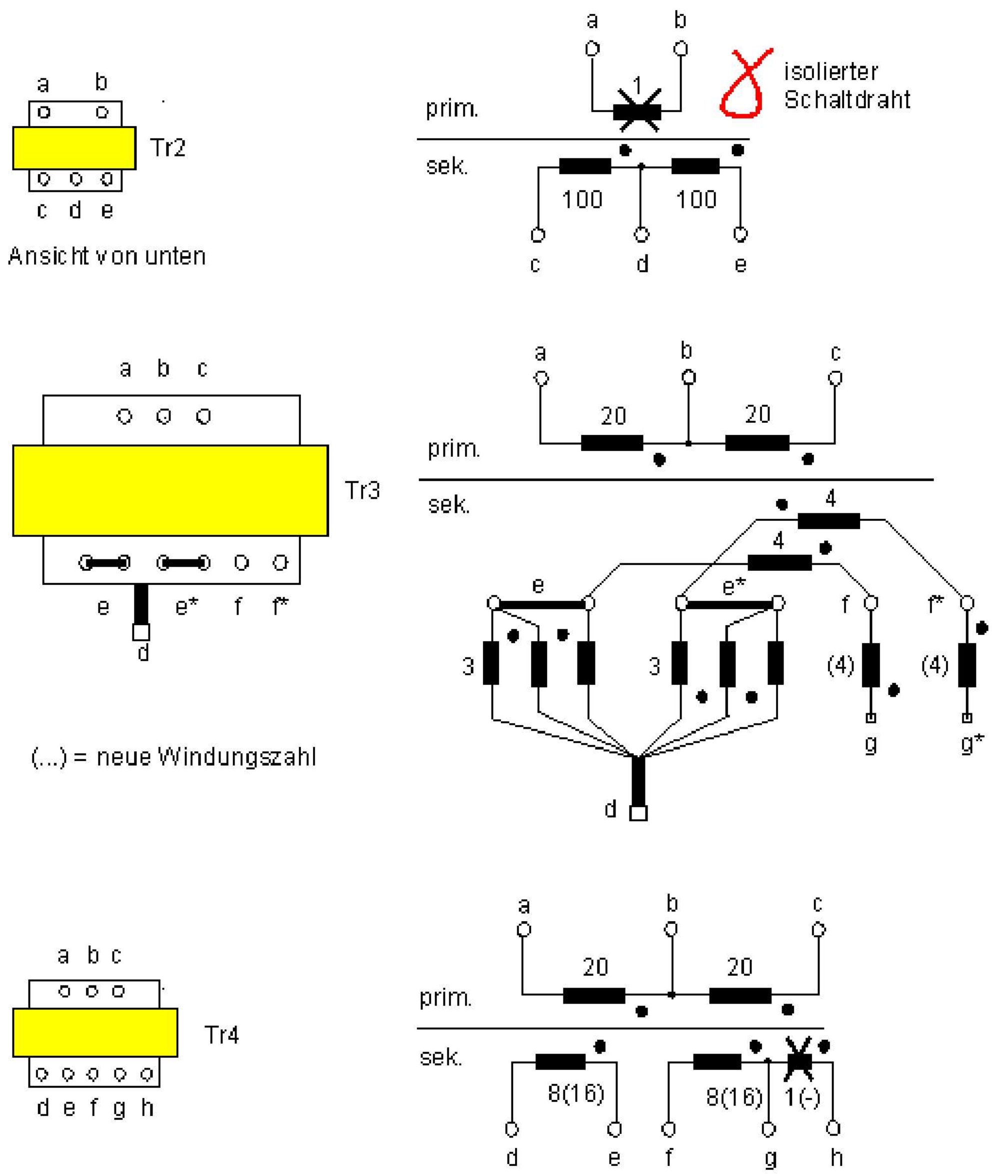


Transformers

The following drawing shows the transformers stripped from a PC switching power supply. The data were determined so far as possible by measurements, counting turns and calculations.

