



Application Note: AZD051

Electrical Fast Transient Burst (EFT/B) Guidelines

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1 Introduction:

Origins of EFT/B testing

Whenever a substantial current along an inductive path is interrupted by a mechanical switch, a large voltage will develop across the switch contacts. The magnitude of this voltage is proportional to the total inductance of the path and the rate of change of the current. If the voltage becomes large enough, air breakdown may occur between the contacts, i.e. there will be an arc of ionised air connecting the two contacts with an extremely small impedance. Therefore voltage across the switch contacts will reduce to almost zero. As the arc is extinguished, breaking the current path again, another large voltage will develop across the switch contacts due to the inductive path. However, the switch contacts would have moved slightly further apart by now. So air breakdown occurs at a higher voltage than before, and it takes more time before the arc forms. This process will continue until the switch contacts reach a point where the inductive energy stored in the current path cannot produce a voltage high enough to cause an arc. Figure 1 illustrates the above, and the resulting transient waveform qualitatively.

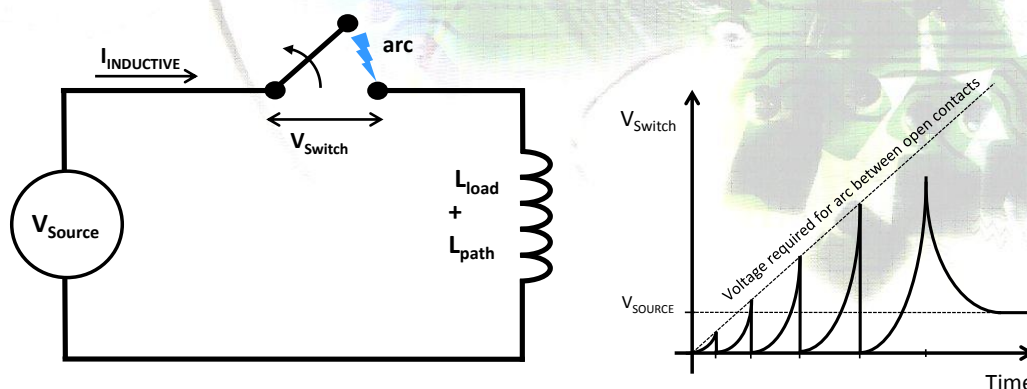


Figure 1: High frequency transients due to arcing contacts in an inductive path.

Such transients are especially severe and prevalent in heavy industry and electrical switching installations, where high current contactors and relays result in severe arcing. But even in typical residential and commercial applications, high frequency transients due to the above mechanisms in main switches, power drills etc will be encountered, albeit at lower voltage levels.



The above is the basis for the EFT/B immunity requirement imposed on a large number of electronic products today. With typical transient rise times in the nano-second range, frequencies of a few hundred MHz can be realised. EFT/B testing is more applicable to mains powered equipment, although off-line products might also be required to be immune. It is also obvious that rise time, inter-transient period and amplitude are very much application specific, with factors such as the switch opening time, mechanical aspects and path inductance influencing the resultant transient train. However, in an effort to have at least some testing standard in place, the IEC published 61000-4-4. It needs to be stressed that conformance to IEC 61000-4-4 does not guarantee immunity to all real world EFT/B events. However, chances are that a product with high immunity under IEC 61000-4-4 will also suffer less from other types of EFT/B events in the field.

Overview of IEC 61000-4-4

The IEC 61000-4-4 standard describe the EFT/B generator and the test set-up to be used in detail. It is beyond the scope of this application note to repeat these details. We advise clients to purchase a copy of IEC 61000-4-4, to ensure they are using a conforming generator and that the test set-up is correct. The salient points of the test set-up for most mains powered Prox-Sense designs are:

- Always use a ground plane of sufficient size to allow the product under test to be placed above it with 0.1m margins between product under test perimeter and ground plane edges. The minimum allowed size for the ground plane is 1m by 1m.
- Connect the above ground plane to the ground connection of the EFT/B generator with a proper grounding strap, preferably braided.
- Maintain 0.1m vertical spacing between product under test, and the ground plane.
- Ensure that the power cable between generator and product under test is between 0.5 and 1m long.
- Live and Neutral of the product under test are connected directly to an IEC 61000-4-4 compliant generator, although both need not necessarily be subjected to transients at the same time.

In terms of waveform, the standard specifies approximately three bursts per second, each containing 75 transient pulses. The pulse burst frequency can be either 5kHz or 100kHz. For 5kHz, this means total burst period is 15ms. For 100kHz it is 0.75ms. Each transient pulse rises to 90% of its peak within 5ns, and rise from and decays back to 50% of peak value within 50ns. Figures 2 and 3 illustrates the prescribed waveforms.

