



Technology performance comparison of Triacs
subjected to fast transient voltages

Introduction

This paper presents an experimental comparison of several Triac devices under immunity tests, as described in the IEC 61000-4-4 standard. After a short reminder of the different Triac technologies available today (Top, mesa and planar technologies), the IEC 61000-4-4 test procedure to compare the devices is explained. The immunity results are discussed according to the device technology and the gate current sensitivities. A discussion about relevance of dV/dt parameter and die area is carried on to differentiate the devices in term of immunity capability.

Home appliances such as washing machines, refrigerators and dishwashers integrate a lot of low power loads such as valves, door lock systems, dispensers and drain pumps. These loads are usually powered by the mains in on / off mode, and are mostly controlled by Triacs.

The direct connection of the silicon switch to the mains, through the load, requires that these devices must withstand line transients to make the system compliant with the international electromagnetic compatibility (EMC) standards. The silicon devices are then subjected to fast transient voltages, as described in the IEC/EN 61000-4-4 standard.

The immunity of several Triac technologies is evaluated here experimentally. Several guidelines can then be pointed out to design high immunity appliances.

1 Triac technologies and immunity

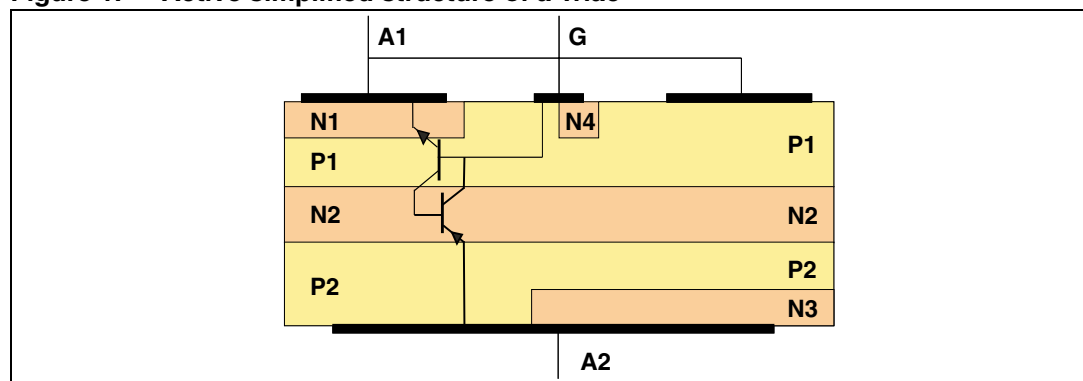
1.1 Triac silicon structures

Triac devices are by far the most used silicon devices to drive AC loads directly connected on the mains voltage. Triacs are widely used because they present three major advantages:

- Low forward voltage drop
- Turn on by gate current pulse
- High voltage immunity

The first two advantages come from the active silicon structure of the Triac which is based on four alternatively doped silicon layers (N-P-N-P). These four layers implement two bipolar transistors which are coupled to maintain the on state even if the gate current is removed (see [Figure 1](#)).

Figure 1. Active simplified structure of a Triac



The third advantage comes from the fact that the voltage is withstood by the silicon thickness. It's then quite easy to reach breakdown levels above 1 kV. The main issue is then the junction termination. Several low cost technologies are used since the 70's which used a glass passivation. For example the "Mesa" technology (see [Figure 2](#)) uses glass on both sides of the die (see References 1, 2, and 3) to passivate both junctions, which hold both forward and reverse high voltages (referred to as "Cathode" or "A1" or "COM" polarity). The "Top" glass technology (see References 1, 2, and 3) uses only one glass layer (see [Figure 3](#)). This avoids having some glass at the bottom of the die, and so it is easier to put such dies in every kind of package.

