



## 90W SMPS FOR MONITORS WITH STANDBY FUNCTION

by Claudio Adragna

*Purpose of this note is to provide a brief summary of the specifications and the functionality of the application board implementing a 90W multioutput SMPS for monitors, based on the L5991, current mode PWM controller.*

*Evaluation results are also presented so as to underline the benefits offered by the L5991 in such a new generation of SMPS that requires a superior efficiency in standby conditions, aiming at compliance with energy saving standards.*

### Design Specifications

Table 1 summarises the electrical specification of the application. The complete electrical schematic is shown in fig. 1 and the bill of material is listed in Table 2.

**Table 1. Design Specification**

Input Voltage Range ( $V_{in}$ )		88 to 264 Vac
Mains Frequency ( $f_L$ )		50/60 Hz
Maximum Output Power ( $P_{out}$ )		90W
Outputs	Horizontal Deflection	$V_{out} = 200V$
		$I_{out} = 0.325A$
		Full load ripple = 1%
	Video Amplifier	$V_{out} = 80V$
		$I_{out} = 0.125A$
		Full load ripple = 1%
	Vertical Deflection	$V_{out} = \pm 15V$
		$I_{out} = 0.33A$
		Full load ripple = 1%
	Heater	$V_{out} = 6.3V$
		$I_{out} = 0.8A$
		Full load ripple = 2%
Switching Frequency in Normal Mode ( $f_{osc}$ )		40kHz
Switching Frequency in Suspend / OFF mode ( $f_{SB}$ )		18kHz
Target Efficiency (@ $P_{out} = 90W$ , $V_{in} = 88 \div 264$ Vac) ( $\eta$ )		> 80%
Maximum Input Power (@ $P_{out} = 0.5$ W, $V_{in} = 88 \div 264$ Vac)		$\leq 2W$

The selected topology is flyback. The operation mode (@  $P_{out} = 90W$ ) is CCM (Continuous Conduction Mode) at low mains voltage, DCM (Discontinuous Conduction Mode) at high mains voltage. This design choice relieves the stress on the power components at low mains voltage, compared with a full DCM solution.

The application will benefit from the features of the L5991 PWM controller in order to minimise the power drawn from the mains under light load conditions: low start-up and quiescent currents, and Standby function.

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Figure 1. Electrical Schematic.

