

Control ICs for Switched-Mode Power Supplies

TDA 4601

Bipolar IC

Features

- Direct control of the switching transistor
- Low start-up current
- Reversing linear overload characteristic
- Base current drive proportional to collector current
- Protective circuit in case of disturbance

Type	Ordering Code	Package
TDA 4601	Q67000-A2379	P-SIP-9
TDA 4601-D	Q67000-A2390	P-DIP-18 L9 (pin 6 and pins 10 to 18 grounded)

The integrated circuit TDA 4601/D is designed for driving, controlling and protecting the switching transistor in self-oscillating flyback converter power supplies as well as for protecting the overall power supply unit. In case of disturbance, the rise of the secondary voltage is prevented. In addition to the ICs application range including TV receivers, video tape recorders, hifi devices and active loudspeakers, it can also be used in power supply units for professional applications due to its wide control range and high voltage stability during increased load changes.

Absolute Maximum Ratings

Parameter	Symbol	Limit Values		Unit
		min.	max.	
Supply voltage	V_9	0	20	V

Voltages

Reference output	V_1	0	6	V
Zero passage identification	V_2	- 0.6	0.6	V
Control amplifier	V_3	0	3	V
Collector current simulation	V_4	0	8	V
Blocking input	V_5	0	8	V
Base current cut-off point	V_7	0	V_9	V
Base current amplifier output	V_8	0	V_9	V

Currents

Zero passage identification	I_{I2}	- 5	5	mA
Control amplifier	I_{I3}	- 3	3	mA
Collector current simulation	I_{I4}	0	5	mA
Blocking input	I_{I5}	0	5	mA
Base current cut-off point	I_{Q7}	- 1	1.5	A
Base current amplifier output	I_{Q8}	- 1.5	0	A
Junction temperature	T_j		125	°C
Storage temperature range	T_{stg}	- 40	125	°C
Thermal resistances:				
system-air TDA 4601	$R_{th SA}$		70	K/W
system-case TDA 4601	$R_{th SC}$		15	K/W
system-air ¹⁾ TDA 4601 D	$R_{th SA}$		60	K/W
system-air ²⁾ TDA 4601 D	$R_{th SA1}$		44	K/W

Operating Range

Supply voltage	V_9	7.8	18	V
Case temperature TDA 4601	T_c	0	85	°C
Ambient temperature range ³⁾ TDA 4601 D	T_A	0	70	°C

1) Case soldered on PC board without cooling surface

2) Case soldered on PC board with copper-clad 35 µm layer, cooling surface 25 cm²3) $R_{th SA1} = 44$ K/W and $P_V = 1$ W

Characteristics $T_A = 25\text{ }^{\circ}\text{C}$

according to measurement circuit 1 and diagram

Parameter	Symbol	Limit Values			Unit
		min.	typ.	max.	

Start Operation

Current consumption (V_1 not yet switched on)					
$V_9 = 2\text{ V}$	I_9			0.5	mA
$V_9 = 5\text{ V}$	I_9		1.5	2.0	mA
$V_9 = 10\text{ V}$	I_9		2.4	3.2	mA
Switching point for V_1	V_8	11.0	11.8	12.3	V

Normal Operation $V_9 = 10\text{ V}$; $V_{\text{cont}} = -10\text{ V}$; $V_{\text{clock}} = \pm 0.5\text{ V}$; $f = 20\text{ kHz}$;

duty cycle 1:2 after switch-on

Current consumption					
$V_{\text{cont}} = -10\text{ V}$	I_9	110	135	160	mA
$V_{\text{cont}} = 0\text{ V}$	I_9	50	75	100	mA
Reference voltage					
$I_1 < 0.1\text{ mA}$	V_1	4.0	4.2	4.5	V
$I_1 = 5\text{ mA}$	V_1	4.0	4.2	4.4	V
Temperature coefficient of reference voltage	TC_V		10^{-3}		1/K
Control voltage $V_{\text{cont}} = 0\text{ V}$	V_3	2.3	2.6	2.9	V
Collector current simulation voltage					
$V_{\text{cont}} = 0\text{ V}$	$V_{Q4}^*)$	1.8	2.2	2.5	V
$V_{\text{cont}} = 0\text{ V}/-10\text{ V}$	$\Delta V_{Q4}^*)$	0.3	0.4	0.5	V
Clamping voltage	V_5	6.0	7.0	8.0	V
Output voltages					
$V_{\text{cont}} = 0\text{ V}$	$V_{Q7}^*)$	2.7	3.3	4.0	V
$V_{\text{cont}} = 0\text{ V}$	$V_{Q8}^*)$	2.7	3.4	4.0	V
$V_{\text{cont}} = 0\text{ V}/-10\text{ V}$	ΔV_{Q8}	1.6	2.0	2.4	V
Feedback voltage	$V_{2}^*)$		0.2		V

*) DC component only

Protective Operation

$V_9 = 10 \text{ V}$; $V_{\text{cont}} = -10 \text{ V}$; $V_{\text{clock}} = \pm 0.5 \text{ V}$; $f = 20 \text{ kHz}$;
duty cycle 1:2

Parameter	Symbol	Limit Values			Unit
		min.	typ.	max.	
Current consumption $V_5 < 1.9 \text{ V}$	I_9	14	22	28	mA
Switch-off voltage $V_5 < 1.9 \text{ V}$	V_{O7}	1.3	1.5	1.8	V
Switch-off voltage $V_5 < 1.9 \text{ V}$	V_4	1.8	2.1	2.5	V
Blocking input Blocking voltage $V_{\text{cont}} = 0 \text{ V}$	V_5	$\frac{V_1}{2} - 0.1$	$\frac{V_1}{2}$		V
Supply voltage blocked for V_8 $V_{\text{cont}} = 0 \text{ V}$	V_9	6.7	7.4	7.8	V
V_1 off (with further reduction of V_9)	ΔV_9	0.3	0.6	1.0	V

Characteristics

$T_A = 25^\circ\text{C}$; according to measurement circuit 2

Parameter	Symbol	Limit Values			Unit
		min.	typ.	max.	
Switching time (secondary voltage)	t_{on}		350	450	ms
Voltage variation S3 = closed $\Delta V_3 = 20 \text{ W}$	$\Delta V_{2 \text{ sec}}$		100	500	mV
Voltage deviation S2 = closed $\Delta V_2 = 15 \text{ W}$	$\Delta V_{2 \text{ sec}}$		500	1000	mV
Standby operation S1 = open secondary useful load = 3 W	$\Delta V_{2 \text{ sec}}$ f	70	20 75	30	V kHz

The cooling conditions have to be optimized with regard to maximum ratings
(T_A ; T_I ; R_{thJC} ; R_{thSA}).

Circuit Description

The TDA 4601 is designed for driving, controlling and protecting the switching transistor in flyback converter power supplies during start-up, normal and overload operations as well as during disturbed operation. In case of disturbance the drive of the switching transistor is inhibited and a secondary voltage rise is prevented.

I. Start-Up

The start-up procedures (on-mode) include three consecutive operating phases as follows:

1. Build-Up of Internal Reference Voltage

The internal reference voltage supplies the voltage regulator and effects charging of the coupling electrolytic capacitor connected to the switching transistor. Current consumption will remain at $I_9 < 3.2$ mA with a supply voltage up to V_9 approx. 12 V.

2. Enabling of Internal Voltage - Reference Voltage $V_1 = 4$ V

Simultaneously with V_9 reaching approx. 12 V, an internal voltage becomes available, providing all component elements, with the exception of the control logic, with a thermally stable and overload-resistant current supply.

3. Enabling of Control Logic

In conjunction with the generation of the reference voltage, the current supply for the control logic is activated by means of an additional stabilization circuit. The integrated circuit is then ready for operation.

The start-up phase above described are necessary for ensuring the charging of the coupling electrolytic capacitor, which in turn supplies the switching transistor. Only then is it possible to ensure that the transistor switches accurately.

II. Normal Operating Mode / Control Operating Mode

At the input of pin 2 the zero passages of the frequency provided by the feedback coil are registered and forwarded to the control logic. Pin 3 (control input, overload and standby identification) receives the rectified amplitude fluctuations of the feedback coil. The control amplifier operates with an input voltage of approx. 2 V and a current of approx. 1.4 mA. Depending on the internal voltage reference, the overload identification limits in conjunction with collector current simulator pin 4 the operating

range of the control amplifier. The collector current is simulated by an external RC combination present at pin 4 and internally set threshold voltages. The largest possible collector current applicable to the switching transistor (point of return) increases in proportion to the increased capacitance (10 nF). Thus the required operating range of the control amplifier is established. The range of control lies between a DC voltage clamped at 2 V and a sawtooth - shaped rising AC voltage, which can vary up to a max. amplitude of 4 V (reference voltage). During secondary load reduction to approx. 20 W, the switching frequency is increased (approx. 50 kHz) at an almost constant pulse duty factor (1:3). During additional secondary load decreases to approx. 1 W, the switching frequency increases to approx. 70 kHz and pulse duty factor to approx. 1:11. At the same time collector peak current is reduced to < 1 A.