Figure 2. "Mesa" glass technology

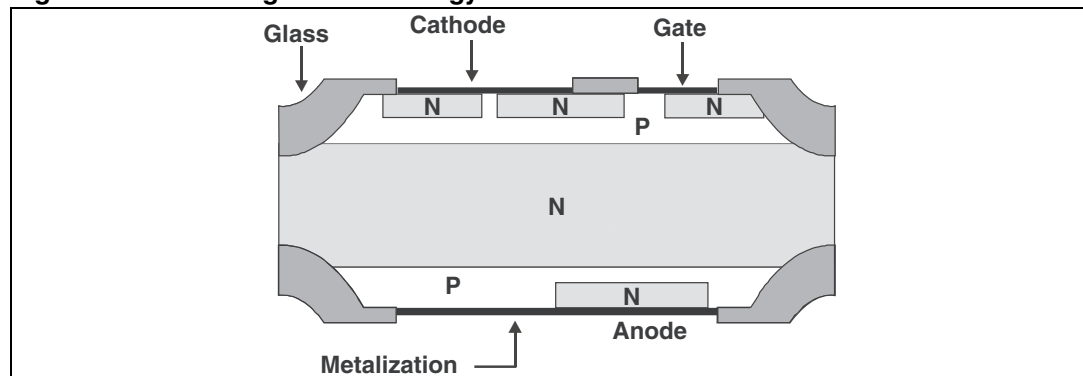
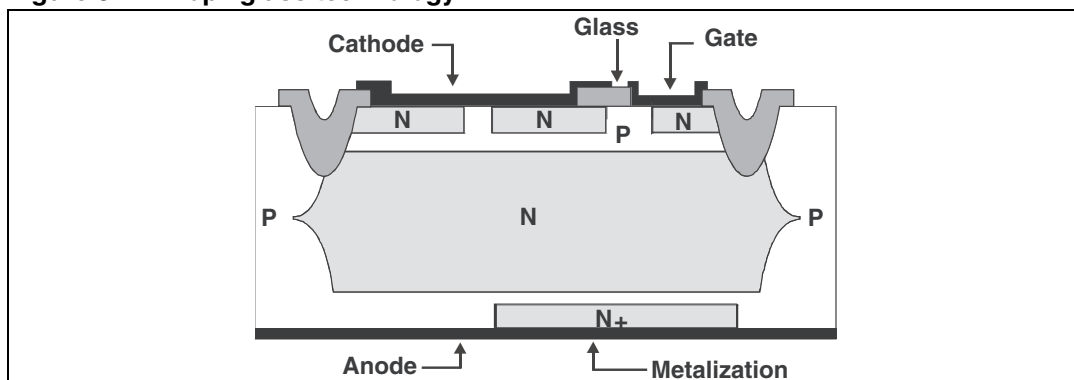
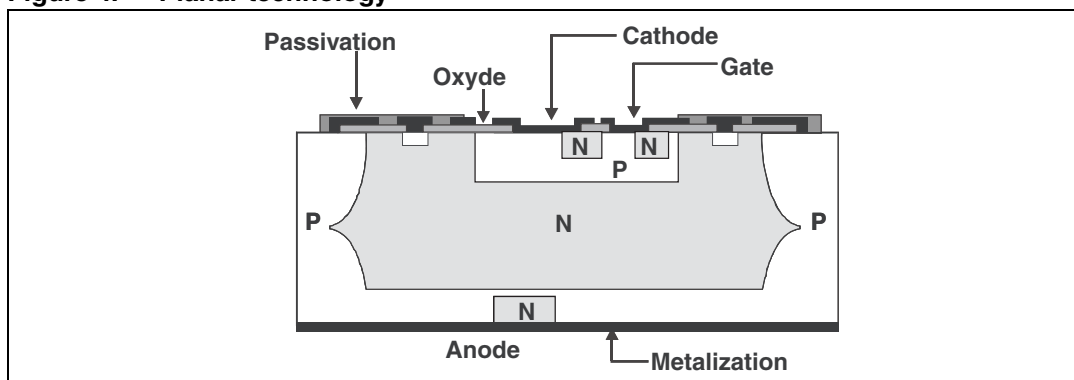


Figure 3. “Top” glass technology

Both top and mesa glass technologies are very cost effective. The insulation capability of glass is very high. This helps to achieve high voltage devices with a limited periphery area. Mesa glass technology is the cheaper one as this technology uses less silicon area to withstand reverse voltage. For top technology, the reverse PN junction is terminated on the upper side of the die thanks to the deep P well. Such dies are bigger for the same active area than mesa dies. This is the reason why top technology is mainly used for low current Triacs.

Unfortunately it is not possible to ensure a good operation of a die with glass passivation when the voltage exceeds its maximum allowed value (V_{DRM} or V_{RRM} parameters). If the voltage reaches the breakdown value, a current will flow through the die periphery, causing heat dissipation at the glass-silicon interface. This heat could cause mechanical stress and damage this interface. The device could then be damaged.