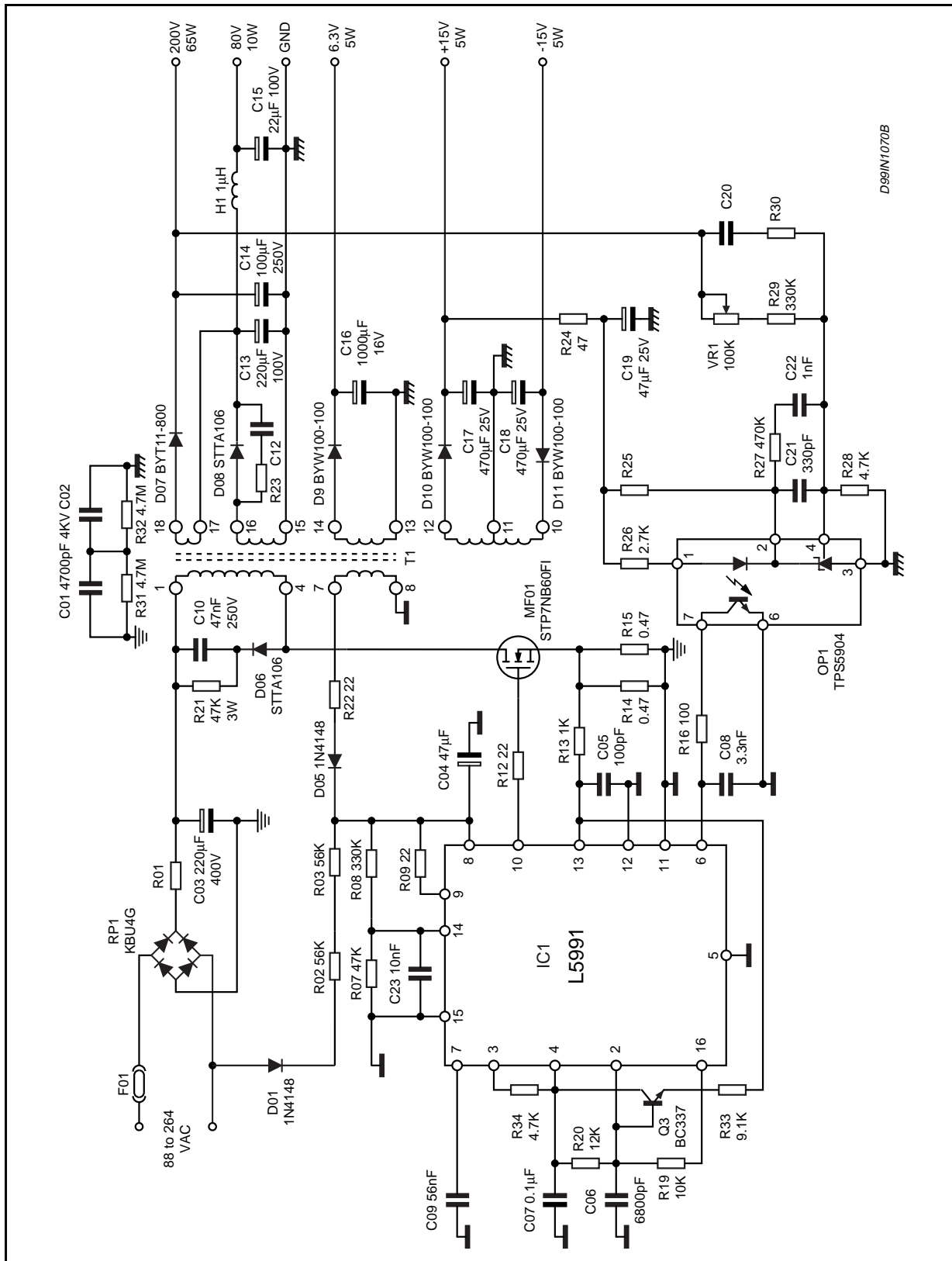


Table 2. Component List of the circuit of fig. 1.

Symbol	Value	Note
R1		NOT USED (shorted)
R2, R3	56k $\Omega$	
R7	47k $\Omega$	
R8, R29	330k $\Omega$	
R9, R12, R22	22 $\Omega$	
R13	1k $\Omega$	
R14, R15	0.47 $\Omega$	metallic film
R16	100 $\Omega$	
R19	10k $\Omega$	
R20	12k $\Omega$	
R21	47k $\Omega$	3W
R24	47 $\Omega$	
R26	2.7k $\Omega$	
R27	470k $\Omega$	
R28	4.7k $\Omega$	
R31, R32	4.7M $\Omega$	
R33	9.1k $\Omega$	
VR1	100k $\Omega$	multiturns, Bourns 3296W or equivalent
C1, C2	4.7nF	1kV
C3	220 $\mu$ F	400V, electrolytic, Panasonic TSUP or Roederstein EYS
C4, C19	47 $\mu$ F	25 V, electrolytic
C5	100pF	plastic film
C6	6.8nF	ceramic multilayer
C7	100nF	plastic film
C8	3.3nF	plastic film
C9	56nF	plastic film
C10	47nF	250V, polypropylene o polystyrene film (Siemens-Matsushita)
C13	220 $\mu$ F	100 V electrolytic, Roederstein EKE or equivalent
C14	100 $\mu$ F	250 V, electrolytic, Roederstein EKS or equivalent
C15	22 $\mu$ F	100 V, electrolytic, Roederstein EKE or equivalent
C16	1000 $\mu$ F	16V, electrolytic, Panasonic FA or equivalent
C17, C18	470 $\mu$ F	25 V, electrolytic, Panasonic HFZ or equivalent
C21	330pF	ceramic or plastic film
C22	1nF	ceramic or plastic film
C23	10nF	plastic film
D1, D5	1N4148	
D6, D8	STTA106	ST, TurboSwitch
D7	BYT11-800	ST, Ultrafast
D9, D10, D11	BYW100-100	ST, Ultrafast
IC1	L5991	ST
T1	ETD4407	ITACOIL, see Table 3
OP1	TPS5904	TI
MF1	STP7NB60FI	ST
RP1	KBU4G	GI, or equivalent 4A rectifier bridge
Q3	BC337	
F1		5A fuse
H1	1 $\mu$ H	axial inductor
M1, M2, M3		connectors