The output levels of the control amplifier as well as those of the overload identification and collector current simulator are compared in the trigger and forwarded to the control logic. Via pin 5 it is possible to externally inhibit the operations of the IC. The output at pin

pin 8 will be inhibited when voltages of $\leq \frac{V_{REF}}{2} - 0.1 \text{ V}$ are present at pin 5.

Flipflops for controlling the base current amplifier and the base current shut-down are set in the control logic depending on the start-up circuit, the zero passage identification as well as on the enabling by the trigger. The base current amplifier forwards the sawtooth-shaped V_4 voltage to the output of pin 8. A current feedback with an external resistor ($R = 0.68 \Omega$) is present between pin 8 and pin 7. The applied value of the resistor determines the max. amplitude of the base driving current for the switching transistor.

III. Protective Operating Mode

The base current shut-down activated by the control logic clamps the output of pin 7 to 1.6 V. As a result, the drive of the switching transistor is inhibited. This protective measure is enabled if the supply voltage at pin 9 reaches a value $\leq 6.7 \text{ V}$ or if voltages of

$$\leq \frac{V_{REF}}{2} - 0.1 \text{ V} \text{ are present at pin 5.}$$

In case of short-circuits occurring in the secondary windings of the switched-mode power supply, the integrated circuit continuously monitors the fault conditions. During secondary, completely load-free operation only a small pulse duty factor is set. As a result the total power consumption of the power supply is held at $N = 6 \dots 10 \text{ W}$ during both operating modes. After the output has been inhibited for a voltage supply of $\leq 6.7 \text{ V}$, the reference voltage (4 V) is switched off if the voltage supply is further reduced by $\Delta V_9 = 0.6 \text{ V}$.

Protective Operating Mode at Pin 5 in Case of Disturbance

The protection against disturbances such as primary undervoltages and/or secondary over- voltages (e.g. by changes in the component parameters for the switched-mode power supply) is realized as follows:

Protective Operating Mode with Continuous Fault Condition Monitoring

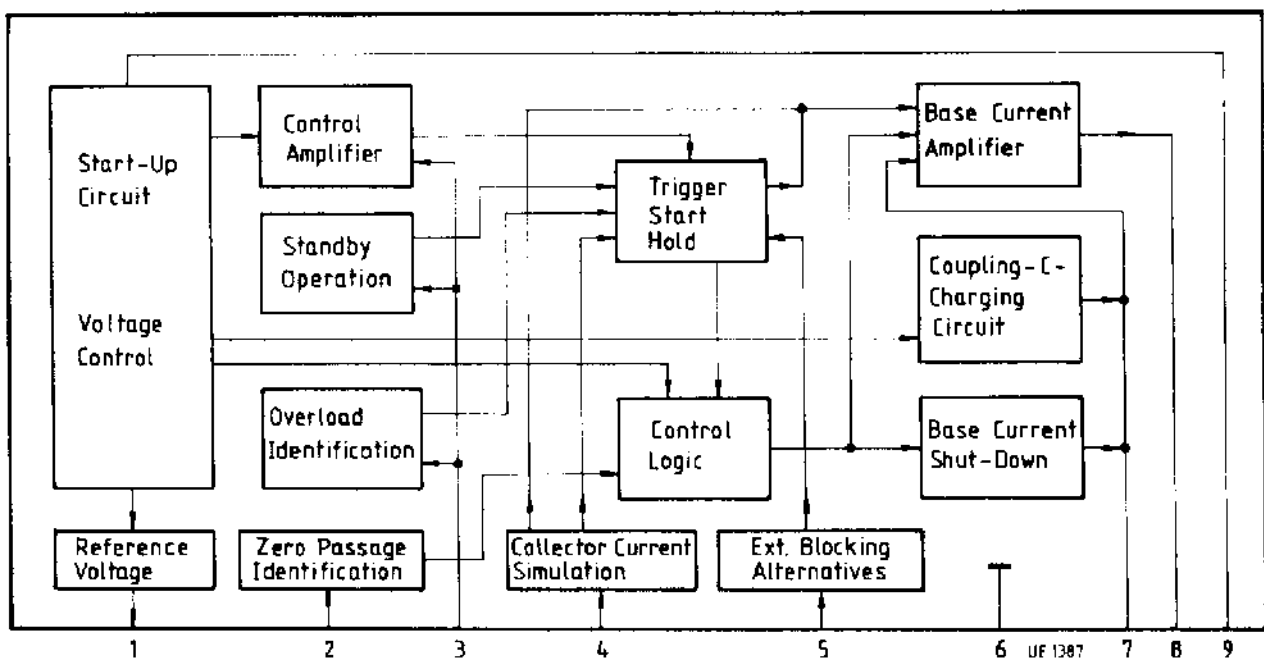
In case of disturbance the output pulses at pin 8 are inhibited by falling below the protective threshold V_5 , with a typical value of $V_1/2$. As a result current consumption is reduced ($I_9 \geq 14$ mA at $V_9 = 10$ V).

With a corresponding **high-impedance** start-up resistor*), supply voltage V_9 will fall below the minimum shut-down threshold (5.7 V) for reference voltage V_1 . V_1 will be switched off and current consumption is further reduced to $I_9 \leq 3.2$ mA at $V_9 \leq 10$ V.

Because of these reductions in current consumption, the supply voltage can rise again to reach the switch-on threshold of $V_9 \geq 12.3$ V. The protective threshold at pin 5 is released and the power supply is again ready for operation.

In case of continuing problems of disturbance ($V_5 \leq V_1/2 - 0.1$ V) the switch-on mode is interrupted by the periodic protective operating mode described above, i.e. pin 8 is inhibited and V_9 is falling, etc.

Block Diagram



*) in application circuit 1 10 k Ω /3 W

IV. Switch-On in the Wide Range Power Supply (90 Vac to 270 Vac) (application circuit 2)

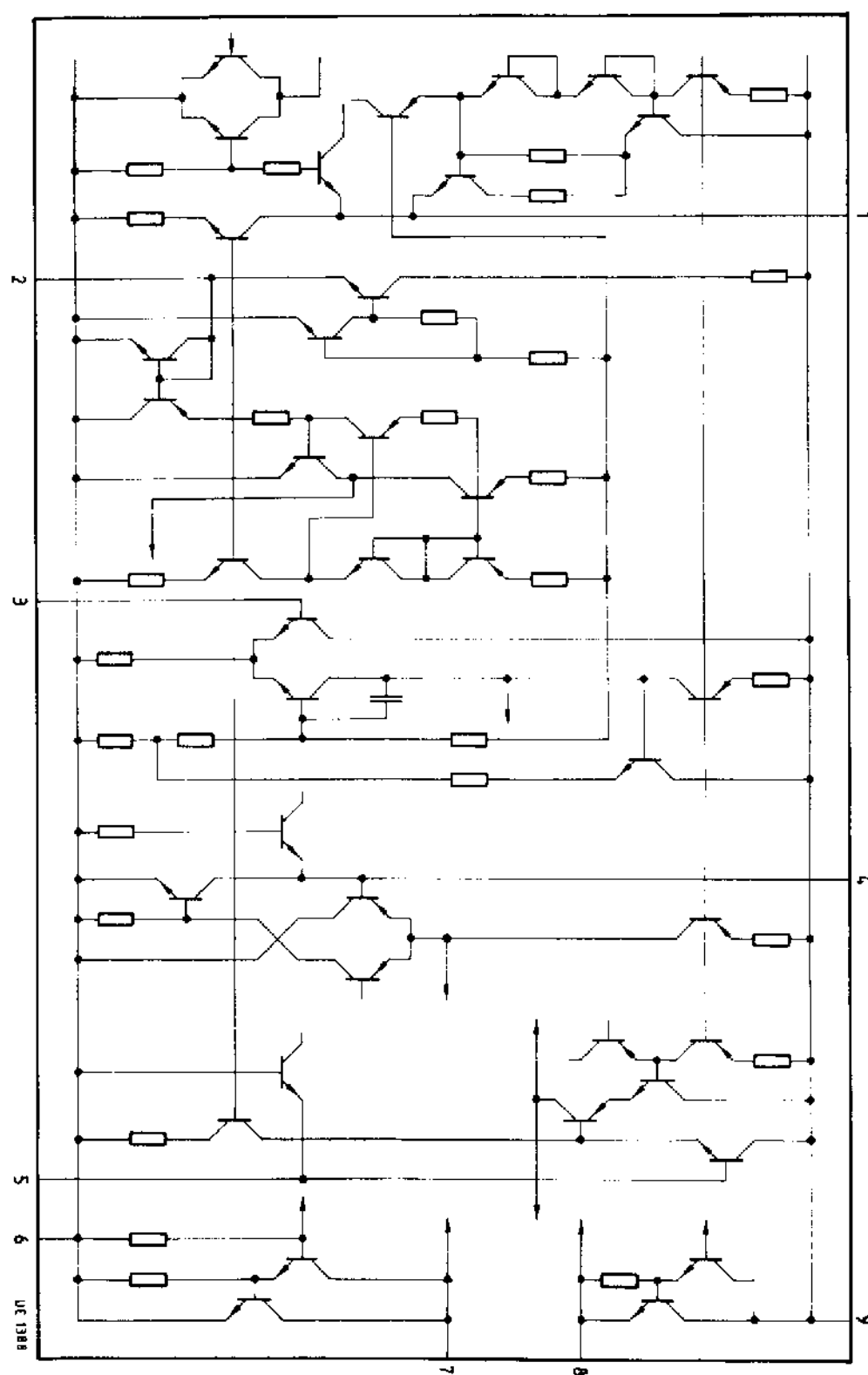
Self-oscillating flyback-converters designed as wide range power supplies require a power source independent of the rectified line voltage for TDA 4601. Therefore the winding polarity of winding 11/13 corresponds to the secondary side of the flyback converter transformer. Start-up is not as smooth as with an immediately available supply voltage, because TDA 4601 has to be supplied by the start-up circuit until the entire secondary load has been charged. This leads to long switch-on times, especially if low line voltages are applied.