To develop switches able to work up to their breakdown voltage, a planar technology has to be implemented. Such a technology uses photolithography to terminate the PN junction at the top of the die, and oxide passivation instead of glass (see [Figure 4](#)). There is no more glass-silicon interface issue. ACST devices use this kind of technology (see [Reference 4](#)).

Figure 4. Planar technology

1.2 Sensitivity and dV/dt immunity

This experimental comparison on immunity level has been performed on different devices which target the same application. This application is the control of valves or pumps in white goods. The load current is usually less than 1 A. Anyway, appliances designers use, to control these loads, 1 A, 2 A and even 4 A Triacs. The use of a high current rating device is usually motivated by desire for highly immune and robust systems.

To rationally compare the different devices, we have selected devices with the same voltage and sensitivity ratings. The voltage rating is given by the V_{DRM} and V_{RRM} parameters (800 V in this application note). The sensitivity is given for Triacs by the I_{GT} parameter which is the minimum gate current that should be applied to turn on the device. The devices we have chosen all have a 10 mA maximum I_{GT} .

The Triac sensitivity can not be reduced too much. An appliance designer has to work with the sensitivity (supply consumption) and immunity compromise. If the I_{GT} is too low, the device will not be able to withstand excessive dV/dt rates across its power terminals (A1 and A2 for Triacs, or OUT and COM for ACST). Triac manufacturers then give a dV/dt parameter which is measured at the maximum junction temperature. Results of [Table 1](#) are given for dV/dt tests performed at a 125 °C junction temperature and a 400 V applied voltage. It should be noted that some values are lower than values given in constructors datasheet for the devices which are specified at 110 °C instead of 125 °C. This is a normal result as the dV/dt immunity decreases with the temperature.

[Table 1](#) gives the I_{GT} and dV/dt parameters that we measured for the different samples we used during IEC 61000-4-4 tests, and for the different bias polarities.

The products tested are:

- the Z0409N: a top glass 4 A Triac
- the T410-800: a mesa glass 4 A Triac
- the ACST2: a planar 2 A Triac
- the COMP.1A: a planar 1 A Triac
- the COMP.2A: a planar 2 A Triac

Table 1. Measured I_{GT} and dV/dt parameters of tested samples⁽¹⁾

P/N	Techno.	Sample	I_{gt} (mA)			dV/dt (V/ μ s) 125 °C	
			Q1	Q2	Q3	Positive	Negative
Z0409N	Top	1	1.02	3.37	4.69	118	94
		2	0.90	2.90	3.49	140	135
		3	1.02	2.99	4.08	120	95
		4	0.98	2.72	3.69	160	138
T410-800	Mesa	1	1.57	5.82	3.43	200	450
		2	1.67	7.14	3.69	180	710
		3	1.52	5.43	3.31	180	525
		4	1.65	6.99	3.64	170	630
ACST2	Planar	1	3.54	6.20	6.83	>5000	>5000
		2	3.48	6.20	6.82	>5000	>5000
		3	3.45	6.20	6.83	>5000	>5000
		4	3.47	6.20	6.73	>5000	>5000
COMP.1A	Planar	1	4.89	4.05	5.10	500	470
		2	4.85	4.28	5.22	580	500
		3	4.86	4.05	5.05	530	430
		4	4.85	4.16	5.34	540	560
COMP.2A	Planar	1	5.27	6.25	5.65	>5000	>5000
		2	4.57	4.36	4.27	>5000	>5000
		3	3.81	3.39	3.09	>5000	>5000
		4	4.82	4.68	4.49	>5000	>5000

1. I_{GT} is measured with standard 30 Ω / 12 V circuit and dV/dt with standard test circuit: open gate and 400 V applied peak voltage

2 IEC 61000-4-4 Tests

2.1 Test procedure

To compare the immunity capabilities of the different technologies, we have performed tests as described in the IEC 61000-4-4 standard [5]. European appliance manufacturers usually require that their equipment will not present any malfunction for burst levels up to 2 kV.