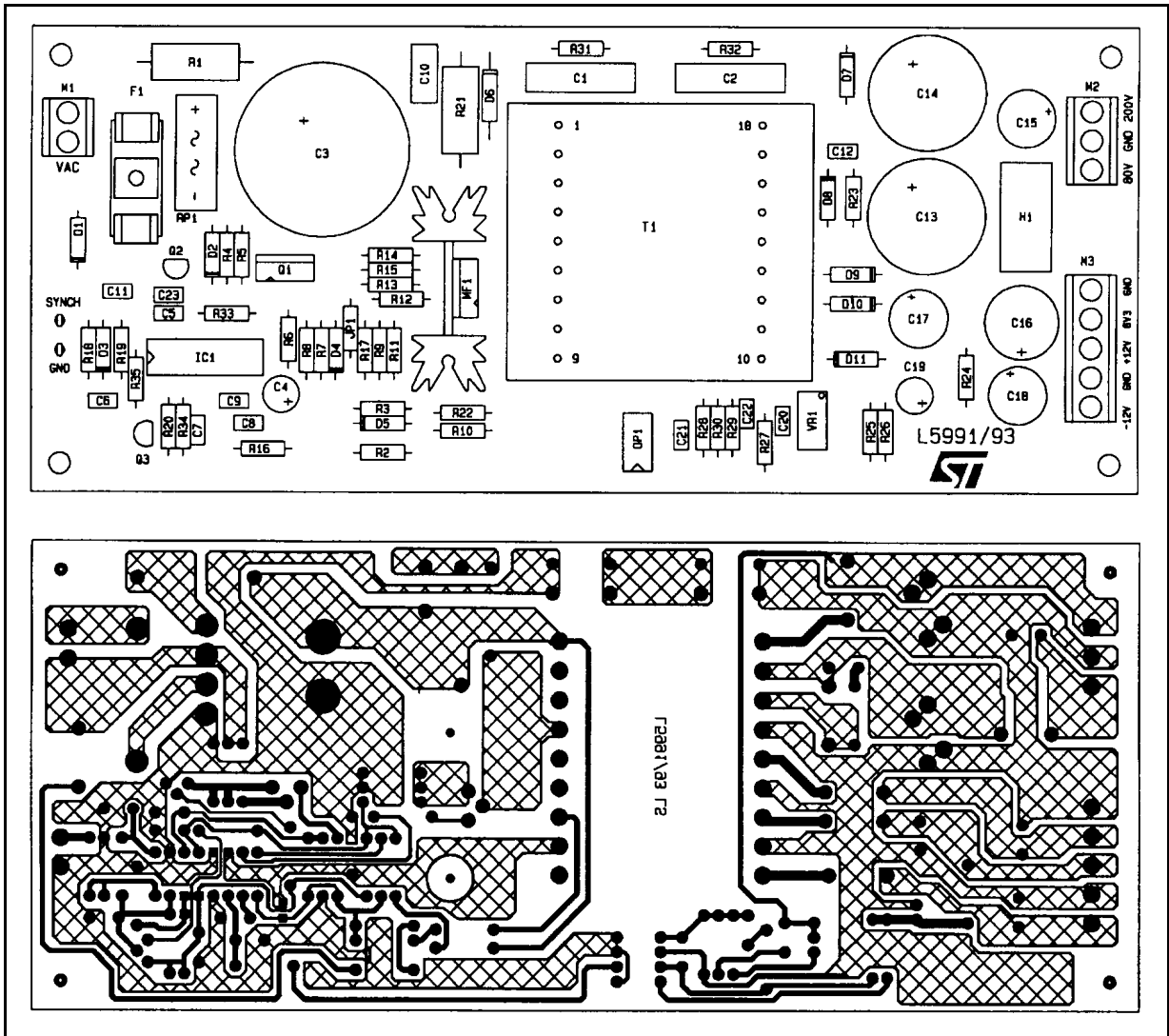
**Notes:** - if not otherwise specified, all resistors are 1/4 W, 1%  
- the MOSFET is provided with a 9.5 °C/W heatsink  
- components indicated in the PCB and not quoted in table 2 are not assembled

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**Table 3. Transformer Specification (Part Number ETD4407, supplied by ITACOIL).**

Core	Philips ETD44, 3C85 Material				
Bobbin	Horizontal mounting, 18 pins				
Air gap	$\cong 1$ mm for an inductance 1-4 of 380 $\mu$ H				
Leakage inductance	< 10 $\mu$ H				
Windings Spec & Build	Winding	Wire	S-F	Turns	Notes
	Pri1	4xAWG29	2-4	19	
	Sec1	AWG25	17-18	48	
	Sec2	AWG25	15-16	32	
	Sec3	AWG25	13-14	3	Evenly spaced
	Sec4	AWG25	11-12	6	Bifilar with Sec5
	Sec5	AWG26	10-11	6	Bifilar with Sec4
	Pri2	4xAWG29	1-2	19	
Aux	AWG29	8-7	8	Evenly spaced	

**Figure 2. PCB layout: Component side and bottom layer (top view); 1:1.33 scale**



**Application Board Functionality**

The outstanding feature of this application board is the so-called Standby Function, directly available from the L5991. When the power demanded by the load is roughly included between 40 and 90 W (Normal mode) the switching frequency of the converter is set at 40 kHz. When the monitor enters in low-consumption mode (Suspend or OFF mode), the power demanded by the load will be much lower, few Watts. The L5991 will automatically recognise this new operating condition and change the oscillator frequency to 18 kHz. The capacitor C6, along with the parallel of R19 and R20, sets  $f_{osc}$ ;  $f_{SB}$  is set by C6 and R20.

If the user would like to fine tune the power level that causes the switching frequency to be moved from  $f_{osc}$  to  $f_{SB}$  ( $P_{inSB}$ ), he or she can add a fixed DC offset (typically in the range 0-200 mV) on the current sense pin (13, ISEN). This can be accomplished by means of R17, currently not used. The offset will be the partition of the reference voltage (pin 4, VREF) through R17 and R13.

To change the power level that causes the switching frequency to be moved from  $f_{SB}$  to  $f_{osc}$  ( $P_{inNW}$ ), the ratio  $f_{osc} / f_{SB}$  should be changed.

R10 and R11 allow to provide an additional DC offset on the current sense which depends on the supply input voltage. This can be used for compensating L5991's delay to output. In the present case the delay is not compensated (R10 and R11 are not assembled) and the effect is a slight dependence of  $P_{inSB}$  and  $P_{inNW}$  on the mains voltage (see table 7). This is reinforced by the slope compensation circuit (Q3 and R33), which adds a little offset (variable with the duty cycle) on the current sense pin.

Additionally, the board includes some protection functions typically required, not only in monitor applications, such as overvoltage (OVP) and overcurrent protection (OCP).

