AN1134
APPLICATION NOTE

45W AC-DC ADAPTER WITH STANDBY FUNCTION

by Claudio Adragna

Purpose of this note is to provide a brief summary of the specifications and the functionality of the evaluation board implementing a 45W, wide-range mains AC-DC adapter, 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 equipment 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 V_{ac}
Mains Frequency (f_L)	50/60 Hz
Maximum Output Power (P_{out})	45W
Output	V_{out} = 18V
	I_{out} = 2.5A
	Full load ripple = 2%
Normal Operation Switching Frequency (f_{osc})	70kHz
Light Load Switching Frequency (f_{SB})	18kHz
Target Efficiency (@ P_{out} = 45W, V_{in} = 88 ÷ 264 Vac) (η)	>80%
Maximum Input Power (@ P_{out} = 0.5W, V_{in} = 88 ÷ 264 V_{ac})	≤2W
Maximum Input Power (Open load, Vin = 88 ÷ 264 V_{ac})	≤1W

The selected topology is flyback. The operation mode (@ P_{out} = 45W) 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 maximum duty cycle will be limited below 50%, thus no slope compensation is needed.

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.

Evaluation Board Functionality

The outstanding feature of this application board is the so-called Standby Function, directly available from the L5991. When the load is such that the power demanded of the mains is greater then about 13W the switching frequency of the converter is set at f_{osc} = 70 kHz (by means of the capacitor C5 and the parallel of R12 and R13). When the input power falls below about 8.5W the L5991 automatically changes the oscillator frequency to f_{SB} =18 kHz (by disconnecting R13 internally and charging C5 through R12 only).

These thresholds are ”static” values, that is are related to slow load variations. In case of step-load changes the output of the error amplifier will experience undershoots and overshoots, thus the ”dynamic” thresholds will be different. Namely, the dynamic threshold for the transition $f_{osc} \rightarrow f_{SB}$ will be greater than the static one, whereas the dynamic theshold for the transition $f_{SB} \rightarrow f_{osc}$ will be lower than the static one (see tables 10 and 11). The gap between static and dynamic thresholds can be reduced to some extent by slowing down the control loop, although this goes to the detriment of the dynamic response of the system.