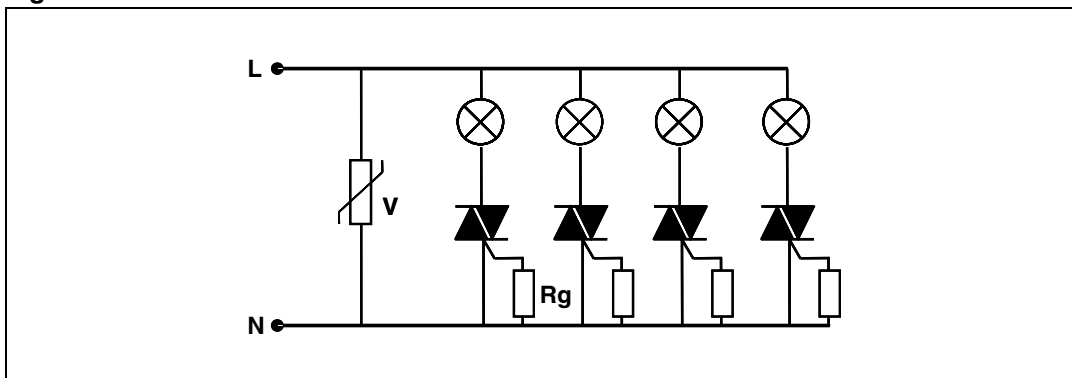
Here, we increase the burst level by 0.1 kV steps to reach at least one device spurious triggering within one minute. To easily compare only the Triacs performance, we used a dedicated board featuring all the AC switches, and their gate connected to their A1 terminals through gate resistors. This allows us to be sure that the spurious triggering comes from the switch itself and not from any control circuit. The spurious triggering is detected when the light bulb, connected in series with one of the switch, is switched on. As a Triac will latch, usually the on time will last several ms. This is long enough for a human eye to detect it.

The tests are carried out in the following conditions.

- The printed circuit board is 10 cm above reference plane.
- A mains S14K300 varistor (refer to “V” on [Figure 5](#)) is connected to the mains input on the PCB.
- The board embeds four Triacs (or ACSTs).
- Each Triac-A2 (or ACST OUT) terminal is linked to a 25 W light bulb (resistive loads are chosen to get easier device turn on as di/dt is higher than with inductive load).
- Each gate is connected to A1 or COM terminals respectively, for Triac and ACST, through a 220 ohm resistor (refer to “R_g” on [Figure 5](#)) to be free of spurious firings coming from any control circuit.
- No snubber circuits are added across the Triacs or ACSTs.
- Ambient temperature is 25° C.
- The board is plugged into an L-N plug which is disturbed by a burst generator (bursts are coupled to N or to L, for positive or negative bias).
- The burst generator is programmed as required in the IEC 61000-4-4 standard (15 ms burst duration, 3 Hz burst frequency, 5 kHz spike frequency, one minute test duration).

Note: Only results with coupling modes to L and N are presented here as the other coupling modes are usually less stressful. For example, a simultaneous coupling of the burst to L, N and the PE (Protective Earth, which is not connected to our board) will lead to a less stressful test.

Figure 5. IEC 61000-4-4 test schematic



2.2 Impact of a varistor on mains input

The IEC 61000-4-4 standard has been developed mainly to protect equipment from fast voltage transients coming from bad mains connection, electrostatic discharge or inductive load disconnection. Designers usually think that the impact of the burst is mainly due to the high dV/dt , and so due to the capacitive currents circulating through all parasitic capacitors. This effect is one of the major ones. Applying bursts can also cause some spurious device turn on due to excessive voltage across the switches. For example, [Figure 6](#) shows the voltage and current waveforms of an ACST2 used in the previously described board but without any varistor for a 1 kV burst. We see that when the voltage spikes are applied at peak mains voltage, the device turns on, and turns off for the next ZCS (zero current switching) point. If we zoom in on this oscillogram with a $0.4 \mu s/\text{division}$ time scale, we clearly see that the triggering comes from an overvoltage. Indeed, [Figure 7](#) shows that the voltage across the ACST2 reaches more than 800 V, and then the device turns on in breakover mode.

Such a turn on can be allowed with ACST2 devices, contrary to other technologies and even contrary to other planar devices from other companies. For ACST2 there will not be any risk of device failure, as long as the applied current remains below the guaranteed limit. But, applying such bursts without any voltage protection on mains input could lead to devices failure with top or mesa glass technologies. This is the reason why we put a varistor on the board we used for IEC 61000-4-4 tests.