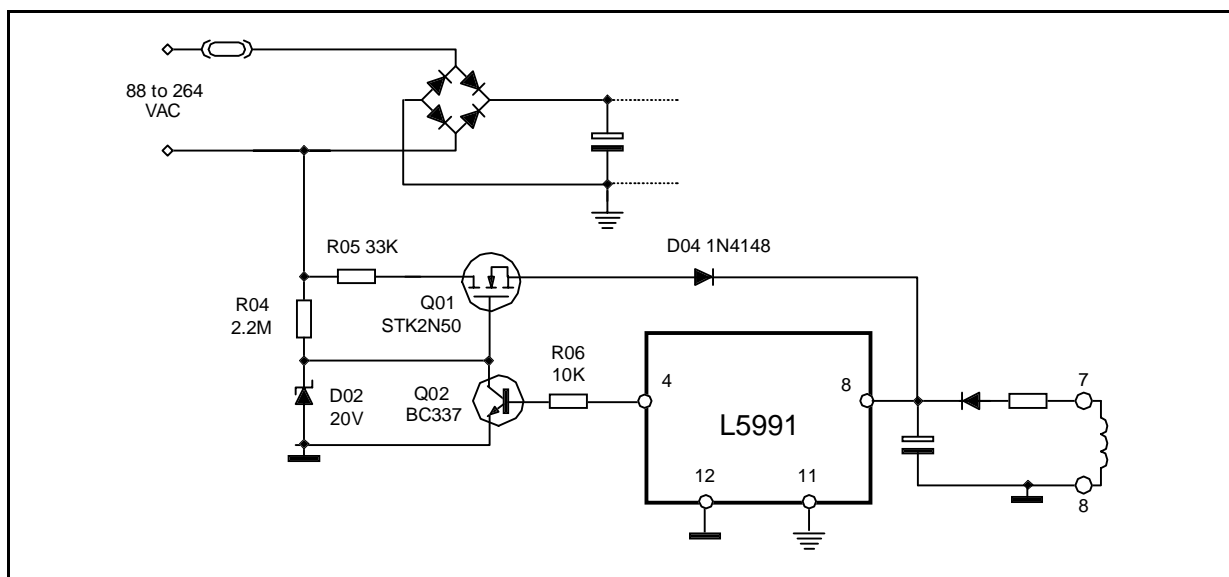
OCP is inherent in the functionality of the L5991: the controller provides both pulse-by-pulse and "hiccup" mode current limitation (see Application Information in the datasheet), which fully protect the converter in case of overload or short circuit.

The OVP, in this specific case, is realised by sensing the supply voltage of the L5991 (generated by the auxiliary winding) through the divider R7-R8 and feeding this partition into pin 14 (DIS). The divider ratio is such that the OVP is tripped when the supply voltage exceeds 20V. This protection is particularly effective in case of feedback disconnection.

At maximum load and minimum mains voltage the converter operates at about 55% duty cycle (this is why slope compensation is required) but no limitation is imposed on its maximum value: L5991's pin3 (DC) is shorted to pin 4 (VREF). If desired, it is possible to set the maximum duty cycle by adding the divider R34-R35. Please refer to Application Information in L5991 datasheet for calculation of the voltage divider.

The application board is supplied with a start-up circuit simply made of a dropping resistor (R2+R3) that draws current from upstream the bridge rectifier.

**Figure 3. Low-consumption start-up circuit (not currently implemented)**



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This circuit, really inexpensive, dissipates about 300 mW @ 264 Vac. The typical wake-up time is 2.8 s at 88 Vac and 0.8 s at 264 Vac. Should the wake-up time become an issue, a more expensive solution would be adopted. The PCB is also able to accommodate an active start-up circuit that, under the same conditions, dissipates less than 10 mW and provides 0.7 s and 0.2 s wake-up times respectively. The schematic is shown in fig. 3 (R2 and R3 will be removed).

A further improvement of light load efficiency can be achieved by replacing the RCD clamp (C10, R21) with a Transil. The suggested part is a 1.5KE150A. This slightly worsens efficiency at full load but allows to save about 200 mW, currently dissipated on R21, at light load.

### Application board evaluation: getting started

The AC voltage, from an AC source ranging from 88 VRMS to 264 VRMS, will be applied to connector M1 (close to the top left-hand corner). The 200VDC and 80VDC outputs are located in connector M2 (top right-hand corner) while  $\pm 15$ VDC and 6.3VDC outputs are available at connector M3, near the bottom right-hand corner.

**Like in any offline circuit, extreme caution must be used when working with the application board because it contains dangerous and lethal potentials. The application must be tested with an isolation transformer connected between the AC mains and the input of the board to avoid any risk of electrical shock.**

### Application board evaluation: results

In the following tables the results of some bench evaluations are summarised. Some waveforms under different load and line conditions, as well as system's transient response are also shown for user's reference and to illustrate the operation of the standby function.