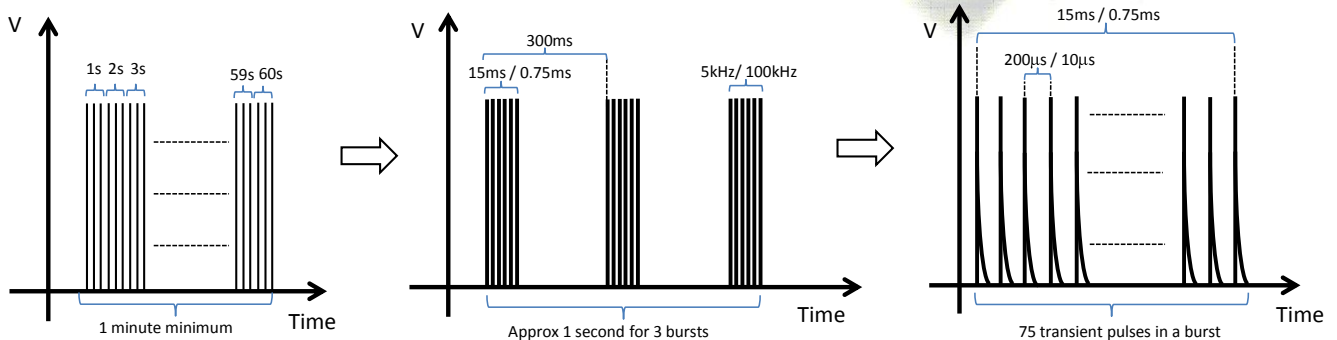


Figure 2: EFT/B transient waveforms prescribed by IEC 61000-4-4

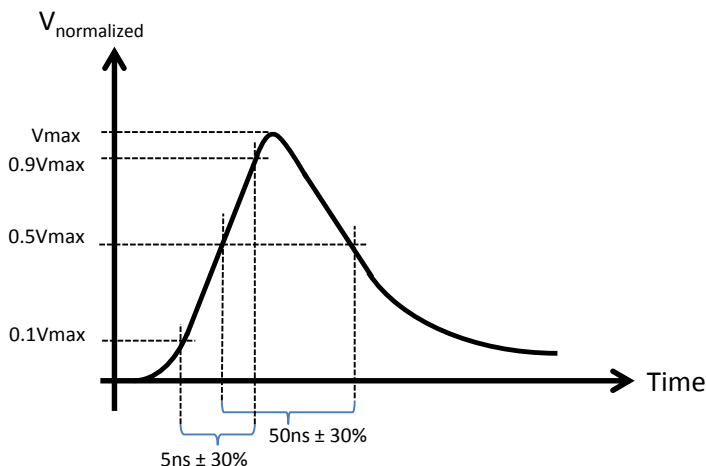


Figure 3: Waveform of the transient pulse according IEC 61000-4-4

Traditionally, EFT/B testing have been done with 5kHz pulse burst frequency. However, according to IEC 61000-4-4, testing at 100kHz may be more representative of the real world, and it is up to specific IEC product committees to decide which will apply. Further, EFT/B must be applied for at least 1 minute for each test set-up.

Transient pulse amplitude specified by IEC 61000-4-4 depends on the application environment, and can be summarised as in Table 1:

Table 1: Immunity levels for EFT/B, as required by IEC 61000-4-4

<u>Level:</u>	<u>Description:</u>	<u>Example & characteristics:</u>	<u>Immunity up to:</u>
Level 1	Well protected environment	Server rooms, stringent layout principles and filtering applied	0.5V
Level 2	Protected environment	Control room, with some filtering Also typical environment for consumer and commercial applications of ProxSense design	1kV
Level 3	Industrial environment	Industrial plant, no transient filtering, cables in close proximity to each other	2kV
Level 4	Severe industrial environment	HV Substations, Electric Power Plants. High current contactor switching	4kV

The standard requires that both positive and negative polarity transients be applied. The definition of polarity is with respect to the large ground plane. I.e. for positive polarity, coupling will be such that the conductors towards the product under test will be positive, and the plane will be at zero potential, and for negative polarity, the conductors will be at zero, and the plane will be positive. In terms of coupling, the standard is not explicit, but most EMC references advise to test with coupling to all combinations of power conductors, i.e. couple to L+N, to L, to N, and if a power earth is used, to L+N+E, to L+E and to N+E. The standard also



requires capacitive clamp based coupling to cables running to auxiliaries of the product under test. This is seldom encountered for ProxSense designs, and as such, discussion is omitted from this application note.

Azoteq pursues Level 3, or 2kV, immunity, L+N coupling, positive and negative polarity, for all its ProxSense evaluation kits. Level 4 immunity has been achieved upon request, but typically requires dedicated layout and engineering resources. Please enquire for further details.

!! IEC61000-4-4 only applies to commercial products, not to Medical, Maritime, Avionics, Machinery and Automotive products where malfunction/failure due to EFT/B could result in loss of life or large scale financial loss. Stringent international / local standards cover such applications.