Figure 6. ACST2 behavior during 1 kV burst (without input varistor)

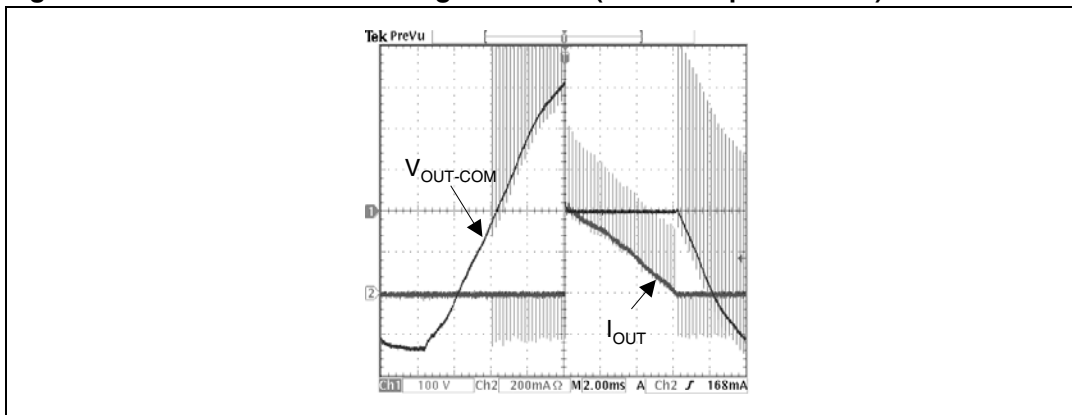
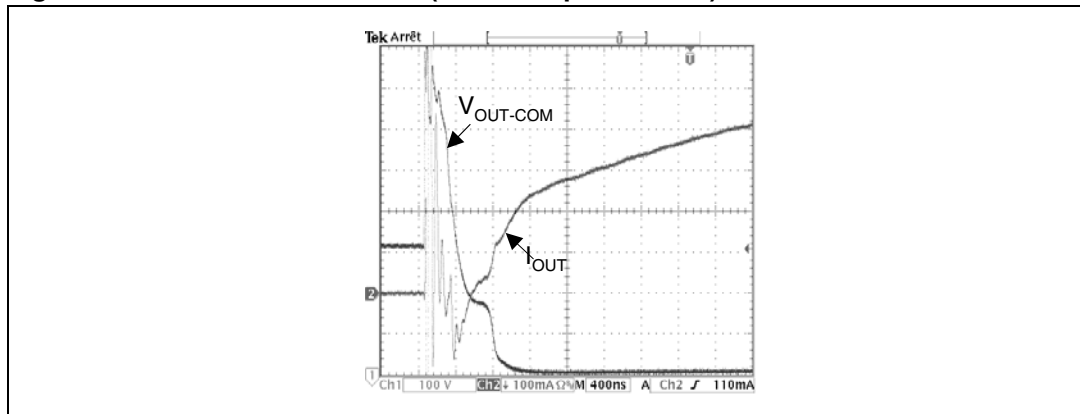


Figure 7. ACST2 turn on zoom (without input varistor)

2.3 Technology impact on immunity levels

Immunity test results according to P/N are given in [Figure 8](#). This graphic gives the maximum burst levels that the different devices were able to withstand before turn on. We see that most of the devices present highly dispersed results. Even if these tests have been performed with devices with a low dispersion on I_{GT} levels (for the same product, refer to [Table 1](#)), their immunity levels can vary with a 1 to almost 3 scale. The coupling mode and burst polarity also have an impact on the immunity capability of a sample. This impact can vary between 20 to 60%. Only the minimum value of the “maximum burst level” range, given in [Figure 8](#), should be taken into account. This minimum level corresponds to the worst-case operation among all the different coupling cases covered by the IEC 61000-4-4 standard.

It should be also noted that the maximum capability of our burst generator is 4.5 kV. That means that we didn't succeed in reaching the maximum immunity level of most ACST2 devices.