**Table 4. Full load measurements**

V <sub>AC</sub> [V]	88	110	160	220	264
Pin [W]	105.4	103.5	101.5	100.6	100.3
Vout [V]	199.9	199.9	199.9	199.9	199.9
	79.43	79.43	79.4	79.36	79.36
	14.27	14.26	14.29	14.26	14.26
	-14.41	-14.4	-14.36	-14.39	-14.38
	6.65	6.65	6.65	6.65	6.65
Pout [W]	89.75	89.74	89.72	89.7	89.7
$\eta$ [%]	85.2	86.7	88.4	89.2	89.4

Load conditions: 200V: 630 $\Omega$ ; 80V: 600 $\Omega$ ;  $\pm 15$ V: 80 $\Omega$ ; 6.3V: 8 $\Omega$

**Table 5. Consumption from the mains in Suspend mode (P<sub>O</sub> = 5.5W)**

V <sub>AC</sub> [V]	88	110	160	220	264
Pin [W]	6.9	7	7	7.1	7.2

Load conditions: 200V: open; 80V: open;  $\pm 15$ V: 0.5W; 6.3V: 8 $\Omega$

**Table 6. Consumption from the mains in OFF mode (P<sub>O</sub> = 0.5W)**

V <sub>AC</sub> [V]	88	110	160	220	264
Pin [W]	1.3	1.4	1.5	1.6	1.8
Pin [W] (*)	1.2	1.2	1.3	1.4	1.5

Load conditions: 200V: open; 80V: open;  $\pm 15$ V: 0.5W; 6.3V: open  
 (\*) With the active start-up circuit of fig.3

Table 7. Standby function: transition thresholds in terms of input power

V <sub>AC</sub> [V]	88	110	160	220	264
P <sub>inSB</sub> [W]	10	11	12.5	14	15
P <sub>inNW</sub> [W]	37	38	39	41	42

Note: there is no risk of premature current limitation or transformer saturation when the system operates at f<sub>SB</sub> up to 60W input power. To reduce P<sub>inNW</sub>, increase f<sub>osc</sub> or reduce f<sub>SB</sub>.

Figure 4. Drain voltage at full load (left: V<sub>in</sub> = 100 VDC, right: V<sub>in</sub> = 300 VDC)

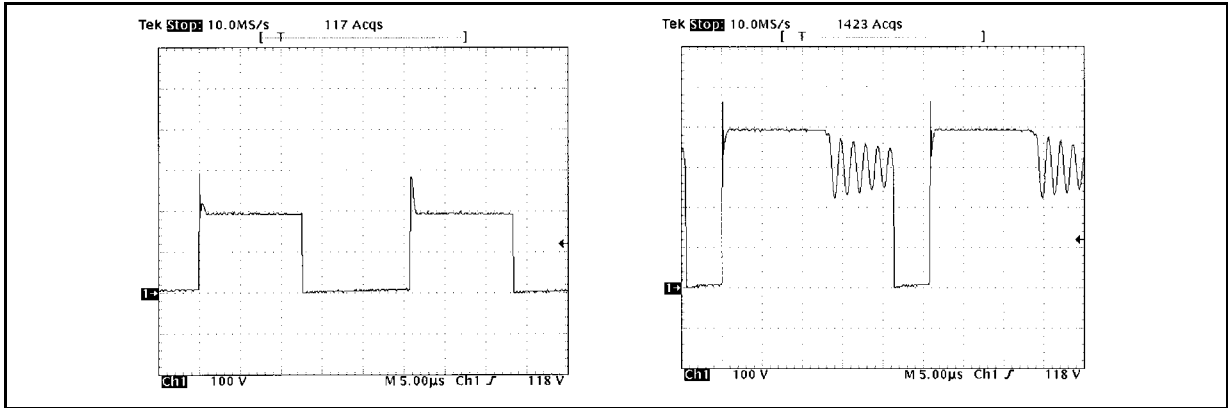


Figure 5. Drain voltage in OFF mode (left: V<sub>in</sub> = 100 VDC, right: V<sub>in</sub> = 300 VDC)