However, the switch-on time can be shortened by applying the special start-up circuit (dotted line). The uncontrolled phase of feedback control winding 15/9 is used for activating purposes. Subsequent to activation, the transistor T1 begins to block when winding 11/13 generates the current supply for TDA 4601. Therefore, the control circuit cannot be influenced during operation.

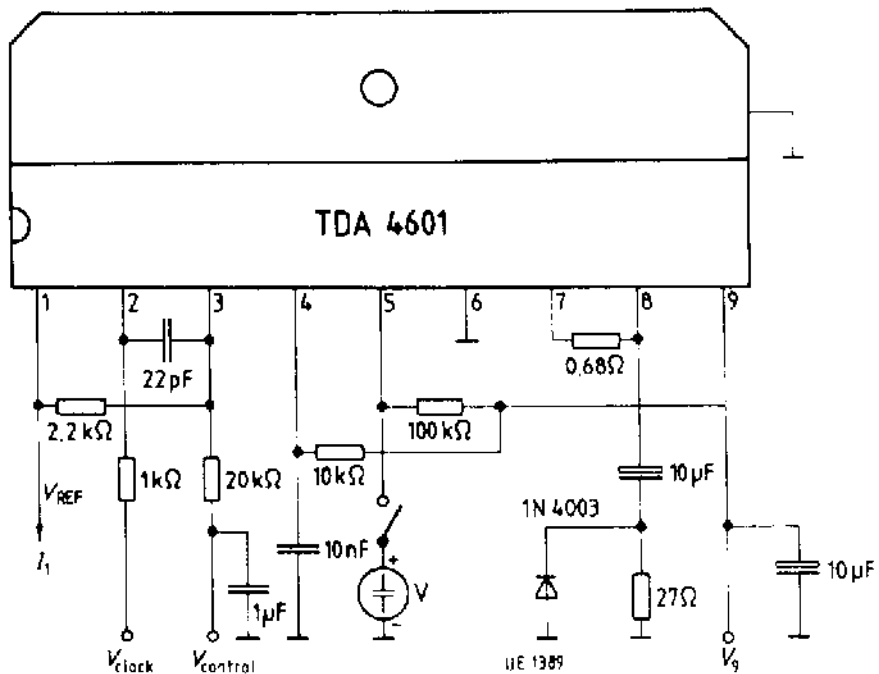
Pin Functions

Pin No.	Function
1	V_{REF} output
2	Zero passage identification
3	Input control amplifier, overload amplifier
4	Collector current simulation
5	Connection for additional protective circuit
6	Ground (rigidly connected to substrate mounting plate)
7	DC output for charging coupling capacitor
8	Pulse output - driving of switching transistor
9	Supply voltage