2 Understanding EFT/B current paths:

From a Power Supply Perspective

To understand EFT/B failure mechanisms, two aspects must be understood. Firstly, EFT/B is mostly a common-mode test, with the transient pulses applied between power conductors and the ground plane. Secondly, EFT/B can be classified as an RF-test, with frequency components up to a few hundred MHz. From these two aspects, and the fact that the product under test must be 0.1m above the ground plane with preferably air as separation dielectric, it is clear that EFT/B transient currents are essentially capacitive in nature. Figure 4 illustrates the concept for positive polarity transient pulses. For negative polarity pulses, the current direction reverses.

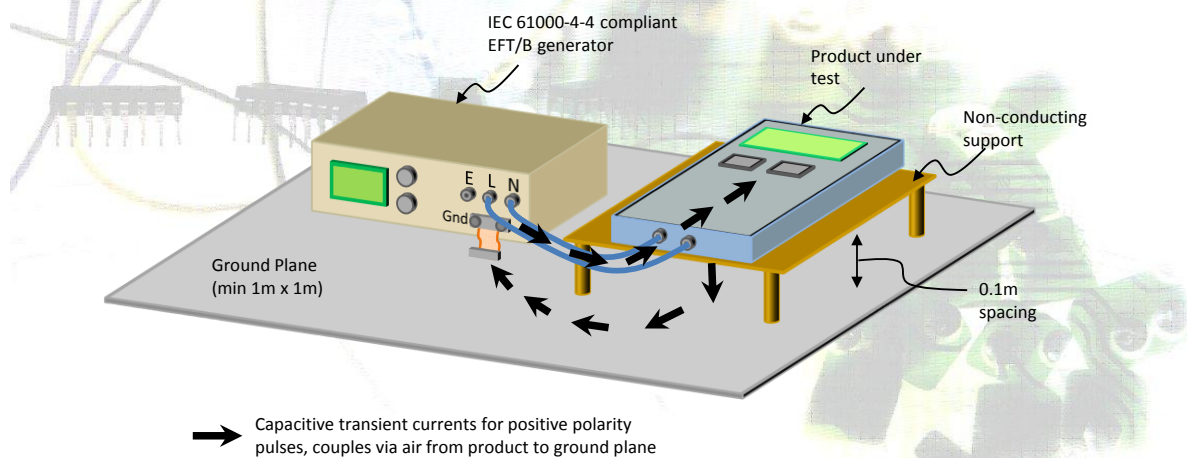


Figure 4: EFT/B as common-mode test, with capacitive transient currents for positive polarity pulses

Being capacitive and RF in nature, the transient currents will avoid inductances in the circuit as they seek large copper areas via which to flow as displacement current to/from the large ground plane underneath. Some of the transient energy will couple from the power leads to the ground plane, but typically this is fairly limited in extent. To further understanding of typical EFT/B current paths, it helps to consider a typical ProxSense design powered by a typical full diode bridge, isolated SMPS. Figures 5 and 6 illustrate the cases of positive and negative polarity EFT/B transients being coupled to both Live and Neutral.

For the positive polarity event, transient current flows via the diode bridge to the high voltage (HV) bus. From here, two paths exist. The first is via the main reservoir capacitor to the grounded copper of the HV section. If sufficient copper has been placed, most of the transient current will flow via this path to the large ground plane connected to the generator, as it will have the least inductance, and reservoir capacitors normally



have substantial capacitance. If the grounded copper of the HV section is insufficient, current will also flow substantially along the second path. This is across the SMPS isolation barrier, with two further alternatives