Before using the transformers it has to be checked exactly whether the size, number of layers, wire size, number of turns and phasing correspond to the specification in the drawing and the photos. If doubts exist in the matching, the transformers should better not be used.

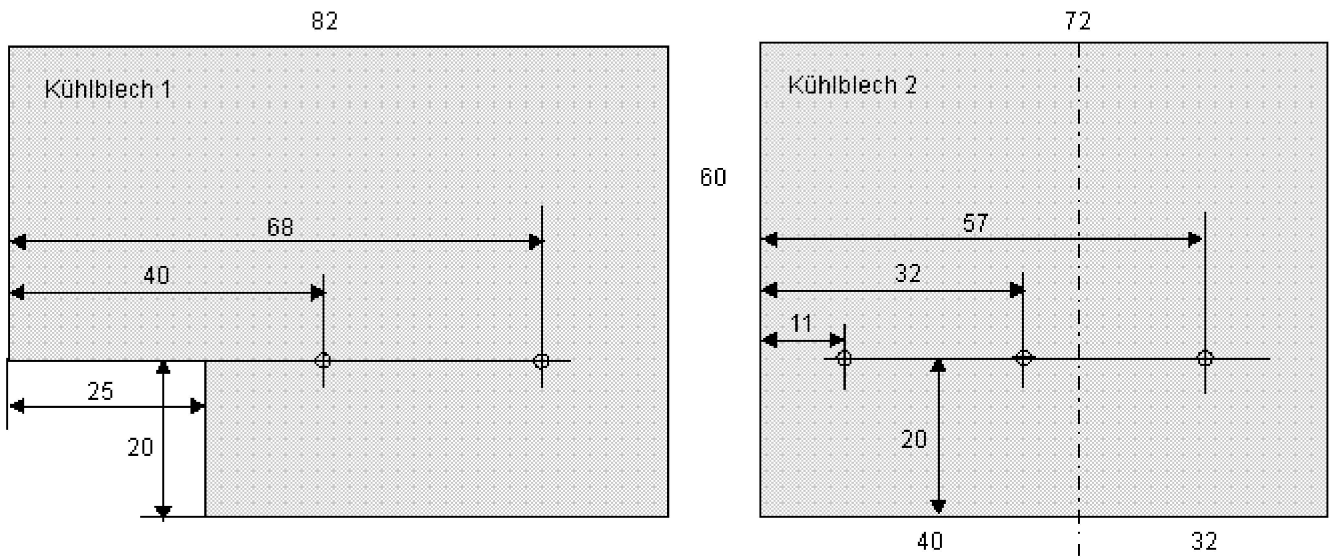
Fig. 8: PC transformers and modifications



Heat sinks

At the heat sinks is nothing special. They are manufactured from an approx. 1 mm thick aluminum plate. VT1 and VT2 are to be fastened isolated on the first heat sink. The FETs may not have a electrical connection against each other and against the heat sink. With professional assembling of the transistors touching the heat sink is without danger. On the secondary side it is somewhat simpler. VT3, VT4 and D3 carry no dangerous voltage and need thus no isolation for this reason. Because of the FETs case and the Schottky diodes case have the same potential, there is no objection against mounting all three components directly onto the second heat sink. It is to be made certain however that there is not electrical connection between the heat sink itself and the power supply housing or electrical components.

Fig.9: Heat sink drawings



Parts list (1)

Resistors, capacitors and semi conductors

Parts No.	Value
R1, 2	120 kOhm, 0,5 W
R3	100 Ohm , 2 W
R4, 5, 9	1 kOhm
R6	10 Ohm, 2 W
R7, 10	10 kOhm
R8	1,5 KOhm + 150 Ohm
R11	5,6 kOhm
R12, 13, 14	47 Ohm
R15, 16	150 Ohm
P1	10 kOhm trimming pot, 10 turns
NTC	Heissleiter, 5 Ohm at 25 °C
C1, 2	0,1 uF 250 Vac
C3, 4	470 uF 200 V, 22 x 36 mm (diam. , H)
C5, 15	2,2 nF
C6	1 uF, 250 Vac
C9, 10	2200 uF, 35 V low ESR, 16 x 34 mm (Diam., H)
C7	100 µF, 35 V
C8, C20	10 nF
C11,12	0,22 µF
C13	10 uF, 25 V