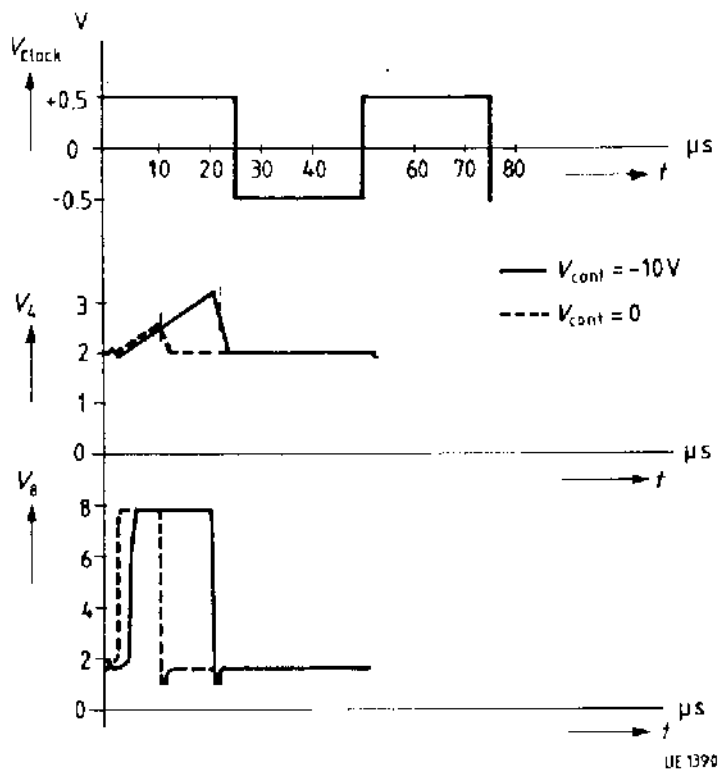
Circuit Diagram



Test and Measurement Circuit 1

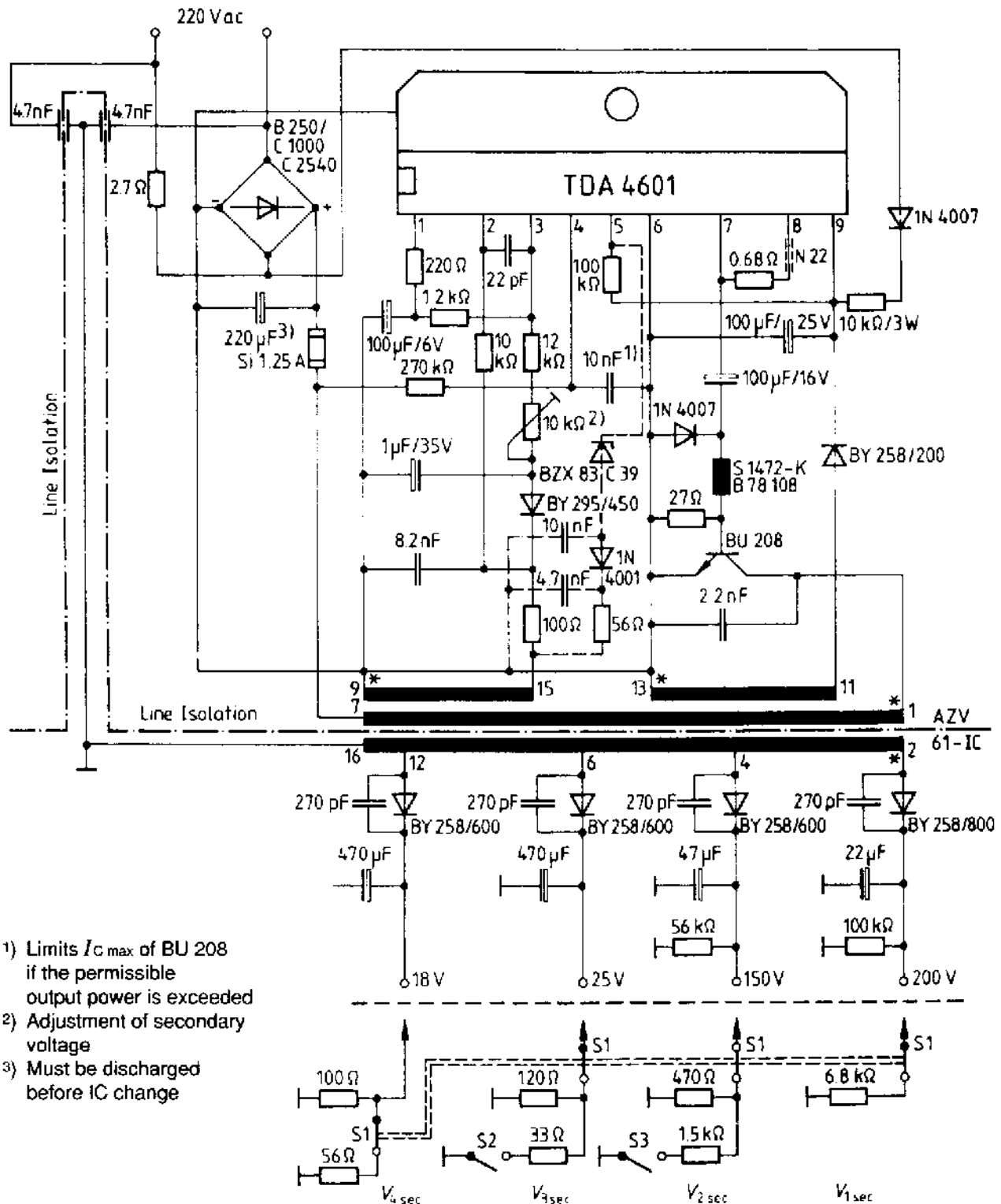


Test Diagram: Overload Operation



Application Circuit 1

Test and Measurement Circuit 2



--- Protective circuit against rise of secondary voltage in case of disturbance

Notes on application circuit 1

Protective Circuit against Secondary Voltage Rise even in Case of Disturbance

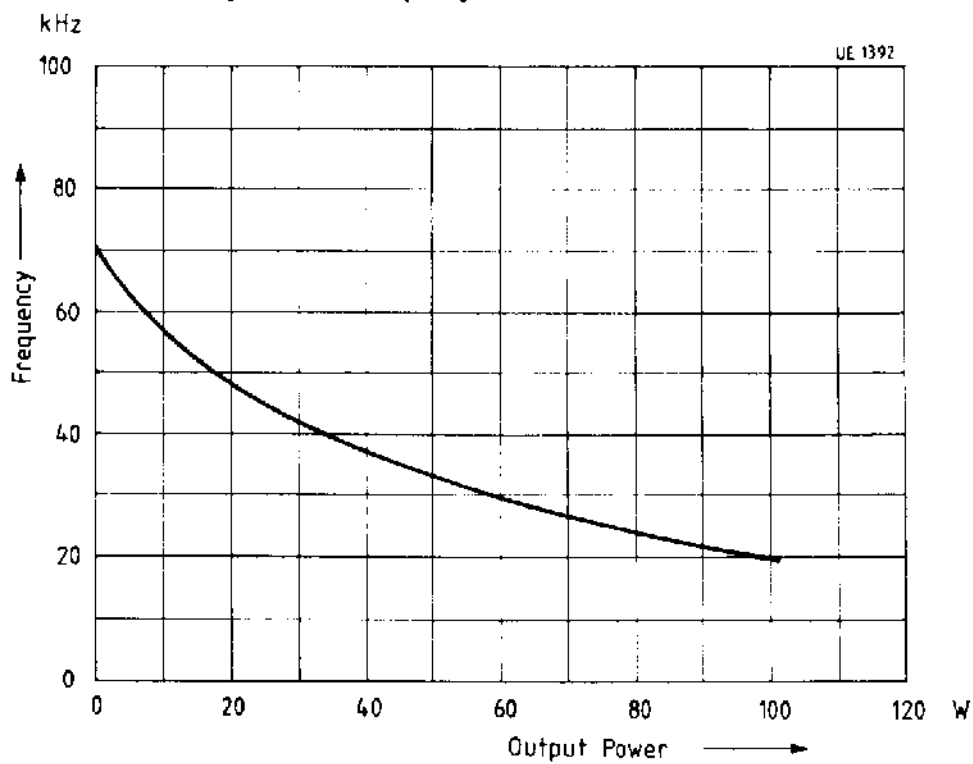
During standby this circuit type is necessary only under certain conditions. If switch S1 is open and the secondary side is loaded with no more than 1 to 5 W, a secondary voltage overshoot of approx. 20% will occur.

In case of disturbance (e.g. if the potentiometer is loosely contacted resulting in 10 k Ω (2), if the capacitor exhibits a 1 μ F loss in capacitance, or if the 2 k Ω resistor increases to a high-impedance value of 32 k Ω), the protective effect of the standard turn-off is not active before the point of return has been reached. The result is that energy is pumped into the secondary side during disturbance, which will not ease off before is reached the point of return at worst and, entails an instantaneous doubling of the voltage to 300 V (endangering the secondary electrolytic capacitors).

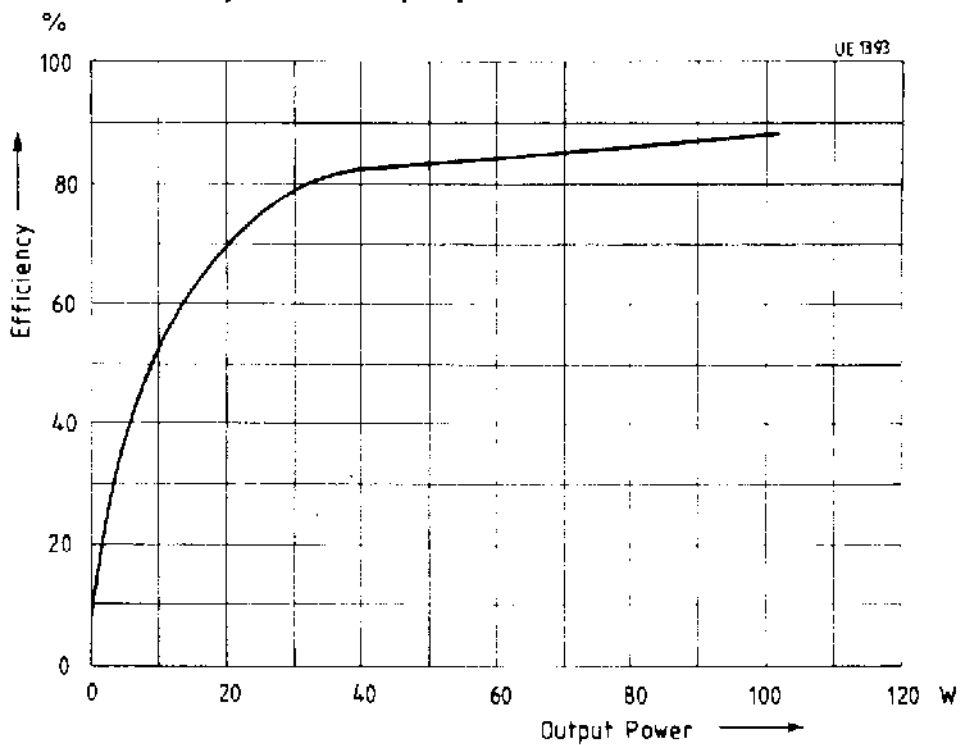
This additional protective circuit, which identifies the energy surge as voltage overshoot, is directly active at control winding 9/15. Through the 56 Ω resistor and the 1N4001 rectifier the negative portion is deducted and stored in the 10 μ F capacitor. If the amplitude exceeds the voltage of Z-diode BZX 83/39, pin 5 is drawn below the turn-off threshold, inhibiting further control pulses at pin 8. During disturbance conditions the voltage overshoot on the secondary side will assume maximum values of approx. 30%.

