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TROUBLE SHOOTING HALOGEN ELECTRONIC TRANSFORMERS

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INTRODUCTION

Halogen Electronic Transformers are basic electronic step–down converters used to supply 12V to low voltage halogen lamps. Based on a high frequency conversion they are less bulky than 50/60Hz transformers. In order to achieve a low cost, electronic transformers are designed using bipolar transistors instead of MOSFETs. The most common topology used is the half bridge converter; its basic schematic is shown Figure 1 (see EB407 “Basic Halogen Converter” for a general circuit description).

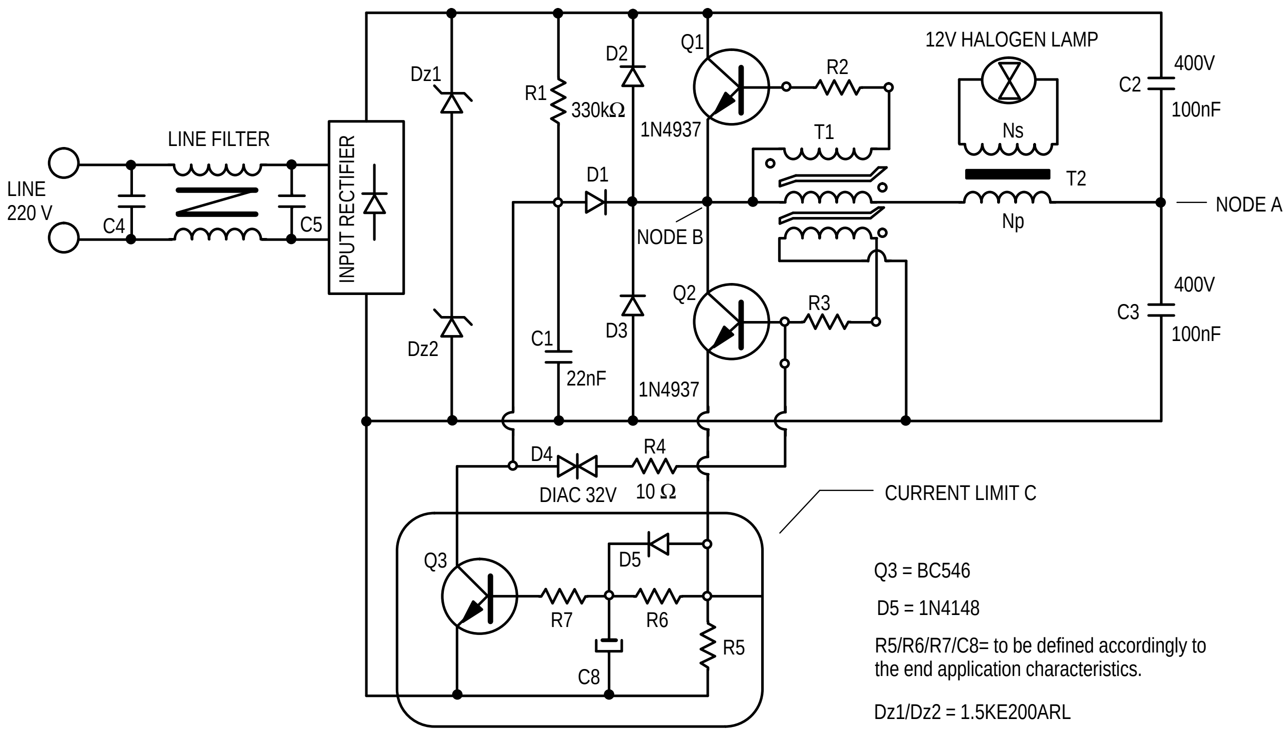

Figure 1. Basic Schematic Diagram for a 12 V Electronic Transformer

This simple circuit normally sees almost no stress under nominal operating conditions (as described in EB407) but because of its particular structure certain phenomena can cause the bipolar transistors to work very close to their limits.

Designers essentially have to deal with problems related to

a) voltage spikes on the mains

b) huge inrush currents due either to a cold lamp start–up or an accidental short circuit

These two points will be discussed in the following pages and some techniques on how to handle these problems will be presented.