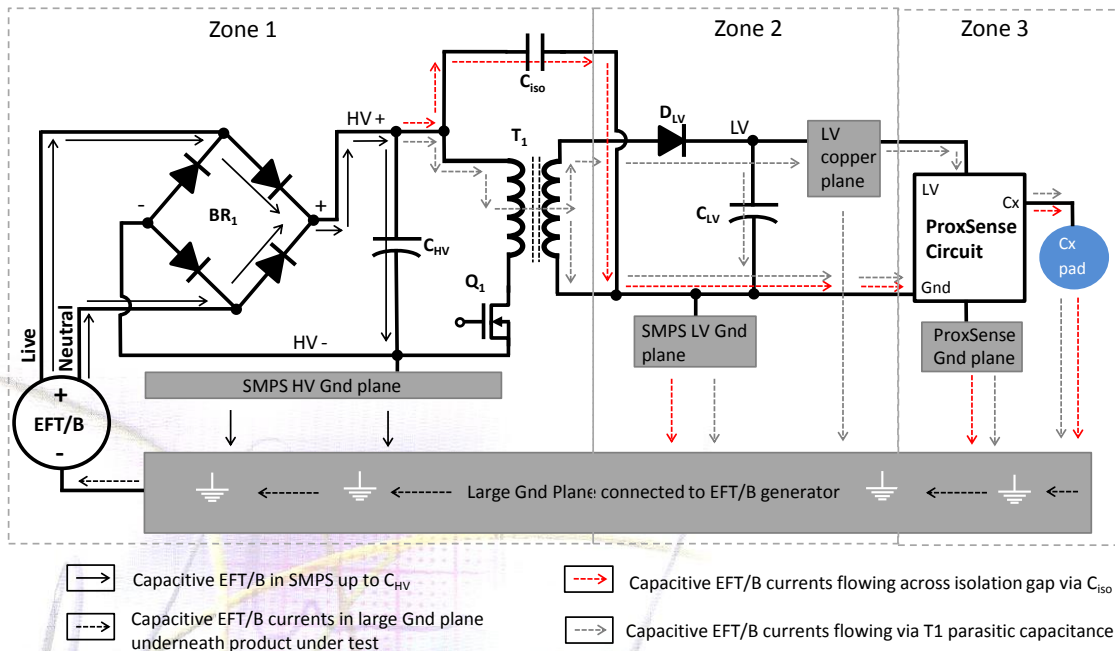


Figure 5: Possible positive polarity EFT/B current paths for an isolated SMPS, as is typical in white goods.

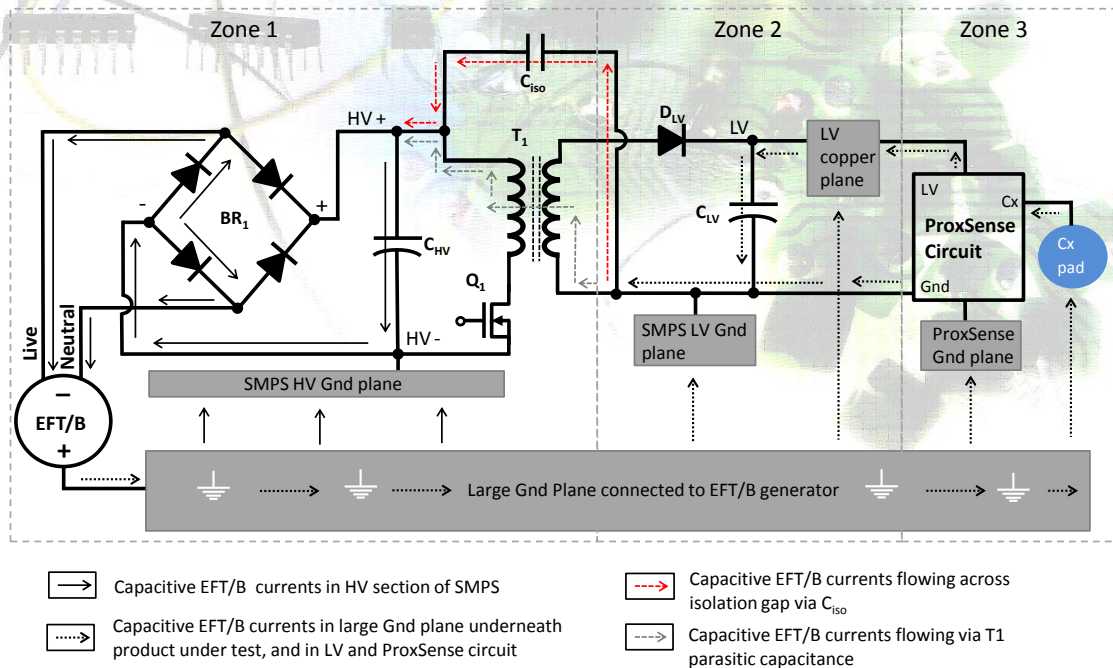


Figure 6: Possible negative polarity EFT/B current paths for an isolated SMPS, typical in white goods.

available. The first is via the high voltage EMC capacitor C_{iso} across the isolation barrier, and the second via the transformer winding parasitic capacitance. The latter is typically much smaller than C_{iso} , with



corresponding lower levels of EFT/B transient currents. Often, C_{iso} is connected between the primary side HV bus, and the secondary side ground, as shown in Figures 5 and 6. EFT/B currents therefore flows directly to the secondary ground. If sufficient copper area is connected to the secondary ground, the transient currents will flow to the large ground plane underneath via this route. However, if the secondary grounded copper is insufficient, the transient currents in the secondary ground will couple to the large, EFT/B generator connected ground plane via the Cx-pads, as discussed below, to the obvious detriment of the ProxSense circuit. Having a large low voltage, for instance a 3.3V, plane on the secondary side will also assist to shunt EFT/B currents to ground before they reach the ProxSense circuit, as shown in Fig. 5.