Supplements to Test and Measurement Circuit 2

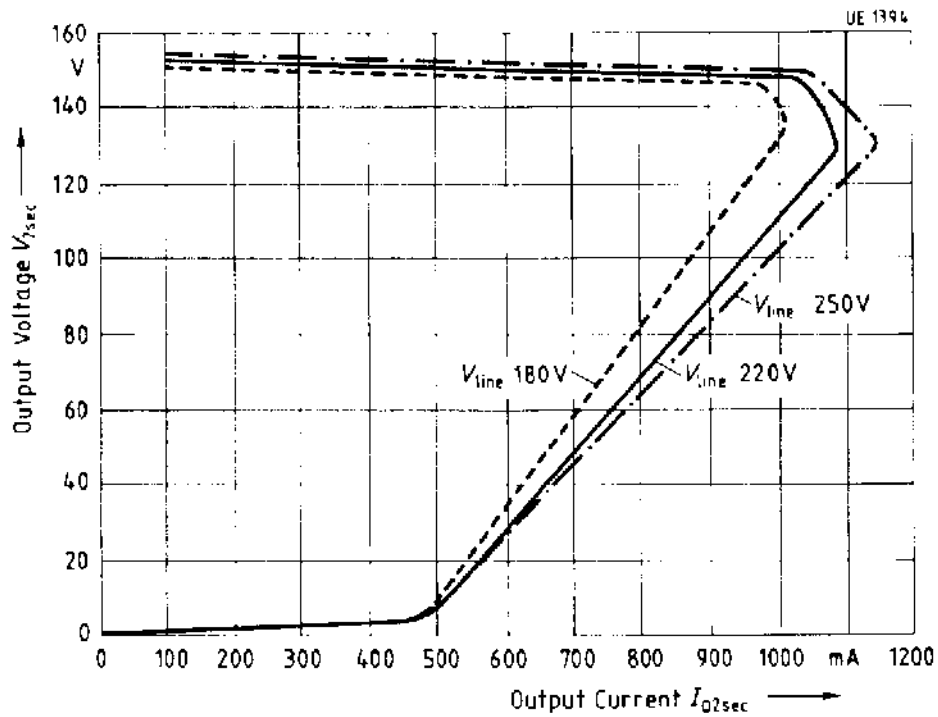
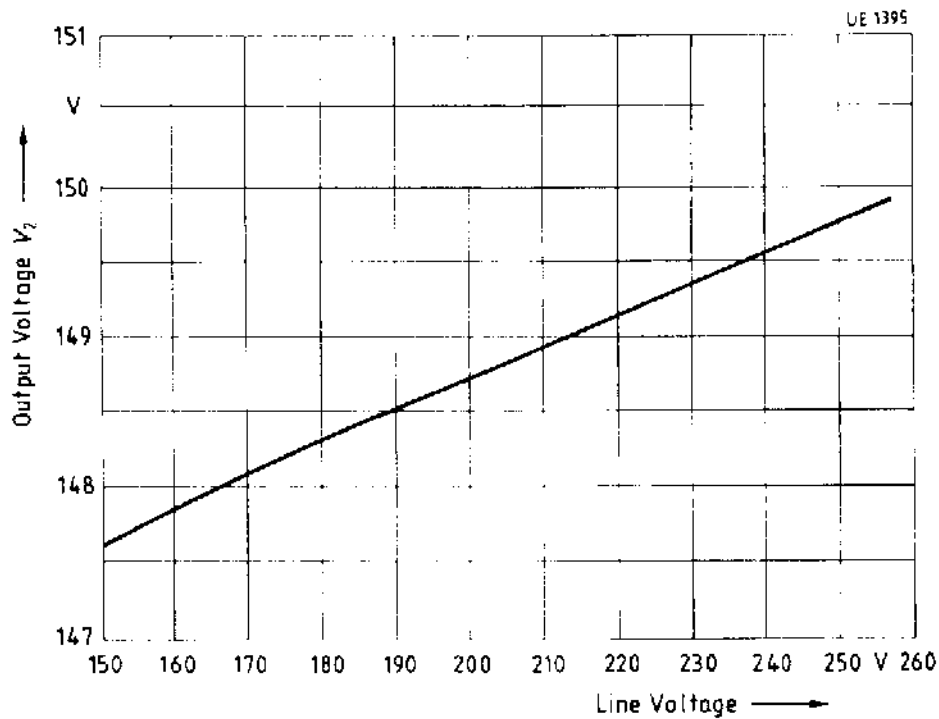
Efficiency versus output power



Efficiency versus output power

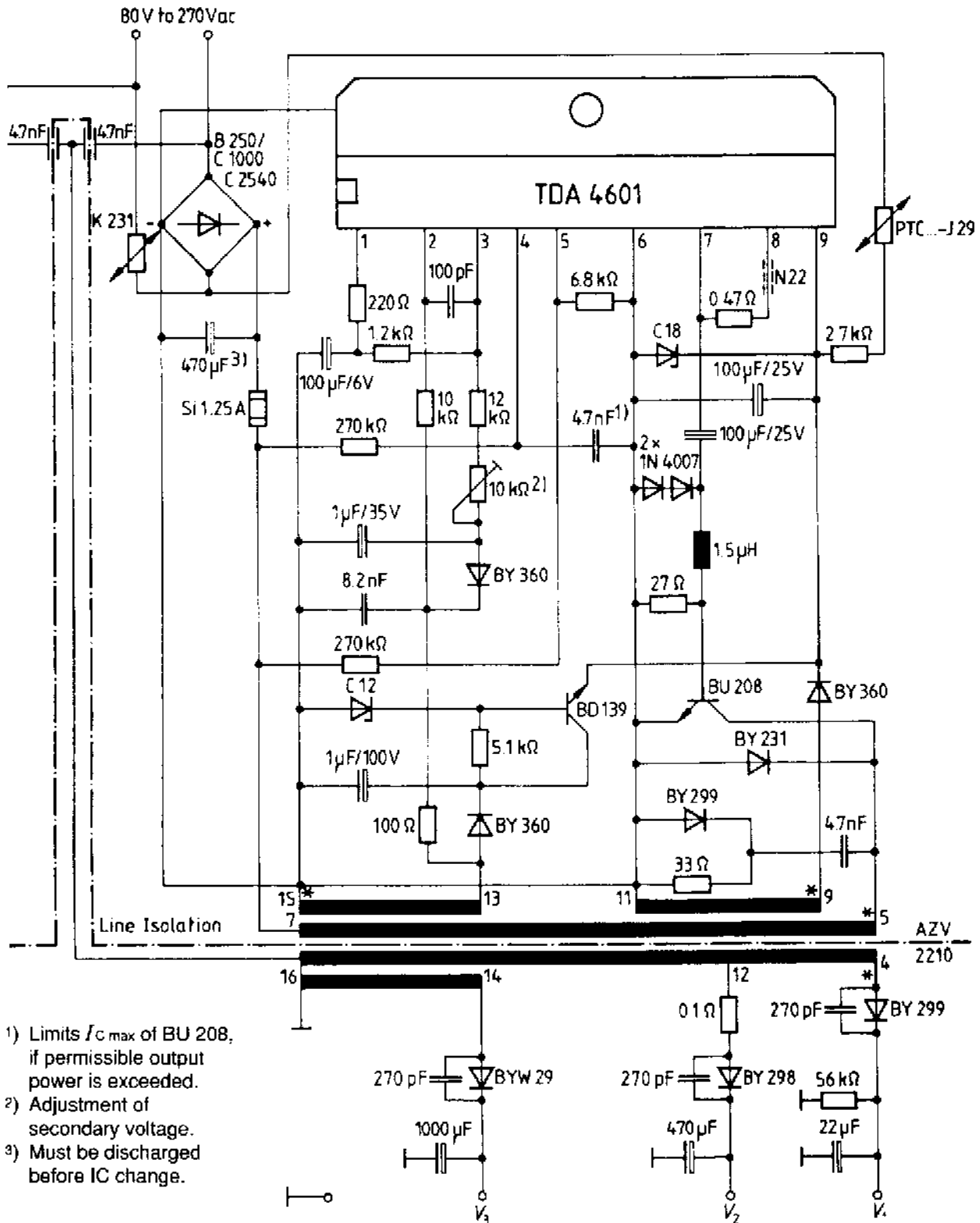


Supplements to Test and Measurement Circuit 2

Load characteristics $V_{2\text{sec}} = f(I_{2\text{sec}})$ Output voltage $V_{2\text{sec}}$ (Line change)

Application Circuit 2

Wide range from 80 to 270 Vac



UE1396

Notes on application circuit 2

Wide Range SMPS

Filtering of the rectified AC voltage has been increased up to $470\ \mu\text{F}$ to ensure a constant and hum-free supply at $V_{\text{line}} = 80\ \text{V AC}$. The stabilized phase is tapped for supplying the IC. In order to ensure good start-up conditions for the SMPS in the low voltage range, the non-stabilized phase of winding 13/15 is used as a starting aid (BD 139), which is turned off after start-up by means of Z-diode C12.

In comparison to the 220 Vac standard circuit, however, the collector-emitter circuit had to be altered to improve the switching behavior of BU 208 for the entire voltage range (80 to 270 Vac). Diode BY 231 is necessary to prevent inverse operation of BU 208 and may be integrated for switching times with a secondary power $< 75\ \text{W}$ (BU 208 D).

Compared to the IC TDA 4600-2, the TDA 4601 has been improved in turn-off during under-voltage at pin 5. The TDA 4601 is additionally provided with a differential amplifier input at pin 5, enabling precise turn-off at the output of pin 8 accompanied by hysteresis. For wide range SMPS, TDA 4601 is recommendable instead of TDA 4600-2. If a constant quality standard equal to that of the standard circuit is to be maintained, wide range SMPS (80 to 270 Vac) with secondary power of 120 W can only be implemented at the expense of time.