PREVENTING HIGH VOLTAGE STRESSES

The theoretical V_{CE} rating for the bipolar transistors is the peak voltage of the rectified mains. In Europe, the mains typically remain within 185 Vac to 265 Vac with an average of 230 Vac. Therefore, for 265 Vac the peak DC voltage seen by the transistors is 375 Vdc.

Taking some safety margin, the BV_{CEO} is chosen between 400 V and 500 V. But we can observe with the base drive conditions depicted Figure 1 that the V_{CE} breakdown voltage of the transistor is no longer the BV_{CEO} (i.e. base–emitter open) but BV_{CER} instead. Due to the low impedance connected between base and emitter, the BV_{CER} is close to 700 V.

If a voltage spike occurs on the mains, this transient is directly applied across the transistors through the filter. Figure 2 shows the average occurrence of transients on the European mains together with their magnitude. The three curves show variations depending on the user surroundings: the mains near factories are exposed to higher transients than the mains near a residential area. Of course this kind of overvoltage occurs randomly.

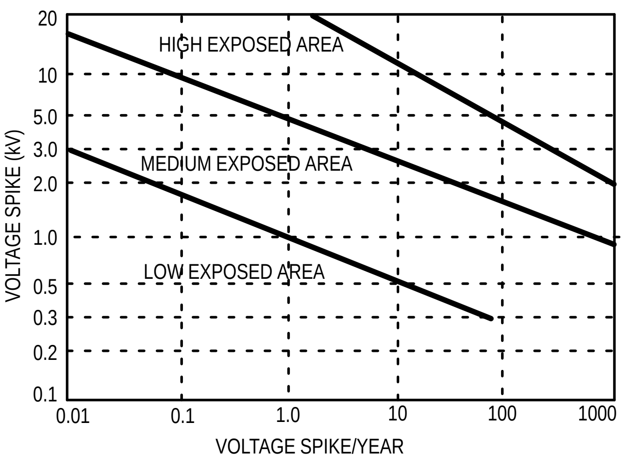

Figure 2. Occurrence of Transients on the Mains

Assuming the transient appears on the peak of the sine wave, the instantaneous collector voltage can reach 1500 to 2000 V. This means an efficient solution cannot be provided by a passive bandpass filter. Even with an 8th order filter the voltage rejection is not high enough to keep the bipolar transistor within its Safe Operating Area.

Another solution could consist in increasing the transistor's BV_{CES} but in that case the die size would need to be significantly larger in order to guarantee the same $V_{CE(sat)}$ and the cost would become prohibitive (e.g. increasing BV_{CES} from 700 V to 1000 V increases the die size by 30%, all other parameters kept constant). Besides, this solution would once again set a breakdown voltage limit that if exceeded would cause the transistor to fail.

Since the higher the voltage spike the shorter the duration, the best way to prevent transients consists in the use of transient suppressors. These active devices are designed to absorb energy voltage transients and are available in two power handling capabilities: 600 W and 1500 W (for a 1ms surge). We recommend the use of a 1.5KE200A as shown in Figure 1 (Dz1, Dz2).

Transient suppressors are also the only safe way of protecting transistors against spikes occurring during short circuit conditions: a high overvoltage combined with a high collector current will force the transistor out of its FBSOA or RBSOA into failure.

PREVENTING HIGH CURRENT STRESSES

The nominal collector current is given by

$$I_C = \frac{P_{out}}{\eta} \times \frac{2}{V_{line}} \qquad (1)$$

Where I_C, Pout and Vline are RMS values and η is the output transformer efficiency.

The peak collector current depends on the I_C wave shape. Assuming a wave shape factor = √2 the peak collector current is 0.7 A for 50 W. The collector current depends on the load impedance. The lamp resistance varies typically from 0.5 Ω while the lamp is cold to 3 Ω at thermal equilibrium. Obviously the collector current decreases when reaching steady state.