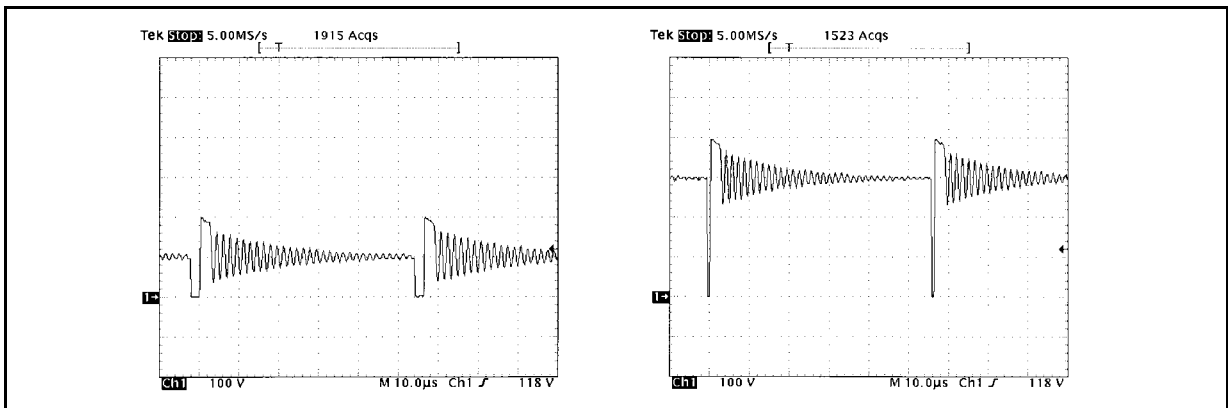
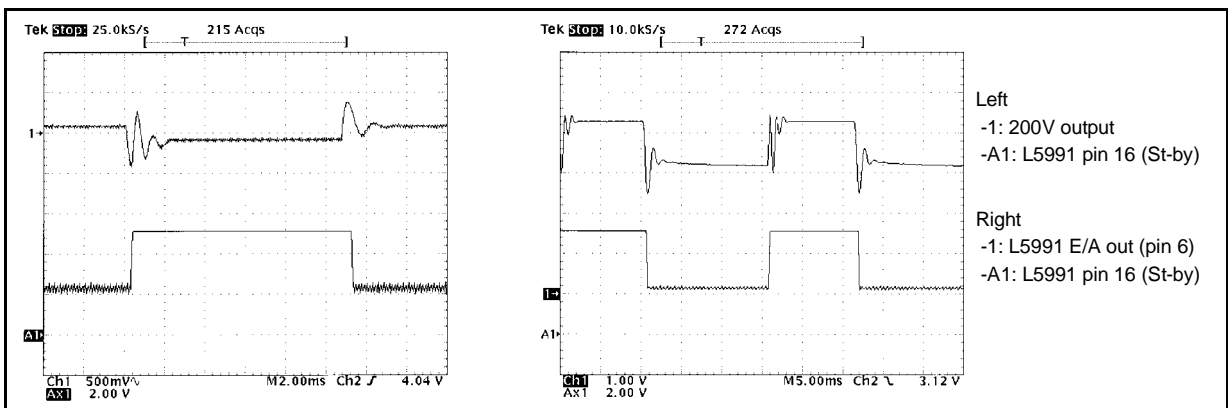
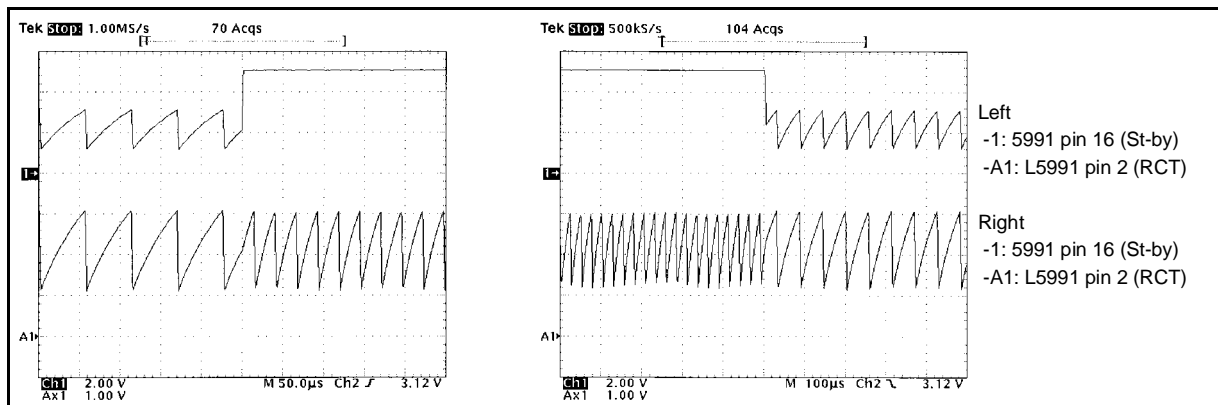


Figure 6. Load transient (0-0.3A) on 200V output



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Figure 7. Load transient (0-0.3A) on 200V output





APPENDIX

**Low-consumption modes management**

The application board is not provided with the circuits that handle the loads in a monitor SMPS during Suspend and OFF modes. As a result, if the board is connected to a monitor unit "as is", the consumption from the mains will be significantly higher than the values shown in tables 5 and 6. In particular, it will not be possible to meet the "less than 3W" specification required by the current energy saving regulations in OFF mode.

This happens because the monitor's circuits, in particular those connected to the high voltage buses, are still powered and have some mA residual consumption, despite they are not operating. The actual load is then heavier than the one assumed in table 5 and 6, where the load conditions in OFF-mode are simulated, provided some "power management" circuit takes care of their reduction.

A popular solution used for cutting down the residual loads and minimizing the power consumption in OFF mode is to reduce 8 to 10 times the voltage of all of the outputs, except the one that powers the  $\mu\text{P}$  governing the entire monitor operation, power management included.

In this way the voltage produced by the SMPS will not be enough to power monitor's circuits and their consumption will drop to zero. Additionally, the reflected voltage during switch OFF-time will be much lower, which will reduce switching and capacitive losses.

The above mentioned functionality can be achieved in a number of different ways. Figure A1 shows the application board schematic modified with the addition of a circuit (pointed out by the shaded areas) that does the job. A 5V linear regulator (L7805CP), which is supposed to supply the  $\mu\text{P}$ , has been added for completeness. The operation of the circuit can be described as follows.