Thermal Resistance TDA 4601 D

Standardized, ambient-related thermal resistance R_{thJA1} versus length l of a square copper-clad cooling area (35 μm copper cladding)

$$R_{thJA} (l = 0) = 60 \text{ K/W}$$

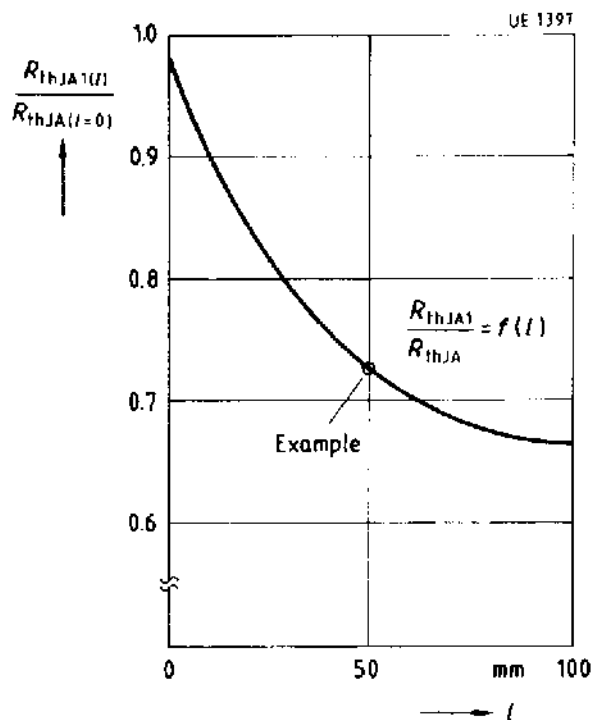
$$T_A = 70 \text{ }^\circ\text{C}$$

$$P_D = 1 \text{ W}$$

PC board in vertical position

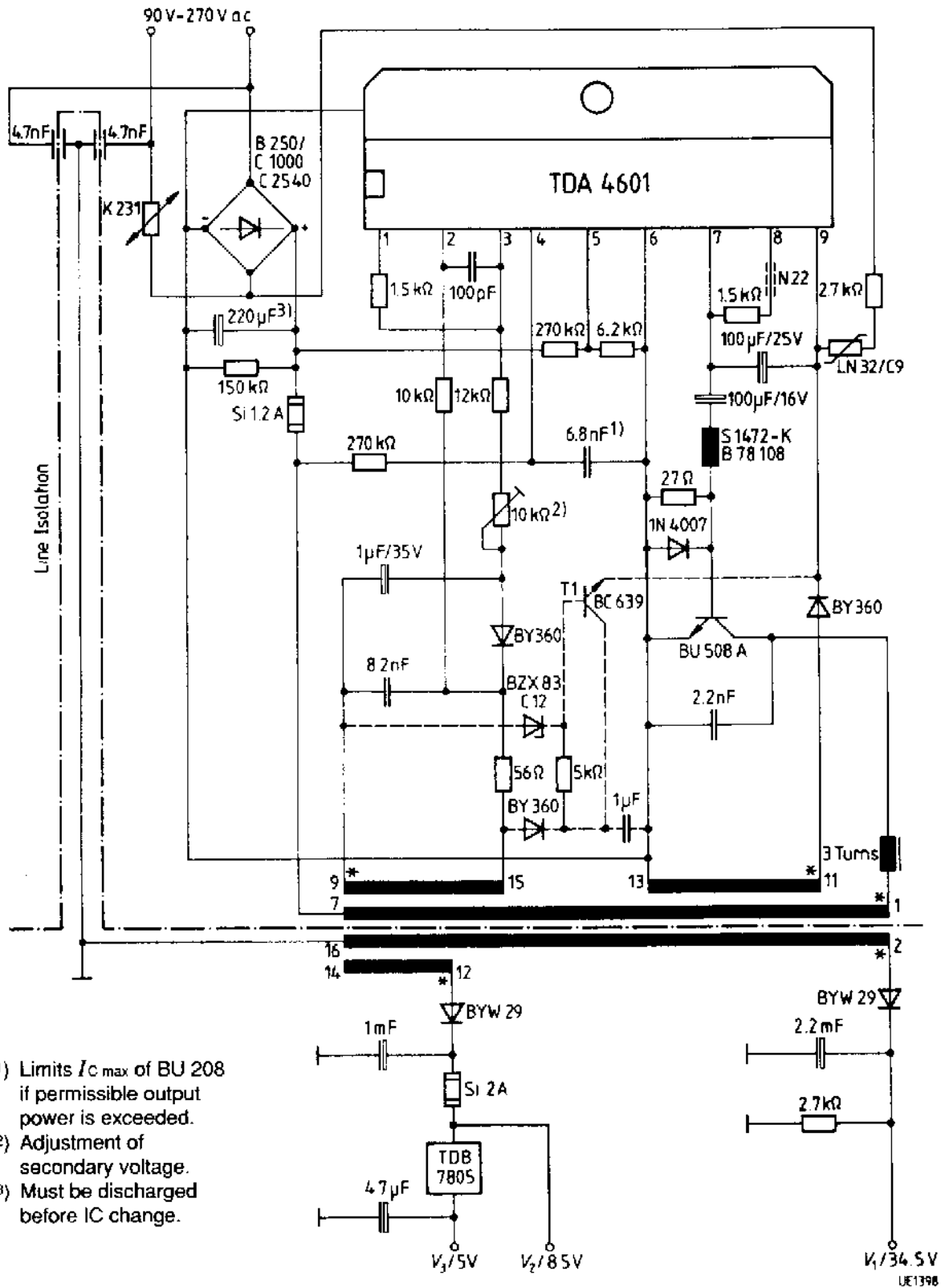
Circuit in vertical position

Still air



Further Application Circuits

Application Circuit 3



- 1) Limits $I_{C \max}$ of BU 208 if permissible output power is exceeded.
- 2) Adjustment of secondary voltage.
- 3) Must be discharged before IC change.

Notes on application circuit 3

Fully Insulated, Clamp-contacted PTC Thermistor Suitable for SMPS Applications at Increased Start-Up Currents

The newly developed PTC thermistor **Q63100-P2462-J29** is designed for applications in SMPS as well as in various other electronic circuits, which, for example, receive the supply voltage directly from the rectified line voltage and require an increased current during turn-on. Used in the flyback converter power supply of TV sets, an application proved millions of times over, the new PTC thermistor in the auxiliary circuit branch has resulted in a power saving of no less than 2 W. This increase in efficiency has a highly favorable effect on the standby operation of TV sets.

The required turn-on current needs only 6 to 8 s until the operating temperature of the PTC thermistor is reached. Low thermal capacitance of the PTC thermistor allows the circuit to be operated again after no more than 2 s. Another positive feature is the improved short-circuit strength. The clamp contacts permit more or less unlimited switching operations and thus guarantee high reliability. A flame-retardant plastic package and small dimensions are additional advantages of this newly developed PTC thermistor.

Technical Data

Parameter	Symbol	Limit Values	Unit
Breakdown voltage at $T_A = 60\text{ }^{\circ}\text{C}$	$V_{BD\text{ rms}}$	350	V
Resistance at $T_A = 25\text{ }^{\circ}\text{C}$	R_{25}	5	k Ω
Resistance tolerance	ΔR_{25}	25	%
Trip current (typ.)	I_K	20	mA
Residual current at $V_{A\text{ max}}$	I_R	2	mA
Max. application voltage	$V_{op\text{ max rms}}$	265	V
Reference temperature (typ)	T_{REF}	190	$^{\circ}\text{C}$
Temperature coefficient (typ)	TC	26	%/K
Max. operating current	I_{max}	0.1	A
Storage temperature range	T_{sig}	- 25 to 125	$^{\circ}\text{C}$

Notes on application circuit 4

Improved Load Control and Short-Circuit Characteristics

Turn-on is the same as for circuit 3.

To make the price more attractive, switching transistor BU 508 A was selected.

To ensure optimum standby conditions, the capacitance between pins 2 and 3 was increased to 100 pF.