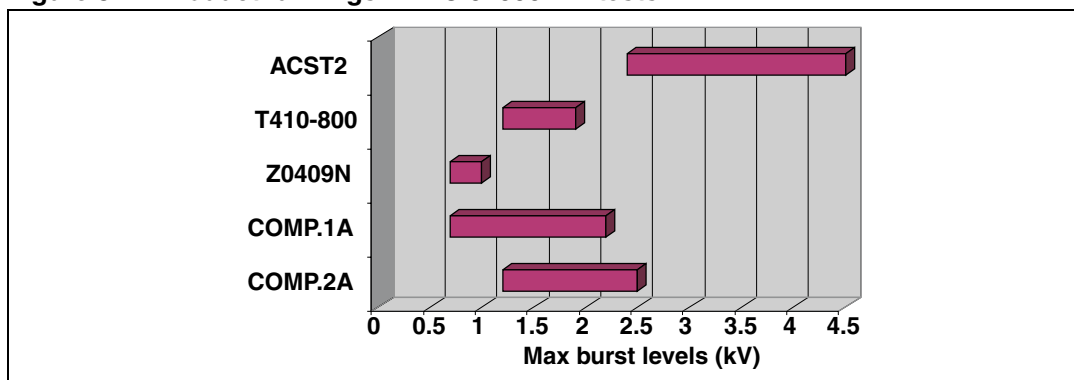
These results offer several interesting considerations.

- The planar technology allows the highest level to be reached, but different companies do not reach the same level.
- ACST2 supports levels twice as high as its closest competitor (COMP.2A).
- The 2 A device (COMP.2A) in planar technology is approximately as immune as the 4 A Triac in mesa glass technology.
- A device which presents a good dV/dt immunity (around 500 V/us for COMP.1A) can only be as immune as a 4 A top device with a dV/dt capability close to 100 V/us.

Concerning the last point, it should be noted that the COMP.1A device presents a die area which is approximately 20% lower than the Z0409. And generally speaking it can be said that the bigger the die area is, the higher the immunity level is. Only the ACST2, which presents the highest immunity level, presents also the highest “immunity-level-to-die-area” ratio.

Indeed, its die area is almost half that of the T410-800 for twice the immunity.

Compared to COMP.2A, this “immunity-area” ratio is also 40% higher. To reach approximately the same immunity level (2.4 kV in average, compare to 3 kV with ACST2), a 47 nF - 100 ohm snubber circuit has to be added across the COMP.2A device.

Figure 8. Product rankings in IEC 61000-4-4 tests

2.4 Sensitivity impact

According to previous results, it is difficult to conclude anything about impact of device sensitivity on immunity. We have even seen that some devices with good dV/dt capability can present poor immunity level. But, such a conclusion is difficult to sustain because we have compared here components from different processes.

To better analyze the sensitivity impact, we have also performed some tests of other Triacs coming from the same process. We took some T405-800 devices which are manufactured with the same process as the T410-800. The T405-800 device is guaranteed to present I_{GT} currents of less than 5 mA. The samples we have tested present measured I_{GT} levels approximately half those of the T410 devices we have tested, and this for the three quadrants. It means that we measured an I_{GT} level of approximately 0.75 mA, 2.30 mA and 1.75 mA respectively for quadrants 1, 2 and 3. The maximum burst level that these devices were able to withstand was around 1 kV, i.e. 30% lower than the T410-800. This result highlights that sensitivity has also a strong impact on immunity, as is well known. But this statement is only valid if one compares two devices from the same process.

3 Conclusion

This application note has given experimental benchmarking analysis among different alternating current switch offerings. The impacts of silicon process technologies and sensitivity levels have been discussed. It has thus been shown that sensitivity and dV/dt parameters are not relevant enough to evaluate the immunity rating of different devices. A lower I_{GT} will lead to a less immune device but only if we compare devices from similar silicon process. It has been furthermore shown that the die area has also a big impact on immunity. Indeed, a bigger die area will lead to a higher device capacitance. This will help to absorb energy coming from the bursts, and thus reducing the dV/dt across the device. On the other hand, when dV/dt immunity of Triacs is measured, the voltage rate is forced across the device. So a bigger die area will lead to a higher capacitive current. So a bigger device, with the same sensitivity level, will withstand a lower dV/dt level.

Planar technology seems to offer devices with the highest immunity. However, Z04 and T410 devices, respectively produced with a top and mesa technologies, offer the same minimum level of immunity as the tested planar devices. ACST2 presents the highest immunity level compared to other technologies or compared to other planar devices from other companies. ACST2 can then be used without any snubber circuit with a high immunity to bursts and is the solution for applications requiring a high immunity level.

4 References

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5 Revision history

Table 2. Document revision history

Date	Revision	Changes
09-Mar-2010	1	Initial release.

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