When the OFF signal is pulled high, Q5 is turned on, the base of Q4 is grounded and Q4 is turned on as well. This connects the 80V winding and the 2.2 $\mu\text{F}$  capacitor, charged at 80V, to C17+C19 charged at 15V. Being the latter much bigger, the transient voltage change is negligible. The 4.7 $\Omega$  resistor in series to Q4's emitter limits the current surge during the transient.

By turning Q5 on, the cathode of the TL431, typically at 11V in normal operation, is now forced to drop at about 4V by the 3.3V zener and the decoupling diode. Considering 1V drop across the photodiode and the drop on R26, which changes very little, the voltage on C17+C19 will be fixed at about 8.5V. The volts-per-turn across the windings will drop from  $80 / 32 = 2.5 \text{ V/turn}$  to  $8.5/32 = 0.265 \text{ V/turn}$ , that is nearly 10 times less. All of the outputs will be reduced by the same ratio (a higher value can be found because of capacitors peak charging due to load absence). The TL431 is cut out: it sees the drop of the 200V output and would try to correct this by increasing its cathode voltage, which is not possible because this is fixed by the 3.3V zener.

The reduction of winding voltages concerns the primary side as well: the voltage generated by the auxiliary winding drops to some 1V and is no longer able to power the L5991. To maintain circuit operation, a second auxiliary winding, stacked on the first one, has been added, with a turn number (40) such that in OFF mode it develops a voltage sufficient to power the L5991.

However, during normal operation the voltage it develops will be much higher (close to 120V). This is why Q6 has been added: during normal operation the first auxiliary winding develops more than 15V thus the base-emitter junction of Q6 is reverse biased and Q6 is cut off, thus blocking the high voltage. When entering OFF mode, Q6 is turned on (it does not work as a linear regulator) and lets the second auxiliary winding supply the L5991.

As Q5 is turned off because normal operation is to be resumed, also Q4 will be turned off and the output voltages will go back to their rated values after a transient similar to the initial power-up.

Table A1 shows the improvement offered by the voltage reduction circuit. A load condition similar to or slightly heavier than that of a real monitor (without any power management circuit) is assumed. The consumption from the mains is shown with and without the additional circuit included in fig. A1.

**Table A1. Consumption from the mains in OFF mode.**

V <sub>AC</sub> [V]	88	110	160	220	264
Pin [W] (*)	4.3	4.4	4.6	4.8	4.9
Pin [W] (**)	2	2.1	2.2	2.4	2.5

Load conditions: 200V: 40 k $\Omega$ ; 80V: 20 k $\Omega$ ; +5V: 47 $\Omega$ ; other outputs open