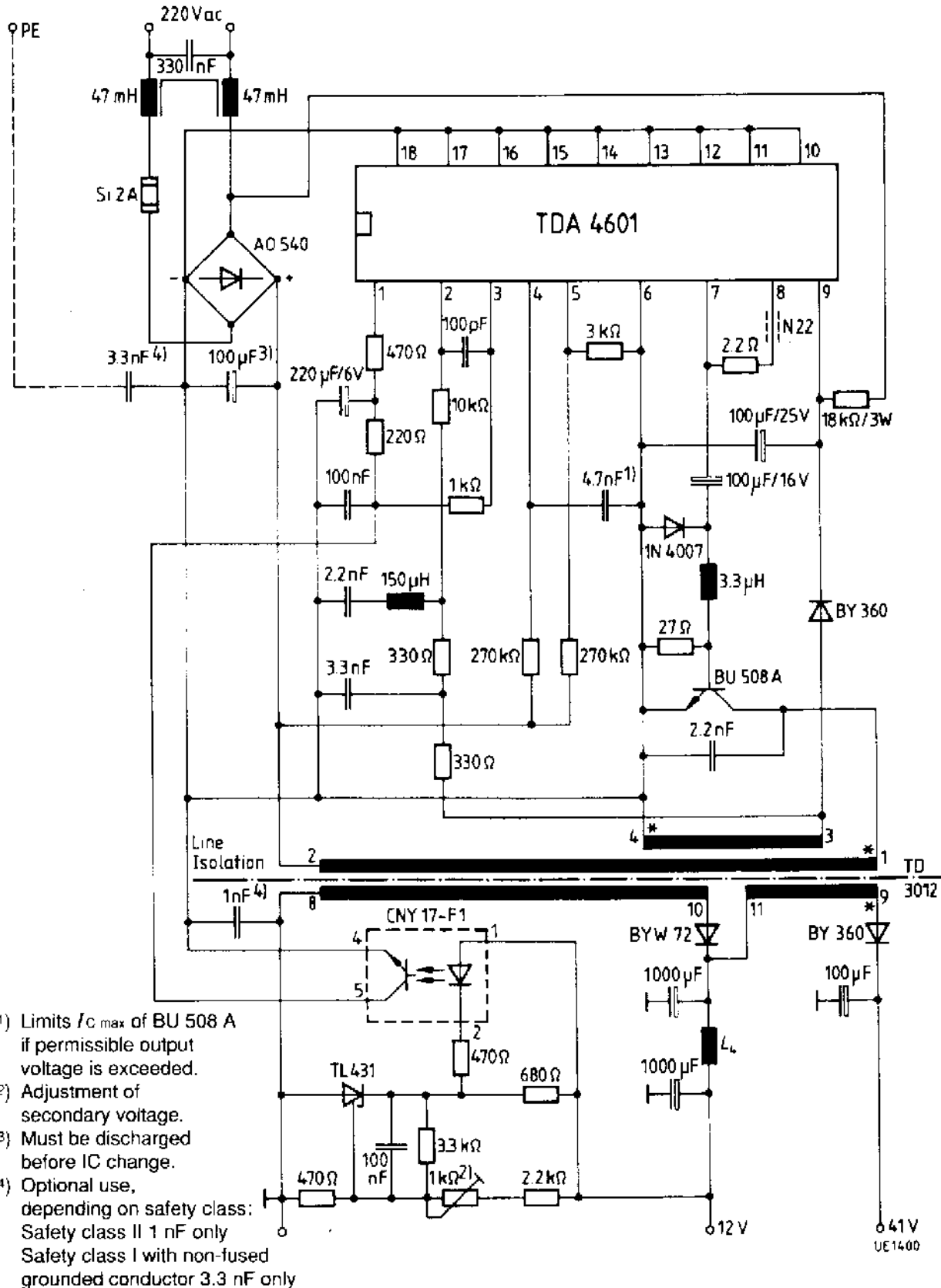
Z- diode C 6.2 transfers control voltage ΔV_{cont} directly to pin 3 resulting in improved load control.

Design and coupling conditions of various flyback transformers were sometimes a reason for overshoot spectra, which, despite the RC attenuating element $33\ \Omega \times 22\ \text{nF}$ and the $10\ \text{k}\Omega$ resistor, even penetrated across the feedback winding 9/15 to the zero passage indicator input (pin 2) and activated double and multiple pulses in the IC. Double and multiple pulses, however, lead to magnetic saturation in the flyback transformer and thus increase the risk of damaging the switched-mode power supply.

The larger the quantities of power to be passed, the more easily overshoots are generated. This can be observed around the point of return. The switched-mode power supply, however, reduces its own power to a minimum in all cases of overload or short-circuit. A series resonant circuit, whose resonance corresponds to the transformer's self-oscillation, was created by combination of the $4.7\ \mu\text{H}$ inductance and the $22\ \text{nF}$ capacitance. This resonant circuit short-circuits overshoots via a $33\ \Omega$ resistor.

$$(f = \frac{1}{2\pi\sqrt{LC}} \approx 500\ \text{kHz})$$

Application Circuit 5



Notes on application circuit 5

Highly Stable Secondary Side

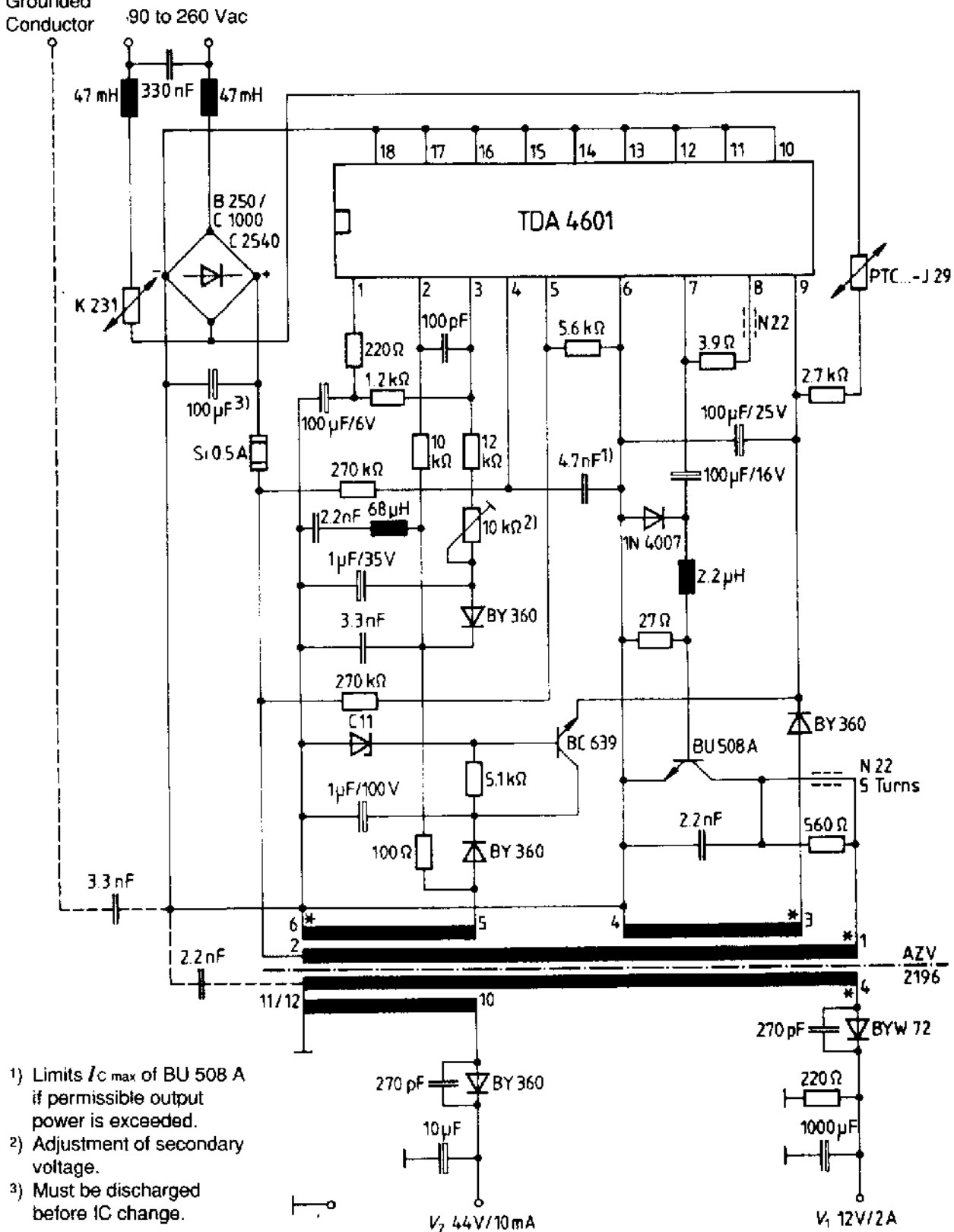
Power supplies for commercial purposes require highly constant low voltages and high currents which, on the basis of the flyback converter principle, can be realized only under certain conditions, but, on the other hand, are implemented for economical reasons. An electrically isolated flyback converter with a highly stable secondary side must receive the control information from this secondary side. There are only two possibilities for meeting this requirement: either through a transformer which is magnetically isolated from the flyback converter or by means of an optocoupler. The development of CNY 17 has enabled the manufacture of a component suitable for electrical isolation and characterized by high reliability and long-term stability.

The IC TDA 4601 D is the successor of the TDA 4600 D. It is compatible with its predecessor in all operational functions and in the control of a self-oscillating flyback converter. Pin 3 is the input for the control information, where the latter is compared with the reference voltage prevailing at pin 1 and the control from the optocoupler and subsequently transformed into a frequency/pulse width control.

The previous feedback and control information winding is not necessary. The feedback information (zero passage) is obtained from winding 3/4 - supply winding. The time constant chain $330\ \Omega/3.3\ \text{nF}$ and $330\ \Omega/2.2\ \text{nF}$ was implemented in series with $150\ \mu\text{H}$ to prevent interference at pin 2. The LC element forms a series resonant circuit for overshoots of the flyback converter and short-circuits them.