Figure 1. Electrical Schematic

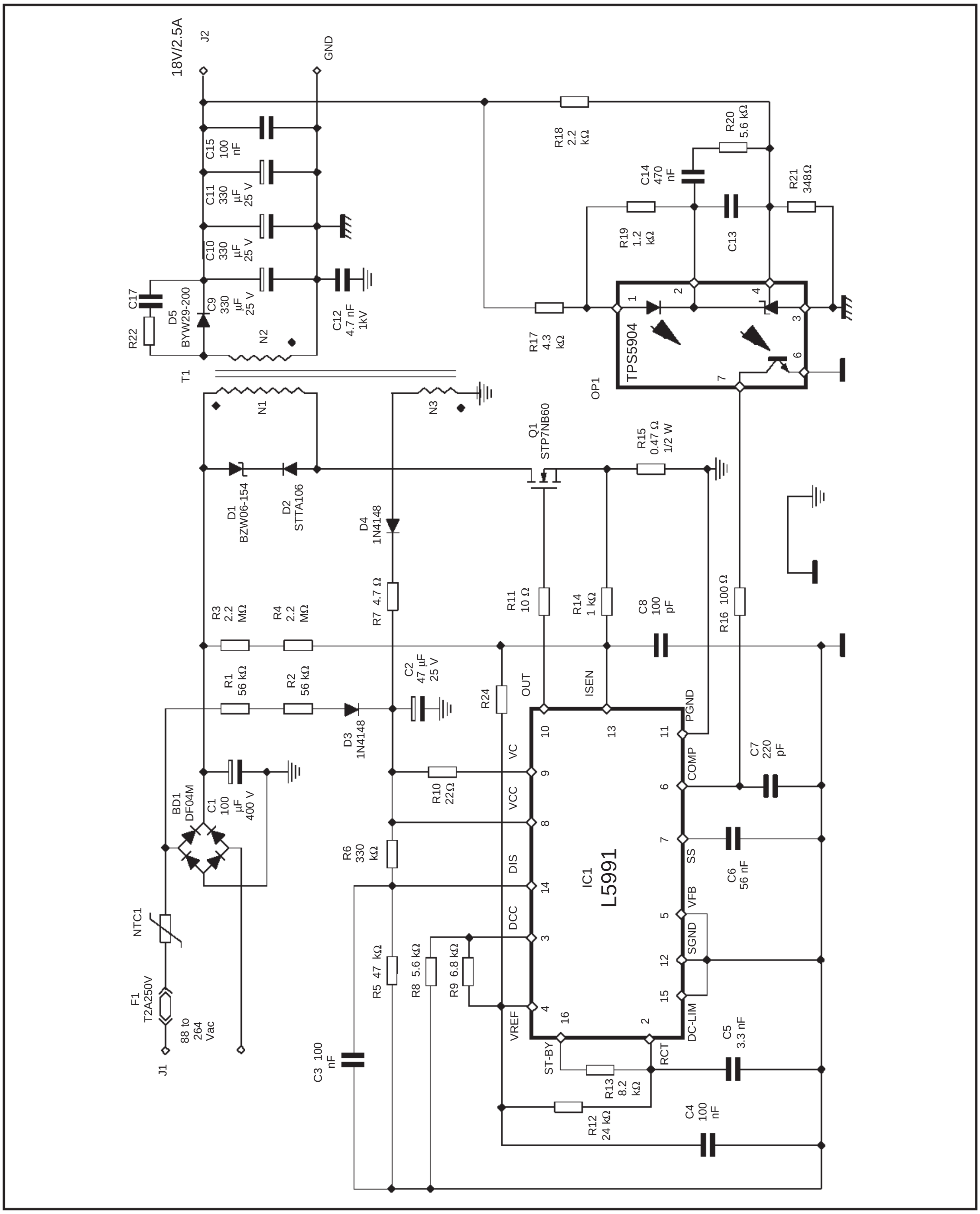


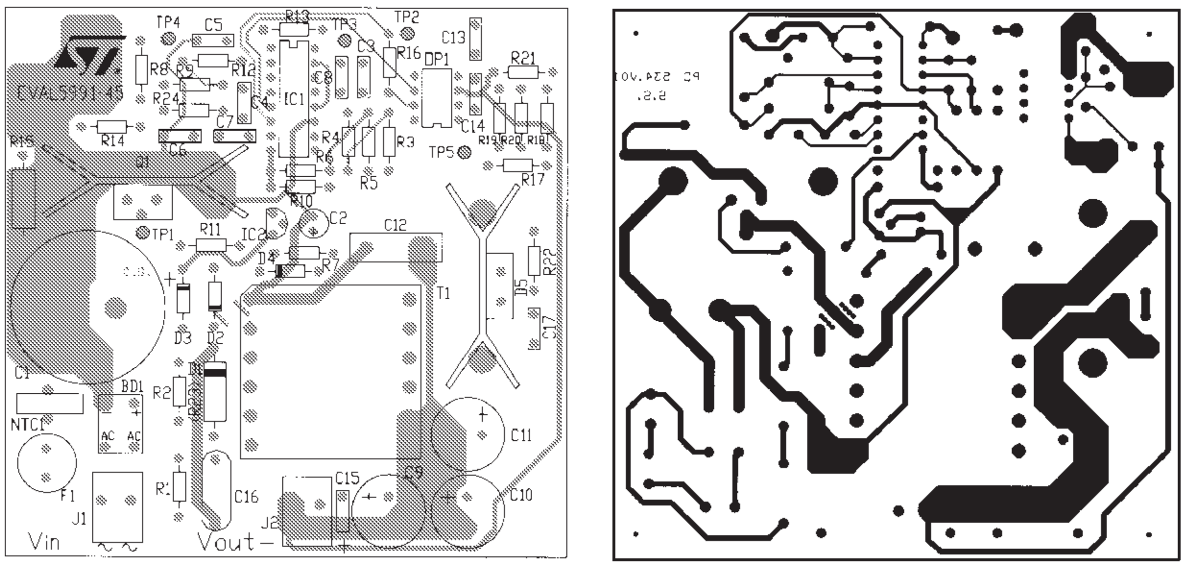
Table 2. Component List of the circuit of fig. 1