C14	2,2 nF Styroflex
C16	2,2 uF
C17, 18, 19	0,047 uF
D1, 2	PXPR1507 etc. fast 200 V / 1A diode
D3	MBR3045, 30 A / 45 V Schottky diode
D4, 5, 6	BAT 46
D7	Zener diode, 13 V / 0,5 W
D8	1N4148
VT1, 2	IRF730
VT3, 4	IRFZ44N
IC1	SG3525A
Gl1	Rectifier bridge, dual in-line B40C800 DIP
Gl2	Rectifier bridge 400 V / 4 A

Parts list (2)

Transformers, chokes and miscellaneous

Parts No.	Value
Tr1	0,5 W print transformer EE20/10, 15 Vac at 34 mA, 24 x 32 mm (Reichelt/Conrad)
Tr2	16 x 15 x 5 mm (W,H,D)
	1 Wdg. prim.
	2x 100 turns sec.
Tr3	40 x 35 x 12 mm (W,H,D) e.g. Tokin 25812 or. 25801
	2x 20 turns prim. (L = 7 mH between a <=> c)
	2x (3 + 4) turns sec. (L = 200 uH between d <=> f or d* <=> f*)
	2x 4 turns sec. auxiliary winding for driving VT3/4
Tr4	22 x 19 x 6 mm (W,H,D)
	2x 26 turns. prim.
	2x 16 turns. sec.
Dr1	current compensated 2A mains voltage choke
Dr2	20 uH, T26-106 (yel. / white), 16 turns. 2x 1 mm Cu wires in parallel
	better Magnetics Kool 259-77934-A7, 20 turns. 2x1 mm Cu wires in parallel
Additional mains filter	general purpose 230 V / 2 A
Si	3,15 AT fuse, slow blow
PS	Two pole mains switch
Miscellaneous	PCB, heat sinks, isolation material, heat sink compounder etc.

The grey marked cells indicate the components, which can be taken over by a PC power supply. The electrical data must be compared before using them and the indicated modifications have to be executed.

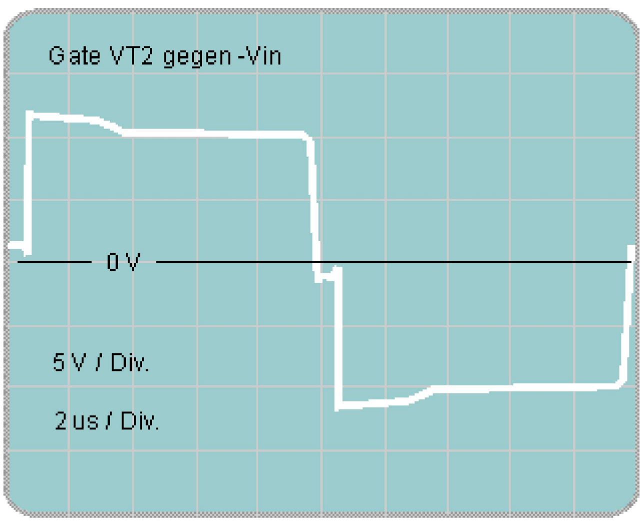
Testing the power supply

I urgently advise against immediate connection to 230 Vac. Testing of the new power supply should take place in several test phases for safety reasons and for the avoidance of component destruction. The high voltage causes an immediate destruction of the components in the case of an error in the circuit.

Warning: Check temperature of components only if the mains voltage is switched off.