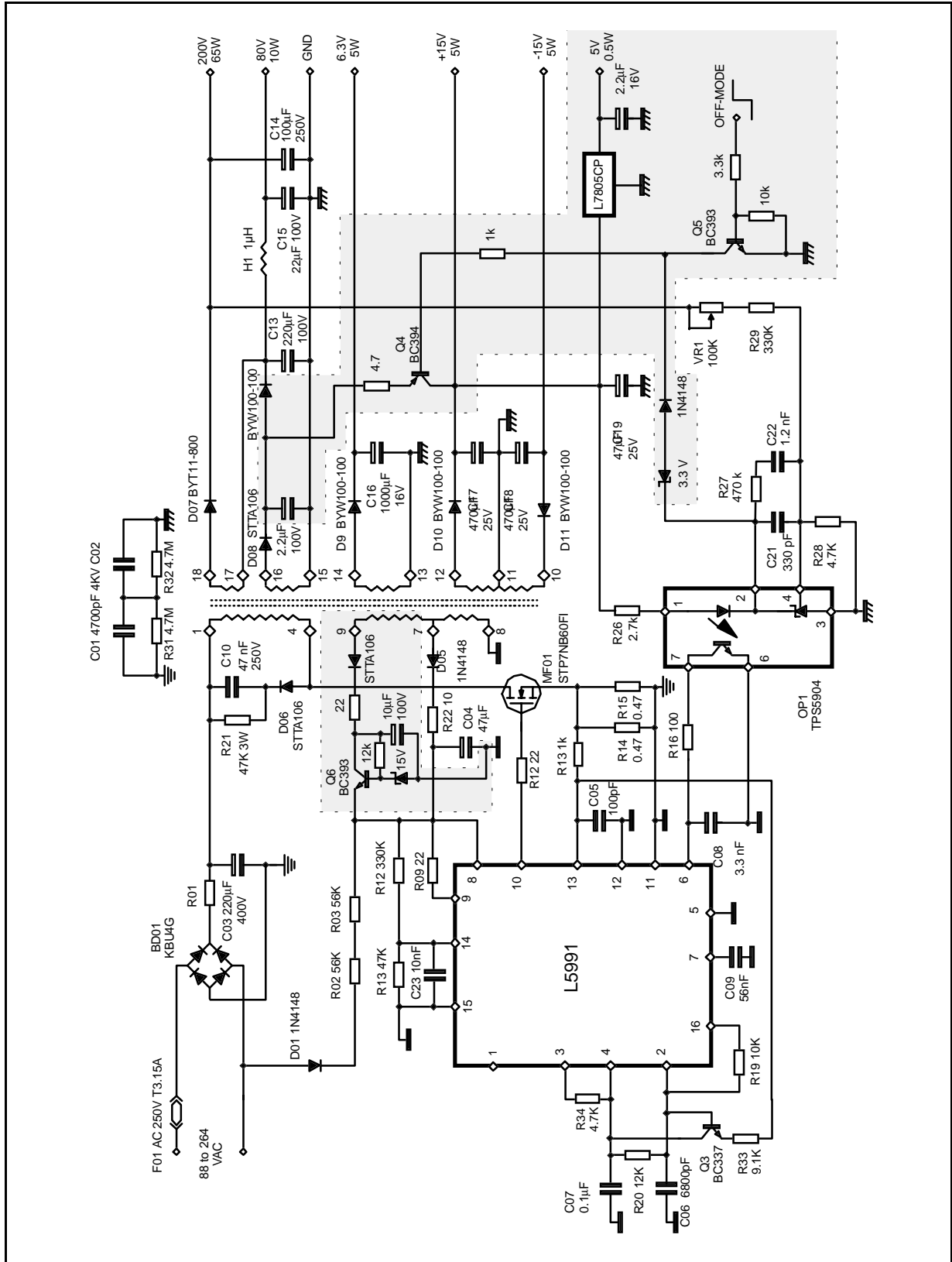
(\*) Without voltage reduction

(\*\*) With voltage reduction



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Figure A1. Application board Electrical Schematic with OFF-mode management.



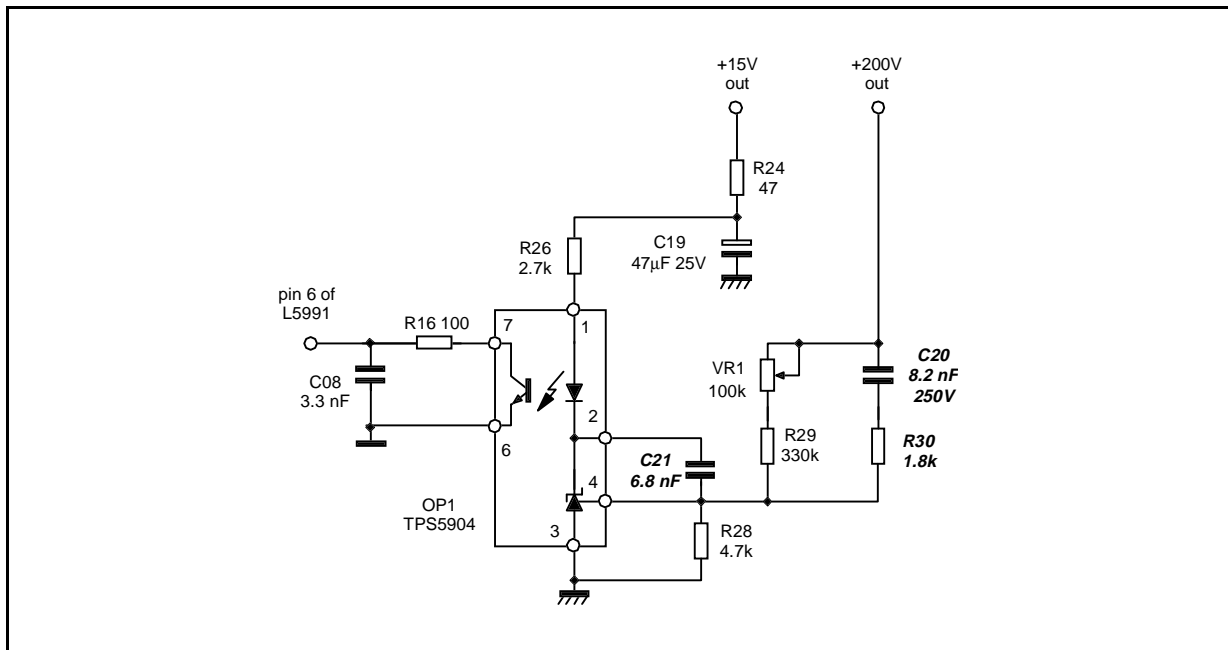
**Alternative Frequency Compensation Network**

A method alternative to the one illustrated in the previous section for cutting down the residual loads is to physically disconnect the loads by means of series switches. In that case the outputs are actually open.

With this approach, if the application board is repeatedly subjected to quick power-off/power-on cycles during OFF mode, it may not start-up. In fact, being the load of the 200V output open, after a power off the output voltage decays very slowly. If the board is powered on again when the output capacitor is still almost fully charged, the output voltage will rise quickly and overshoot the regulated value. The PWM may be stopped so long - to allow the output voltage to decay to its correct value - that the L5991 loses its supply and goes into undervoltage lockout. Next, the L5991 is restarted by R2+R3, the sequence recurs and the system gets stuck in this on-off cycle.

To avoid this, it is recommended to use the other feedback configuration provided in the PCB, which makes use of C20 and R30. As shown in figure A2, in that case C22 and R27 will be omitted and the value of C21 will be changed. C20 provides an anticipatory effect that prevents the overshoot and the resulting vicious circle above described.

**Figure A2. Alternative compensation network to be used with switch-opened loads. Parts added or modified are in bold italics.**



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