Symbol	Value	Note
R1, R2	56kΩ	
R3, R4	2.2MΩ	5%
R5	47kΩ	
R6	330kΩ	
R7	4.7Ω	5%
R8, R20	5.6kΩ	
R9	6.8kΩ	
R10	22Ω	5%
R11	10Ω	5%
R12	24kΩ	
R13	8.2kΩ	
R14	1kΩ	
R15	0.47Ω	metallic film
R16	100Ω	5%
R17	4.3kΩ	
R18	2.2kΩ	
R19	1.2kΩ	5%
R21	348Ω	
R22, R23, R24	–	Not assembled
C1	100µF	400V, electrolytic, Rubycon MXR or equivalent
C2	47µF	25V, electrolytic
C3, C4, C15	100nF	plastic film
C5	3.3nF	plastic film
C6	56nF	plastic film
C7	220pF	plastic film
C8	100pF	plastic film
C9, C10, C11	330µF	25V, electrolytic, Panasonic HFZ or equivalent
C12	4.7nF	1kV
C13, C16, C17	–	Not assembled
C14	470nF	plastic film
D1	BZW06-154	154V/600W peak Transil, ST
D2	STTA106	1A/600V Turboswitch, ST
D3, D4	1N4148	
D5	BYW29-200	8A/200V Ultrafast, ST
IC1	L5991	PWM controller, ST
IC2	–	Not assembled
T1	See specs	RDT 20001, RD Elettronica Milano (Tel. +39 02 66106489)
OP1	TPS5904	Optocoupler + TL431, TI
Q1	STP7NB60FI	1.2Ω/600V, ST
BD1	DF04M	GI, or equivalent 1A, 400V
NTC1	–	Not assembled (shorted)
F1	T2A250V	2A, 250V ELU
Notes: - if not otherwise specified, all resistors are 1/4W, 1% - Q1 and D5 are provided with a 15°C/W heatsink		

Table 3. Transformer Specification (Part Number RDT20001, supplied by RD Elettronica).

Core	Philips EFD30x15x9, 3C85 Material or equivalent				
Bobbin	Horizontal mounting, 12 pins				
Air gap	≅ 0.7 mm for an inductance 2-6 of 400 μH				
Leakage inductance	< 10μH				
Windings Spec & Build	Winding	Wire	S-F	Turns	Notes
	Pri1	AWG27	2-4	25	
	Sec (a)	AWG25	11-7	12	Bifiliar with Sec (b)
	Sec (b)	AWG25	12-8	12	Bifiliar with Sec (a)
	Pri2	AWG27	4-6	25	
	Aux	AWG32	3-1	10	Evenly spaced
	Note: sec (a) and sec (b) are paralleled on the PCB				

Figure 2. PCB layout: Silk + component side and bottom layer (top view); 1:1.25 scale.



If the user wants to decrease 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 L5991's current sense pin (13, ISEN). This can be accomplished by means of R24, currently not used. The offset will be the partition of the reference voltage (pin 4, VREF) through R24 and R14. Consider that applying the offset may require the sense resistor R15 to be reduced, as shown in table 4. Increasing R15 is instead the way to increase P_{inSB}.

Table 4. Adjustment of the static standby thresholds

R24	open	100kΩ	47kΩ	33kΩ	24kΩ
R15[Ω]	0.47	0.43	0.43	0.43	0.39
DC offset[mV]	0	50	100	150	200
P_{inSB}[W]	8.3	6.2	5.1	3.6	2.5
P_{inNW}[W]	13.3	11.9	12.3	11.1	11.5

The power level that causes the switching frequency to be moved from f_{SB} to f_{osc} (P_{inNW}) is proportional to the ratio f_{osc} / f_{SB} and depends only slightly on the offset. Thus to reduce P_{inNW}, f_{SB} needs reducing and vice versa. If, instead, P_{inNW} is increased there is no risk of transformer saturation: the primary peak current is limited by the sense resistor (R15) and cannot definitely exceed the full load value.

The thresholds are expressed in terms of input power (P_{inSB}, P_{inNW}); the relevant output power levels (P_{outSB}, P_{outNW}) can be obtained by multiplying by the efficiency.