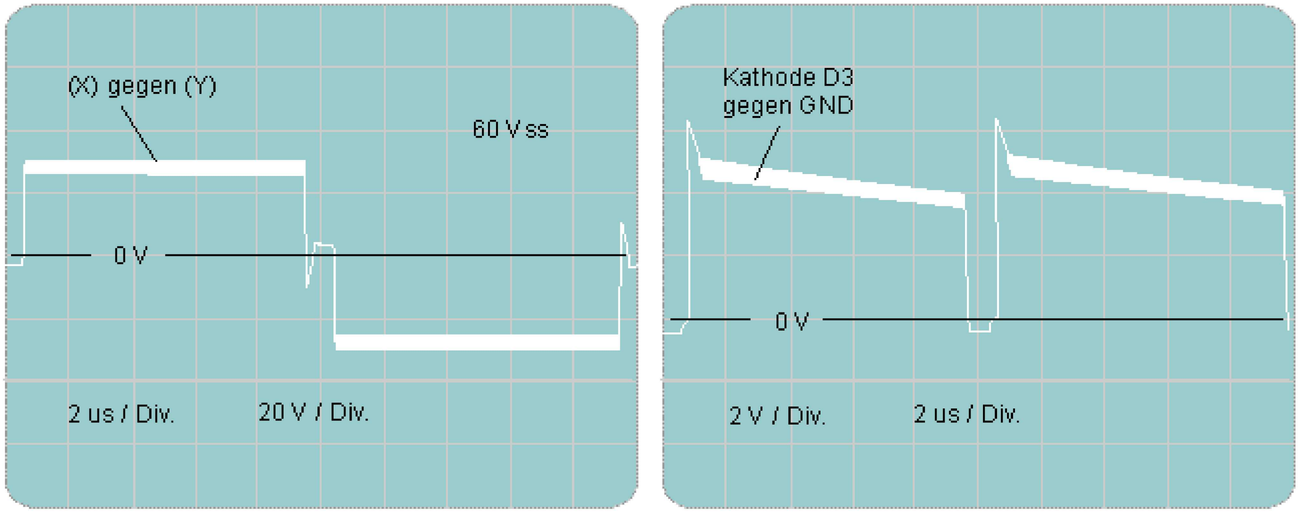
*Phase 1:*The first test applies to the PWM-IC and the power switch control. For running the PWM-IC a lab power supply adjusted to 24 Vdc must be attached to Gnd and the positive plate of C7 (Vx). After switching on the the IC generates sharply rising and falling control pulses with maximum pulse duration at the output pins 11 and 14. With an oscilloscope measured signals at the gate of VT2 (VT1) must look like the one shown in figure 9. It is very important that the signals have the indicated shape, voltage and frequency. The signals at the gates must be further in opposite phase against each other. Otherwise, both FETs would conduct at the same time and produce a short-circuit when later applying supply voltage .

Fig. 9: VT2 (VT1) gate-source voltage



Phase 2: Now, connect three car light bulbs (12 V / 21 W) to the 13,8 V output terminals. A 48 V / 1 A mains transformer feeds the S.M.P.S. via the L1 and N terminal with a galvanical isolated Ac voltage. The + 24 Vdc lab supply is still connected during this test. 60 Vdc at C3 / C4 is in Europe defined as a non-dangerous voltage rate. At this voltage rate the switching transistors can start operating and one can perform test without danger. For measurements with a dual-channel oscilloscope Gnd from the secondary section has to be connected temporary to the (Y) test point of the primary section with a wire link. The bulbs glow at Vout = 4,3 Vdc if everything is right. Rectification is executed by the FETs body diodes only, because the VT3 and VT4 gate-source voltage is not high enough to switch on the FET. The PWM controller tries to offer 13,8 V at the output at maximum pulse duration. The later cannot be successful due to the low 60 Vdc input voltage and the present transformer ratio.

Fig. 10: Voltage at test point (X) against (Y) und cathode D3 against Gnd



Phase 3: If everything is all right up to now, one can proceed with the exciting test at 230 Vac. The laboratory power supply, the 48 V transformer, the measuring instruments and all provisional cable links attached for the test etc. must obviously be removed. The three car bulbs are further needed as a load and for the functional checks. If after applying of the 230 Vac mains voltage the lamps light up brightly, the output voltage amounts to 13.8 V and no undefined noises or smells are noticeable one has won the first round. If a non recognizable error has passed the pre-testing the two switching transistors and copper tracks say good-bye with a more or less loud bang. With 5,7 A the duty cycle D = tp / T = 5 us / 10 us is approximately 50 %.