For the negative polarity event depicted in Figure 6, current paths are fairly similar, with the following differences. Obviously, the current direction has reversed, and the complimentary diode pair of the bridge rectifier now conducts. Diode D_{LV} blocks transient currents, with less current flowing via the transformer winding parasitic capacitance. Once again, if sufficient connected copper is provided for the HV and LV grounds, most of the transient currents will not even reach the ProxSense circuit. Another important difference is that the impedance of the primary side reservoir capacitor C_{HV} is not in the path via the HV grounded copper anymore. This means large copper area for the HV ground will have a much larger effect on negative polarity events.

From Figures 5 and 6, the difference between coupling EFT/B transients to L+N, or to L or N only becomes apparent for the case of an isolated SMPS with full diode bridge. For instance, if we couple only to Live, current paths will be exactly the same, with the exception that transient current will not flow via the Neutral lead or the diodes of BR1 connected to it. Barring input resistances, one would expect not to see a large difference in EFT/B immunity between coupling to L+N and coupling to L or N only, given the small copper area typically presented by the round L and N leads to the large ground plane underneath. (But being EMC, one cannot bank on this expectation, and should always test to be sure.) However, if L and N is supplied with flat bus bars, which couples well capacitively to the large ground plane underneath the product under test, coupling only to L or N versus L+N should result in significant immunity differences.

The EFT/B transient current via transistor Q_1 should be quite negligible for both positive and negative polarity events, as the primary winding inductance would impede current flow significantly.

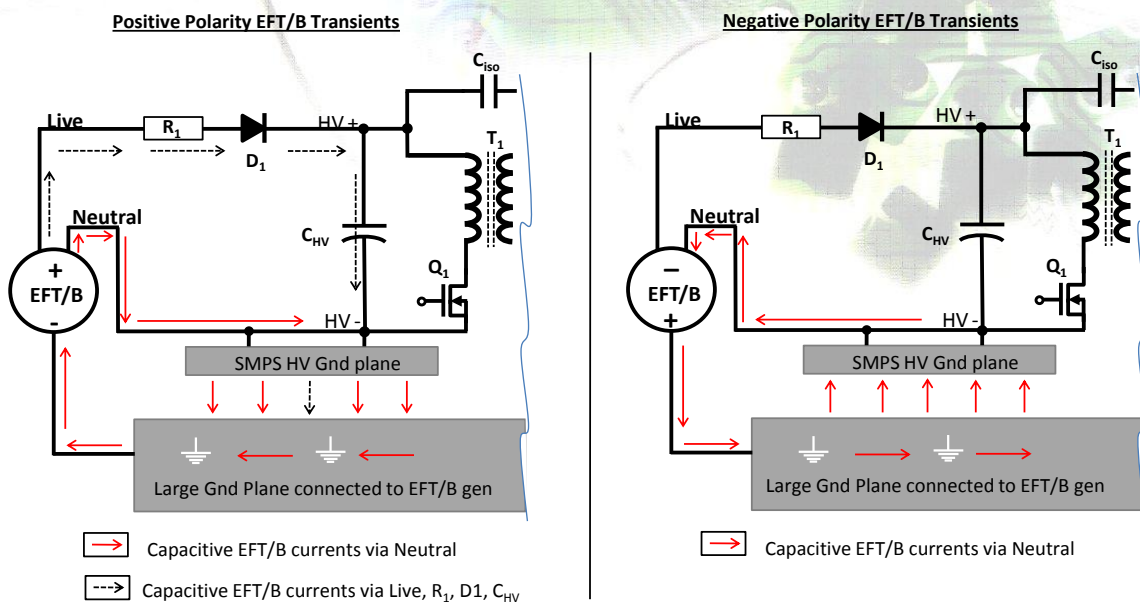


Figure 7: Positive and negative polarity EFT/B currents in SMPS with only single diode rectifier.



If a single diode rectifier is used in the SMPS input stage, as depicted in Figure 7, immunity to L+N coupling EFT/B should be much higher if enough grounded copper area is realised on the primary side of the SMPS. With a positive polarity transient, most of the transient current will flow via the Neutral lead to the primary side grounded copper, and coupled capacitively to the large ground plane underneath the product under test. If a negative polarity transient is applied, all of the transient current will flow via primary side grounded copper and Neutral lead back to the generator.

However, the difference in immunity against negative polarity EFT/B for L+N or L only coupling may be bigger in the single input diode case of Figure 7. If a negative polarity EFT/B is only coupled to L for a single input diode SMPS, transient currents do not have a clear path back to the generator, as D1 will block them. Therefore, currents will seek out other parasitic capacitance paths, with varying immunity.

From ProxSense Perspective

As stated above, if sufficient grounded copper is not provided in Zones 1 and 2 of Figures 5 and 6, EFT/B capacitive transient currents might flow to/from the large ground plane underneath via the large copper areas of Cx pads in Zone 3. This will obviously be detrimental to the operation of the ProxSense circuit, with the possibility of ground reference shifting, or bounce, false touches, data corruption or device hang-up. The internal Cx-pin ESD protection diodes present in all ProxSense devices unfortunately also provides good paths for transient EFT/B currents. This is illustrated by Figures 7 and 8.