R2 and R3 provide an additional DC offset on the current sense which depends on the supply input voltage. This is used for compensating L5991's delay to output and also minimises the dependence of PinSB and PinNW on the mains voltage (see table 7).

Additionally, the board includes some protection functions tipically required in AC-DC adapters, 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 R5-R6 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 (e.g. optocoupler's failure).

At maximum load and minimum mains voltage the converter operates at about 48% duty cycle (this is why slope compensation is not required), however the maximum duty cycle of the L5991 is limited at about 55% to make allowance for load transients. This implies that during transients resulting from a large enough step-load change at minimum mains voltage, subharmonic oscillations are likely to arise. It is, however, acceptable, this being a condition lasting few milliseconds.

To set the maximum duty cycle at 55%, L5991's pin3 (DC) is biased through R8 and R9 at about 2.26V. Please refer to *Application Information* in L5991's datasheet for the calculation of the voltage divider.

The evaluation board is supplied with a start-up circuit simply made up of a dropping resistor (R1+R2), in series with a diode (D3), that draws current from upstream the bridge rectifier.

This circuit, really inexpensive, dissipates about 300 mW @ 264 Vac. The typical wake-up time is 2.8 s at 88Vac and 0.8 s at 264 Vac. Should the wake-up time or the consumption become an issue, a more expensive solution would be adopted. The PCB is also able to accommodate a high-voltage start-up IC (IC2), the LR745N3 available from SUPERTEX and housed in a small TO92 package. In that case R1, R2 and D3 would be removed and the consumption of the start-up circuit would be of few mW. The wake-up time would be about 0.2 s independently of the mains voltage.

To enhance light load efficiency, the EVAL5991-45 board is supplied with the clamping network (for the leakage inductance spike) made up of a Transil diode (D1) instead of the usual RCD type. The PCB is able to accommodate the RCD clamp anyway (R23 and C16). The use of the Transil, although slightly worsens efficiency at full load, allows to save over 100 mW that would have been dissipated on R23 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 J1 (close to the bottom left-hand corner). The 18VDC output (connector J2) is located few centimeters on the right of J1.

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.

There is a number of test points where significant signals can be probed:

TP1: Q1 drain voltage;

TP2: pin 6 of the L5991: output of the error amplifier;

TP3: pin16 of the L5991: standby indicator;

TP4: pin 2 of the L5991: local oscillator;

TP5: pin 1 of the TPS5904: anode of the LED of the optocoupler.

Evaluation board performance: bench 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 5. Typical application performance

Parameter	Value	Unit
Regulated Output Voltage (Vin = 220 Vac, Iout = 2.5A)	18.27	V
Normal Operation Switching Frequency	67.8	kHz
Stanby Switching Frequency	17.6	kHz
Line regulation (Vin = 88 to 264 Vac, Iout = 0.5A)	5	mV
Load regulation (Vin = 220 Vac, Iout = 0 to 2.5A)	15	mV
Full Load peak-to-peak output ripple (Vin = 88 Vac, Iout = 2.5A)	100	mV
Maximum Efficiency (Vin = 160 Vac, Iout = 2.5A)	87.3	%

Table 6. Full load efficiency (%)

V_{AC} [V]		**88**	**110**	**160**	**220**	**264**
Iout [A]	**2.5**	86.2	86.8	87.3	87.2	86.2
	2	86.3	87	87	86.8	85.7
	1.5	86.2	86.6	86.5	85.9	85.1
	1	86	86.2	86	84.6	83.5
	0.5	83.9	84.2	83.1	80.2	79.1
	0.5*	83.5	83.8	82	77.7	76.3
(*) @ $f_{SW} = f_{osc}$ (0.5A applied after opening the load)						

Table 7. Light load consumption (@ Pout = 0.5W), with and without standby function

V_{AC} [V]	**88**	**110**	**160**	**220**	**264**
Pin [W] *	1	1.05	1.15	1.3	1.5
Pin [W] **	1.15	1.2	1.4	1.7	2
(*) @ $f_{SW} = f_{SB}$ (**) @ $f_{SW} = f_{osc}$ (R13 connected to pin 4 instead of pin 16)					