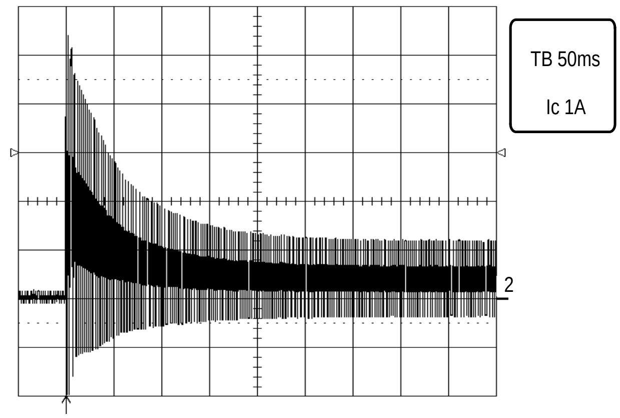

Figure 3. Start Up Collector Current (50 W Transformer), the mains being replaced by a DC power supply V_{CC} = 240 V, T_{amb} = 23°C.

In fact the main current stress appears during an accidental short circuit across the load. Under such conditions the collector current can reach ten times the nominal current, as is shown in Table 1. The collector current is limited by wire and contact resistance but also by the output transformer leakage inductance.

	Steady state	Start–up	Short circuit
50 W	0.7 A	3.5 A	4.5 A
100 W	1.4 A	7.0 A	14 A
150 W	2.1 A	10.5 A	25 A

Table 1. Collector Current Ratings versus Power

The collector current is also limited via the input network by the V_{BE}, I_B and h_{FE}. This high I_C level combined with the high V_{CE} generates high losses or even transistor desaturation, and the transistor fails by a thermal runaway.

A short circuit protection is added to the converter. This circuit turns the converter off and needs a time constant to be triggered. This time constant must be as short as possible to protect the transistor quickly during a short circuit but must be long enough to allow the start–up inrush current So during this time the bipolar transistor must be rugged enough to sustain the short circuit collector current.

Let us examine the two main ways (that can be combined) to limit the short circuit current.

1– **Keeping the transistor in the saturation area**: the base current is not limited by an external circuit, thus the $V_{CE(sat)}$ remains low. In this case the collector current is limited by:

a) Using an inductive load

The inductor sets the collector current slope. The short circuit period being shorter, the peak collector current is limited. In some cases this inductor can be the leakage inductance of the output transformer.

b) Optimizing bridge capacitances

The collector current is supplied by the capacitor bridge setting the half voltage (node A). The smaller these capacitors are sized the smaller the amount of charges available to supply the short circuit collector current. On the other hand the capacitors must be large enough to keep the node voltage roughly constant. Moreover, one must take care of the series resonant frequency of the LC network made by these two capacitors associated in parallel, connected in series with the output transformer leakage inductor. These capacitors must be determined to set the resonant frequency below the operating one. This frequency increases during short circuit conditions and so the impedance of the series resonant circuit is higher, the short circuit current is hence limited.

2– **Reducing the base drive**

a) Using an emitter negative feedback

As the collector current increases, the voltage across Re increases as well, reducing the net driving voltage in the input circuit, so I_B and I_C decrease.

b) Adjusting the base resistor value

Since the base bias resistor influences both the short circuit time capability and the overall losses in steady state, one must make the compromises to get the best behavior under either a fault condition or a normal operation. Based on experiments performed on the BUH50 the value of such a resistor can range between 3.3 Ω to 6.8 Ω (with drive transformer turns ratio 1/3), but further analysis must be done if any of the components are changed (power transistor, drive transformer...).

By reducing the base drive the transistor operates in the linear mode, and the power dissipation can be tremendous. The efficiency of this method appears if I_B is drastically attenuated while I_C tends to increase, keeping the on state product: I_C x V_{CE} lower than the one achieved without resistor bias network.

Whatever the jig used, the halogen application requires a transistor having high gain and high current capabilities. This allows the transistor to be rugged enough to overcome the high current damaging stress.

The BUH series was specifically designed for these applications.