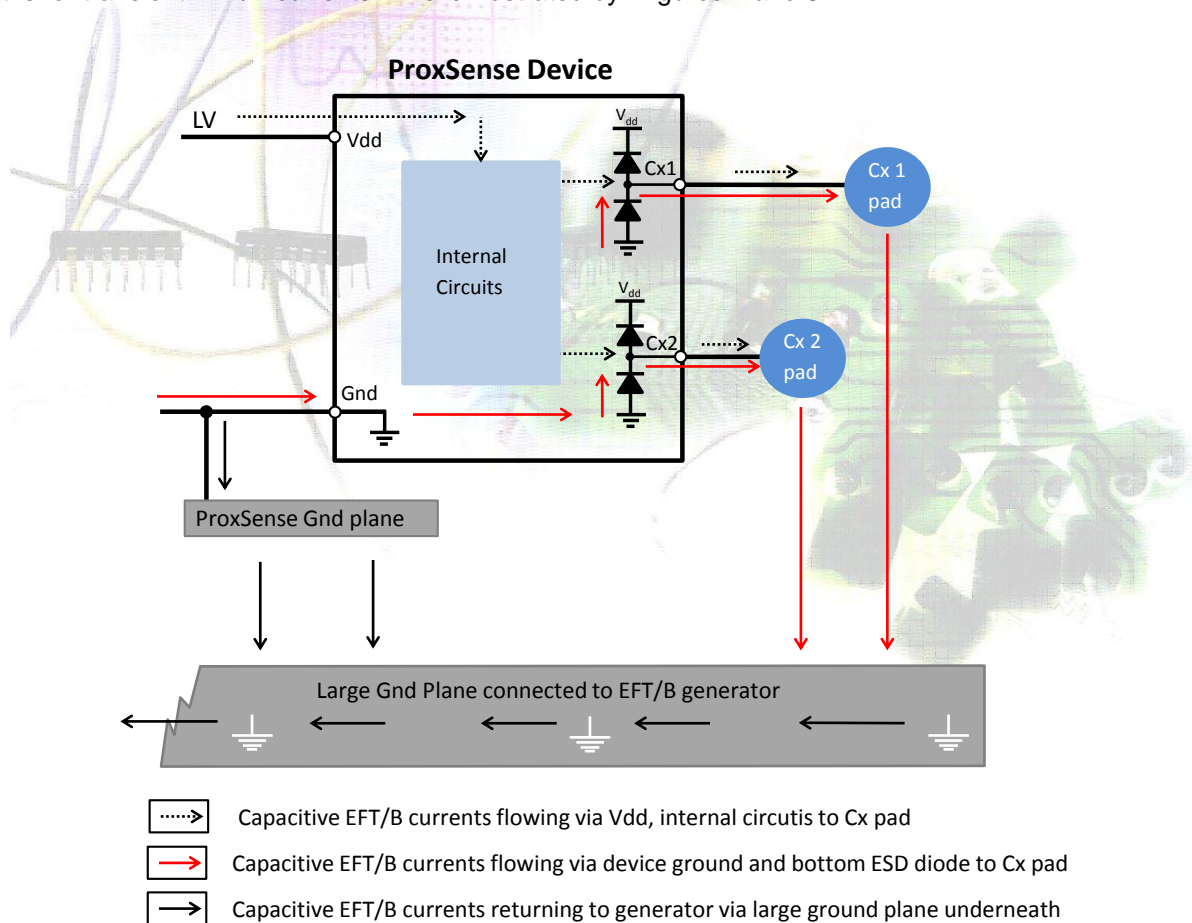


Figure 7: Positive polarity EFT/B currents flowing via bottom internal ESD diodes and Cx pads.