Application Circuit 6

Non-Fused
Grounded
Conductor



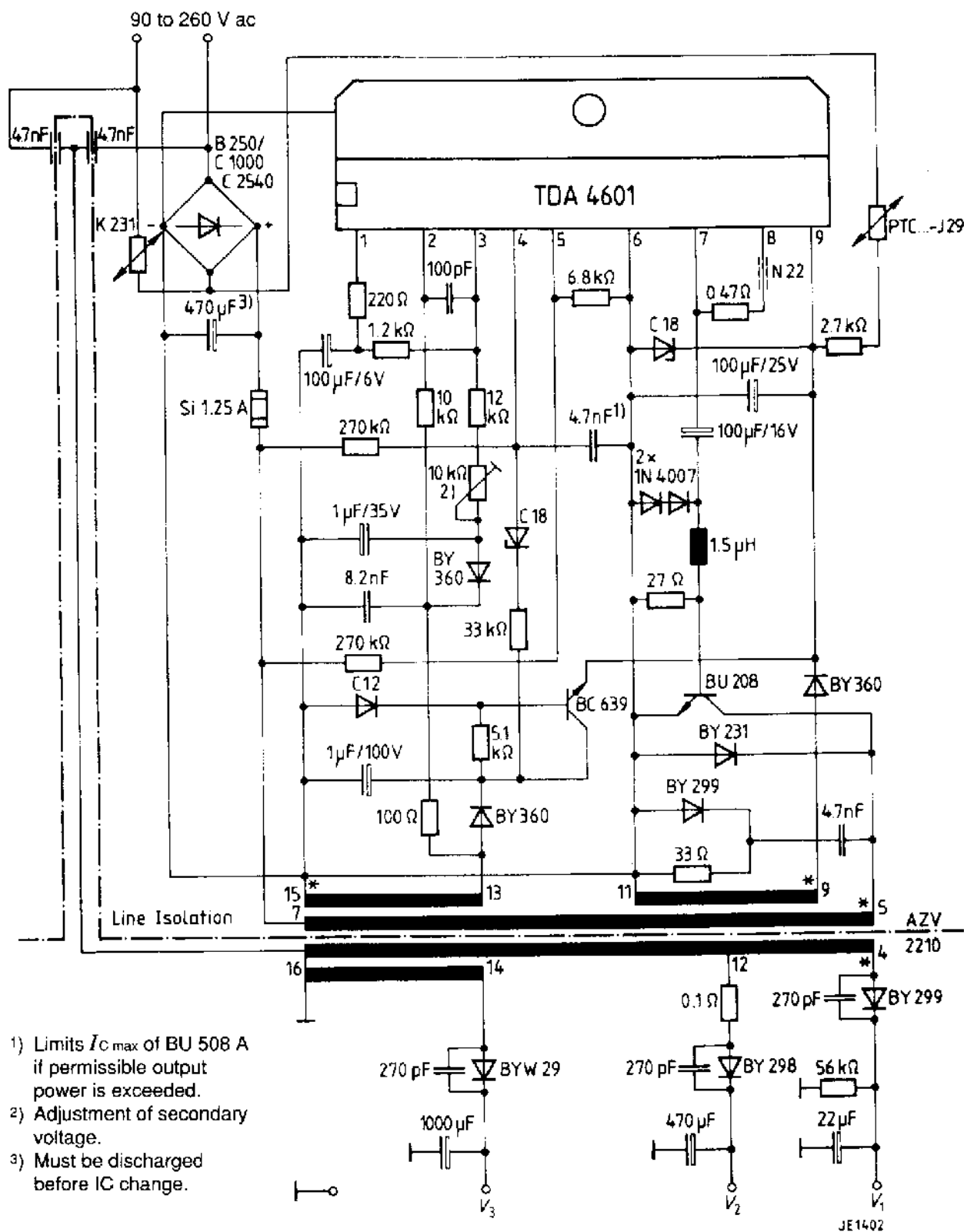
Notes on application circuit 6

Wide Range Plug SMPS up to 30 W

Due to their volume and weight, plug SMPS have so far been limited to a restricted primary voltage and a secondary power of no more than 6 W.

The line-isolated wide range flyback converter presented here has a variable frequency and is capable of producing a secondary power of 30 W. It is characterized by a compact design with an approx. weight of 400 g. The entire line voltage range of 90 to 260 V_{ac} is stabilized to $\pm 1.5\%$ on the secondary side. Load fluctuations between 0.1 and 2 A are regulated to within 5%. The output (secondary side) is overload, short-circuit, and open-loop proof.

Application Circuit 7



- 1) Limits $I_{C \max}$ of BU 508 A if permissible output power is exceeded.
- 2) Adjustment of secondary voltage.
- 3) Must be discharged before IC change.

Notes on application circuit 7

Wide Range SMPS with Reducing Peak Collector Current $I_{C\ BU\ 208}$ for Rising Line Voltage (variable point of return)

Wide range SMPS have to be dimensioned at line voltages of 90 to 260 Vac. The difference between the maximum collector current $I_{C\ BU\ 208\ max}$ and the largest possible limit current $I_{C\ BU\ 208\ limit}$ which causes magnetic saturation of the flyback transformer and flows through the primary inductance winding 5/7 is to be determined at $V_{ac\ min}$ ($I_{C\ BU\ 208\ limit} \geq 1.2 \times I_{C\ BU\ 208\ max}$). Then, the transmissible power of the flyback transformer and its value at $V_{ac\ max}$ is to be determined. In the standard circuit the collector current $I_{C\ BU\ 208\ max}$ is almost constant at the point of return independent of the line voltage. The transmissible power on the secondary side, however, increases at the point of return in proportion to the rising rectified line voltage applied (**figures 1 and 2**).

In the wide range SMPS a line voltage ratio of $270/90 = 3/1$ is obtained, causing doubling of the transmissible power on the secondary side, i.e. in the wide range SMPS a far too large flyback transformer had to be implemented.

The point of return protecting the SMPS against overloads or short circuits, is derived from the time constant at pin 4 $\tau_4 = 270\ k\Omega \times 4.7\ nF$. Thus, the largest possible pulse width is determined.

With the introduction of the 33 k Ω resistor this time constant is reduced as a function of the control voltage applied to winding 13/15, rectified by diode BY 360 and filtered by the 1 μF capacitance, which means that the pulse time becomes shorter. By means of the Z-diode C18 the line voltage level can be defined at which the influence of the time constant correction becomes noticeable. The change in the rectified voltage of winding 13/15 is proportional to the change in the rectified line voltage.

At the point of return $I_{C\ BU\ 208}$ the peak collector current has been reduced with the aid of the given values from 5.2 A at 90 Vac to 3.3 A at 270 Vac. The transmissible power at the point of return remains stable between 125 and 270 Vac due to the set activation point of the point of return correction (unbroken curve in **figure 2**).

Load Characteristics

Figure 1

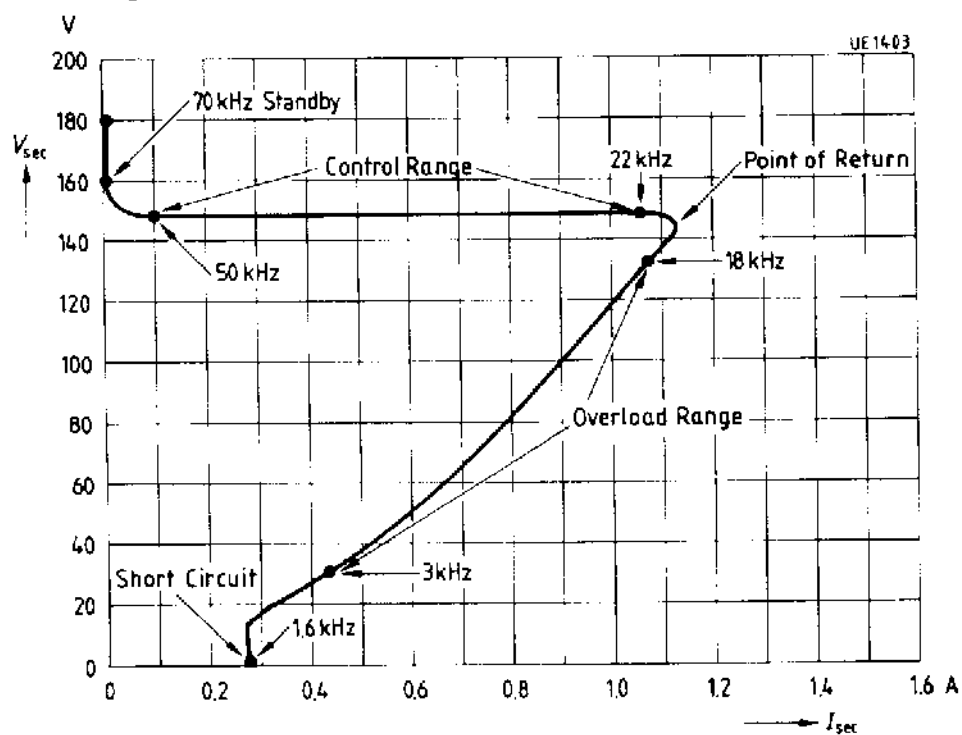


Figure 2