Table 8. Zero Load consumption from the mains

V_{AC} [V]	**88**	**110**	**160**	**220**	**264**
Pin [W]	0.4	0.5	0.6	0.7	0.9

Table 9. Wake-up time

V_{AC} [V]	**88**	**110**	**160**	**220**	**264**
T_{WAKE} [s]	2.8	2.2	1.4	1	0.8

Table 10. Transition from normal operation to standby mode

V_{AC} [V]	**88**	**110**	**160**	**220**	**264**
P_{inSB} / P_{outSB} [W]*	8.3/6.9	8.3/6.9	8.4/6.9	8.5/6.9	8.7/6.9
P_{inSB} / P_{outSB} [W]**	13.3/11.2	13.3/11.2	13.2/10.9	13.2/10.7	13.4/10.7
Note: (*) Load current decreased manually by –1.2mA steps (**) Negative step-load change from 2.5A with 0.25A/µs rate of fall					

Table 11. Transition from standby mode to normal operation

V_{AC} [V]	**88**	**110**	**160**	**220**	**264**
P_{inNW} / P_{outNW} [W]*	13.3/11.2	13.3/11.1	13.3/11	13.4/10.9	13.7/10.9
P_{inNW} / P_{outNW} [W]**	11.5/9.6	11.5/9.6	11.6/9.6	11.8/9.5	11.9/9.5
Note: (*) Load current decreased manually by 1.2mA steps (**) Positive step-load change from 0.4A with 0.25A/µs rate of rise					

Figure 3. Drain voltage at full load (left: V_{in} = 100 V_{DC}, right: V_{in} = 300 V_{DC})

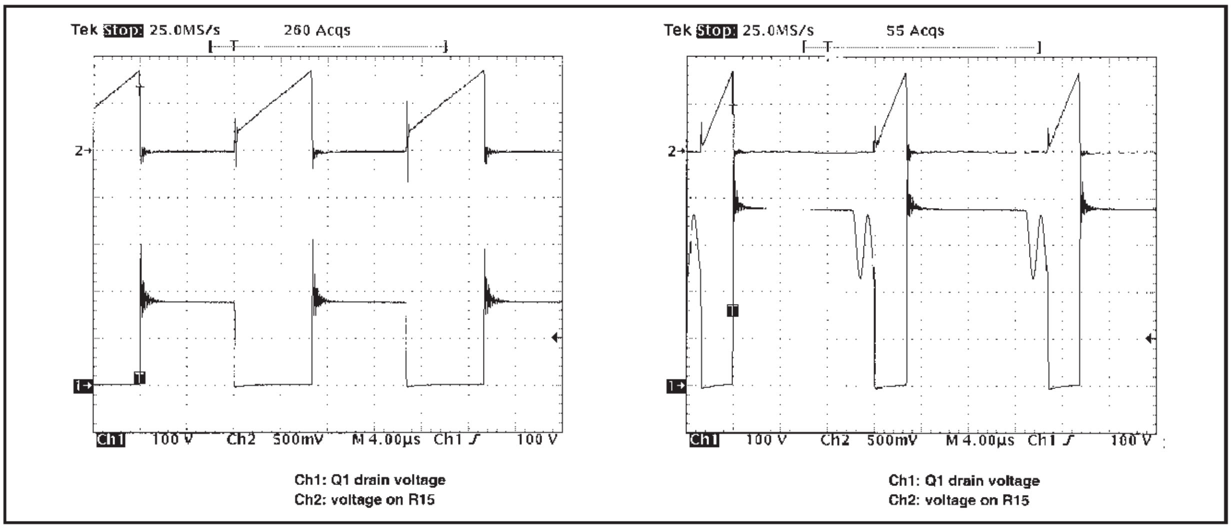


Figure 4. Drain voltage at zero load (left: V_{in} = 100 V_{DC}, right: V_{in} = 300 V_{DC})