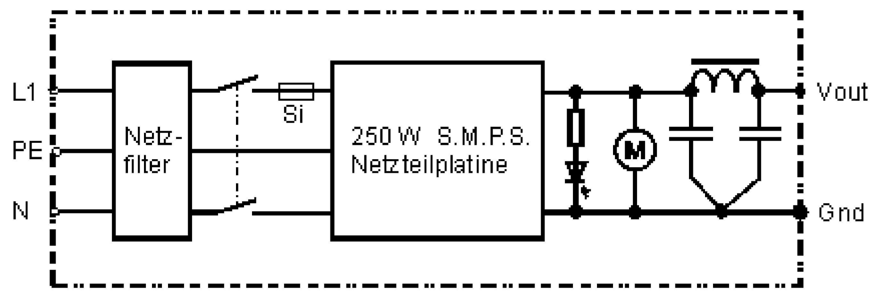
Phase 4: For the following load test a dummy load is needed that can handle up to 300 W. Because such high power resistors are not laying in the junk box and purchasing them is very expensive, I took instead a 50 m a ring installation cable (3 x 1.5 mm2) . An individual wire has a resistance 0.6 ohms and can dissipate the mentioned watts without problems. Depending upon interconnection of the three wires, load resistances of 0,6 / 1,2 and 1.8 ohms are realizable. By the ampmeter impedance, including the appropriate measuring wires positioned in series, the resistance value increases by approx. 0.1 ohms. At Vo = 13,8 V the following table indicates the power output Po and the current Io as a function of the loading.

Rl [Ohm]	car bulbs	Io [A]	Po [W]
- / -	1x 12 V / 21 W	1,9	26
- / -	2x 12 V / 21 W	3,8	52
- / -	3x 12 V / 21 W	5,7	78
1,8 + 0,1	- / -	7,26	100
1,2 + 0,1	- / -	10,6	146
1,2 + 0,1	2x 12V / 21 W	10,6 + 3,8	198
1,2 + 0,1	3x 12V / 21 W	10,6 + 5,7	224
0,6 + 0,1	- / -	19,7	270

Additional measures for RFI noise reduction

Experience during the PC power supply modification have shown that the filtering on the PCB is not sufficient for amateur radio application. A pre-arranged general purpose mains filter and a home made Pi filter direct to the 13,8 V output are used for improved RF noise reduction. To favor of the control loop stability the PI filter voltage drop is not eliminated. Output voltage changes of several ten millivolts at load changes have no importance for running a 100 W transceiver. The additional filter have to be mounted inside the S.M.P.S. case very close to the cable inlet and outlet.

Fig. 11: External components for RF noise reduction



Operation experiences

Up to 10 A continuous output current or operation with 50 % ESD and 18 A peek current one can do without a fan if sufficient natural air flow is present and the ambient temperature does not exceed 30 °C. A small CPU fan (40 x 40 mm) should be used for more than 10 A continuous current. The heatsink surface is not large enough to keep the FETs junction temperature below the limit value (Tj < 100 °C). With a CPU fan the heat sink temperature remains below 28 °C (Tu = 20 °C). The following table shows the measured and calculated power dissipation Pv of the basic components at 250 W output power.

Abbr.	Parts	Pv [W]
Gl2, Dr1	Mains rectifier and filter	2,5
VT1	Switching transistors	4,0
VT2		4,0
R3 / C5	Snubbers	1,5
Tr3	Output transformer	2,0
VT3	Synchronous rectifier	1,8
VT4		1,8
D3	Free wheeling diode	4,6
Dr2	Choke	2,0
IC1	PWM control circuit	1,0
Sum		25,2

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