The BUH transistors have the best FBSOA and RBSOA parameters ever designed by MOTOROLA for a given die size. This technology allows us to fulfill the key parameters required by the application. Moreover this technology allows the manufacturing of 200 W converters with power transistors packaged in the low cost T0220 package, compared to existing solutions running with bulky T0218 or T0247 packages.

Figure 4 a) and b) compares the short circuit behaviour between BUH and standard designs.

The BUH design (4a) recorded at 80 ms shows square waves and only a slight desaturation: losses remain very low. The Standard design (4b) recorded at 13 ms (with the same die size) cannot remain in saturation. A high $V_{CE(on)}$ combined with high current produces extremely high losses. This device will fail within a few µs.

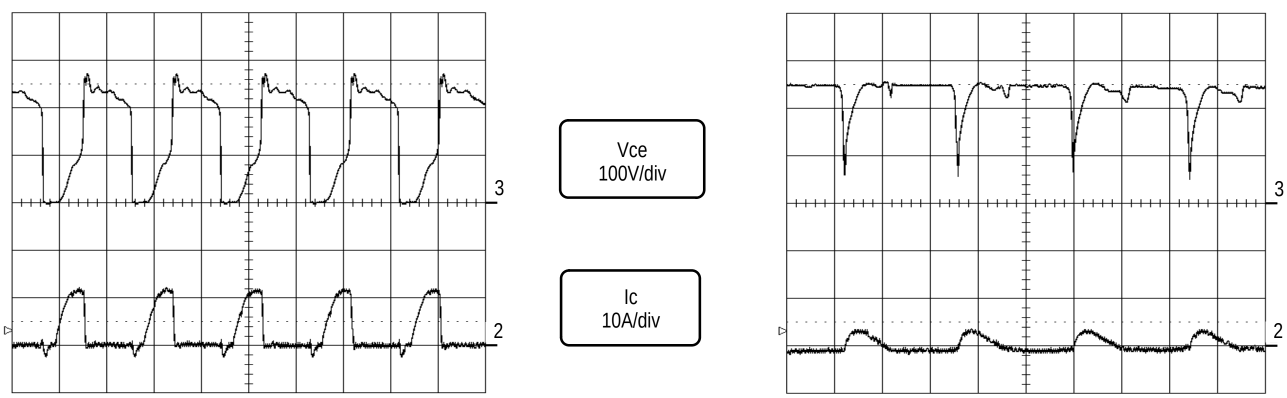

FIGURE 4a FIGURE 4b

Figure 4. Short Circuit Conditions in a 150 W Converter with V_{CC} = 240 V.

PRACTICAL POINT OF VIEW

Since the short circuit collector current can be multiplied by 10 between nominal and short circuit conditions, the collector current value is highly dependent on the resistive path seen from the half bridge middle point (node B). This impedance is made of the winding resistance of the transformer, connection contacts and lamp to module wire resistance.

Therefore one must size the winding and the lamp wires as thin as possible. The limit being of course the Joule losses allowed.

The thermal aspect of the output transformer is critical: its core Bsat will decrease by 25% for a temperature rising from 25°C to 100°C. This parameter is often neglected and will cause unexpected short circuit failures.

For converters with output powers higher than 100 W, the winding wire resistance decreases and the connection contact and wires resistance become preponderant.

CONCLUSION

As discussed, the only safe way to protect a halogen converter against overvoltage transients consists in the use of transient suppressors.

This application requires a high gain and a high current capability to overcome the huge inrush current under short circuit conditions.

Motorola specifically developed the BUH series of transistors to match the halogen converter requirements.

Table 2 here below describes the BUH series.

	BUH51	BUH50	BUH100	BUH150
Power	50 W	50 W	100 W	150 W
Ic continuous	3 A	4 A	10 A	15 A
Ic peak	8 A	8 A	20 A	25 A
Package	TO126/C77	TO220	TO220	TO220

Table 2. BUH Series

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1. EB407, "Basic Halogen Converter", Motorola Engineering Bulletin
2. AN1049, "The electronic control of fluorescent lamps.", Motorola Application Note

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