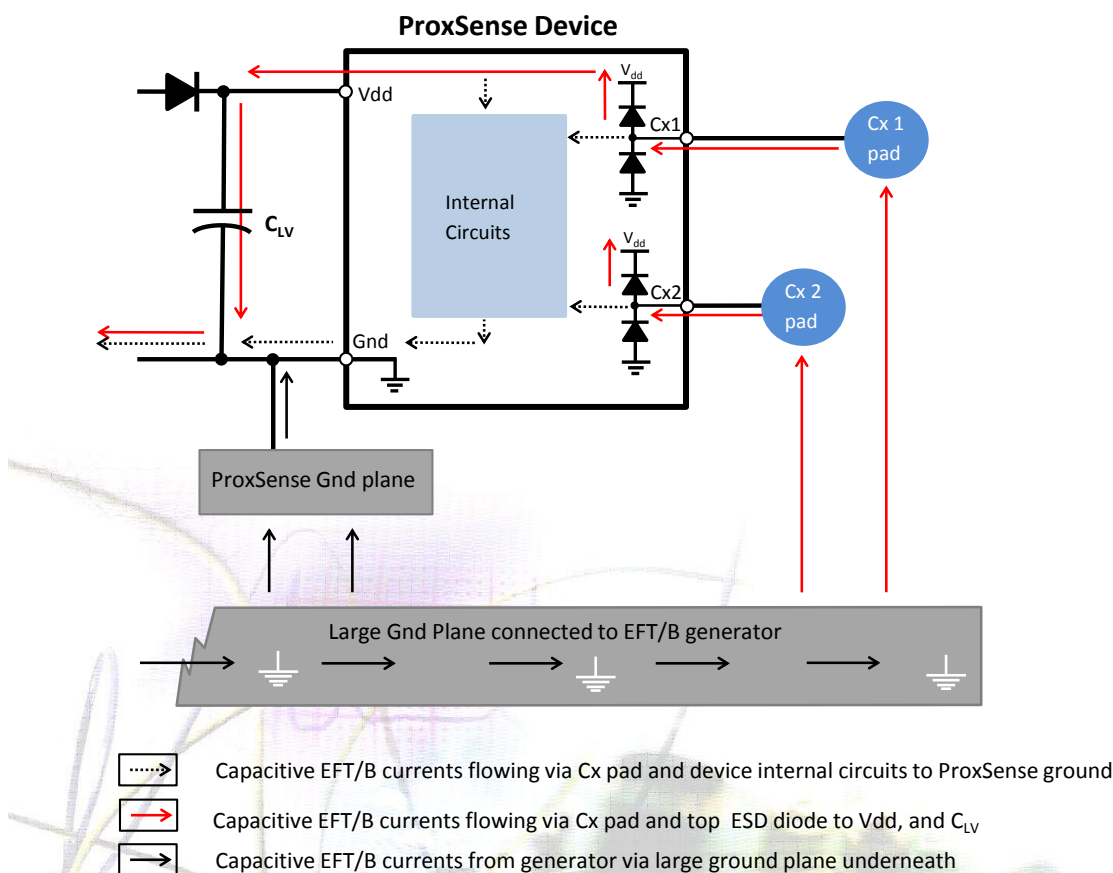
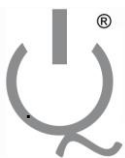


Figure 8: Negative polarity EFT/B currents flowing via top internal ESD diodes and Cx pads.

The amount of EFT/B current flowing via the Cx pads is proportional to the pad size – a larger capacitance between Cx and the large ground plane underneath results in more current, and possibly less EFT/B immunity. It stands to reason that typical projected capacitive sensors therefore has more inherent EFT/B immunity, having far less sensor pad copper area.

On ProxSense devices with an ICTRL pin, such as the IQS316, special care should be taken with the grounding of the resistor attached to this pin. Reference current for the whole device is set by the resistor. A number of operating parameters, including clock speed, are derived from the reference current. If transient EFT/B currents flow via the ICTRL pin and associated resistor to ground, device operation will be severely affected. Large transient EFT/B currents in the grounded copper close to ICTRL could create ground bounce, also to the detriment of normal device behaviour.

3 Increasing EFT/B Immunity:

As with all interference, three alternatives are available to ensure EFT/B immunity:

- First alternative: Reflect the transient energy back to the generator/source with an open circuit in the transient current path.
- Second alternative: Reflect the transient energy back to the generator/source with a short circuit in the transient current path.