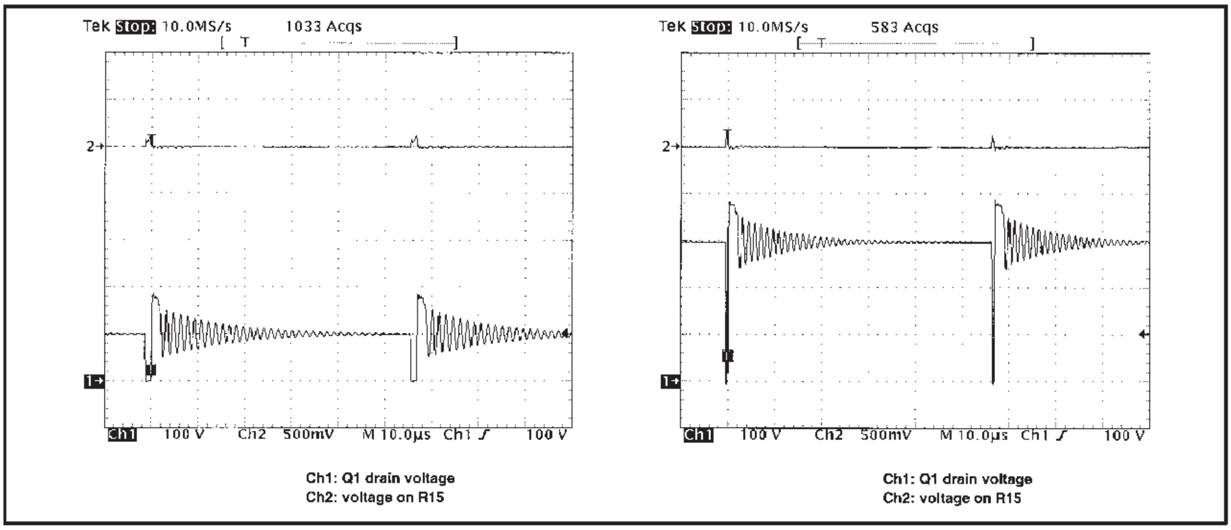


Figure 5. Load transient (0.1-2.5A)

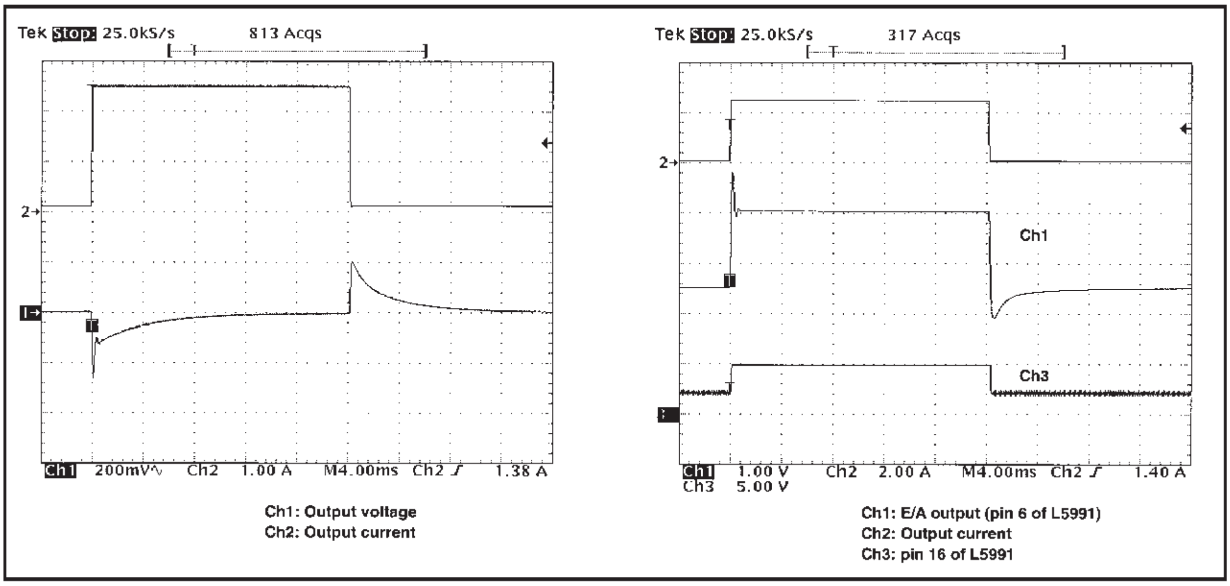


Figure 6. Load transient (0.1-2.5A)