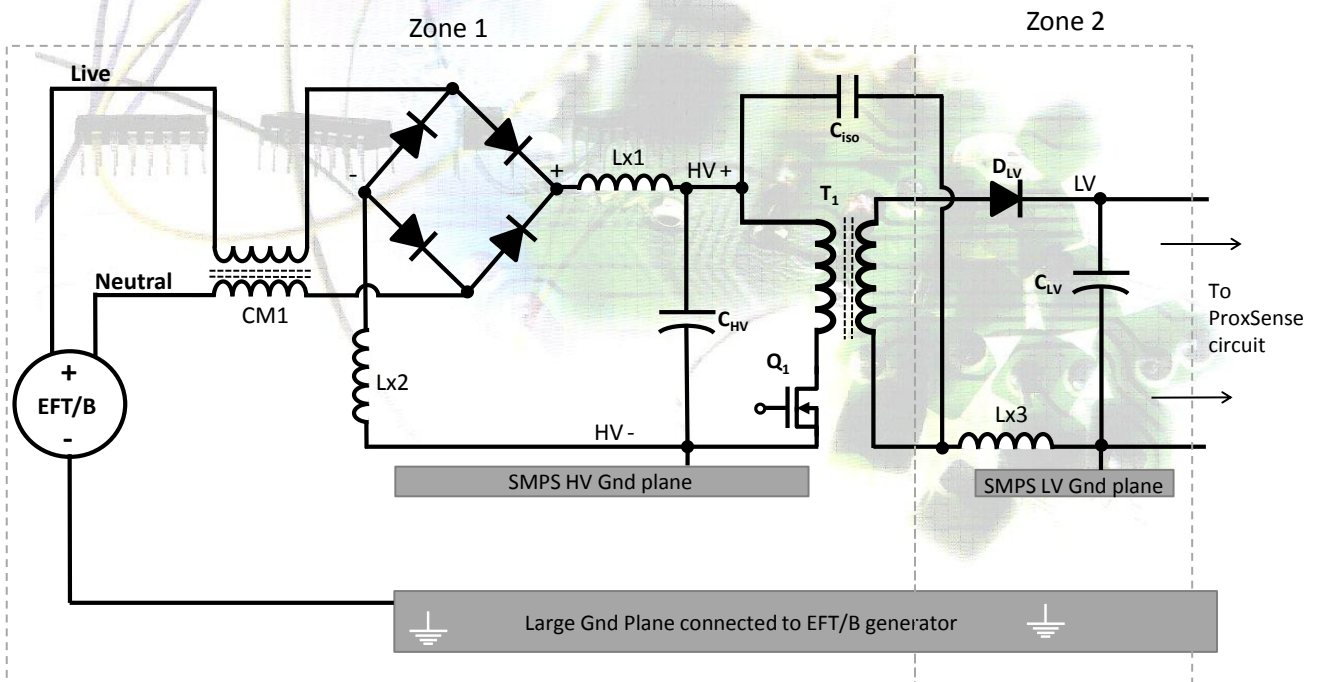
- Third alternative: Dissipate the transient energy before it reaches sensitive circuitry with an appropriate resistive element in the transient current path.

Ideally, to increase immunity to EFT/B events, one of the three alternatives should be implemented in Zones 1 or 2, as illustrated in Figures 5 and 6.

1st Alternative: Reflect energy with series inductance

An inductor of the correct value can be used to implement an approximation of alternative 1. At low frequencies it has negligible impedance. At RF frequencies, it increasingly approximates an open circuit, up to the point where it's parasitic winding capacitance starts to dominate. If we assume the lowest EFT/B frequency to be 1MHz, and would like to have 10kΩ impedance in series at this frequency, we require an inductor of 1.59mH.

Often, the inductance is inserted as a common-mode choke around both the Live and Neutral lines, right at the start of Zone 1, which is good practice. However, for a full diode bridge application, the current paths combine after the bridge, implying a single inductor might suffice if a common-mode choke is impractical or too expensive. Analysis of potential EFT/B current paths, and grounded copper area sizes will reveal where to place the inductor for maximum effect. Figure 9 illustrates the concept of transient energy reflection with additional series inductance. When pursuing additional inductance to increase EFT/B immunity, keep in mind that it might also result in some of the transient energy propagating via previously unused parasitic paths, with detrimental effect.



CM1 – Common mode choke to prevent EFT/B currents from entering Zone 1

Lx1,2 – Possible Zone 1 placements of L to reflect EFT/B energy (Lx1 only effective for pos. polarity, and Lx2 for neg polarity EFT/B events.)

Lx3 – Possible Zone 2 placement of L to reflect EFT/B energy (Note that Lx3 will result in more transient current via D_{LV})

Figure 9: Placing a common mode choke or single inductor to reflect EFT/B energy with series impedance



2nd Alternative: Reflect energy with parallel capacitance

This is the cheapest option to increase EFT/B immunity. Capacitors increasingly approach short circuits in the RF frequency range, up to the point where their parasitic inductance starts to dominate. If the grounded copper in Zone 1 of Figures 5 and 6 is of sufficient area, a significant capacitor will be formed with the large ground plane that is connected to the EFT/B generator. This can be used to reflect all the transient energy back to the source. The salient points of this alternative are:

- Ideally, create as large as possible ground plane in Zone 1 of the SMPS, that is before the isolation barrier.
- Failing the above, the next best option is a maximum ground plane in Zone 2 of the SMPS, after the isolation barrier.
- If the above two options cannot be exercised fully, and additional grounded copper must be placed in Zone 3, the ProxSense zone, careful consideration is required, keeping the following in mind:
- The additional grounded copper must ideally be connected directly to the ground of Zone 2, with a low parasitic inductance connection (i.e. flat wide conductors), and not directly (i.e. with short, low inductance connection) to the ground of the ProxSense circuit.
- If the additional grounded copper must be connected to the ProxSense circuit ground, care must be taken to try and understand how ground currents will flow, and if ground bounce in the vicinity of the ProxSense device is possible. Especially for the ground of the resistor connected to ICTRL, if present.
- Place additional grounded copper around the Cx pads, but not close enough to reduce touch sensitivity below that which is acceptable for the application at hand.

Obviously, with EFT/B a common mode requirement, it is not possible to place a discrete capacitor between the product under test, and the large ground plane underneath. Figure 10 illustrate the above concepts.

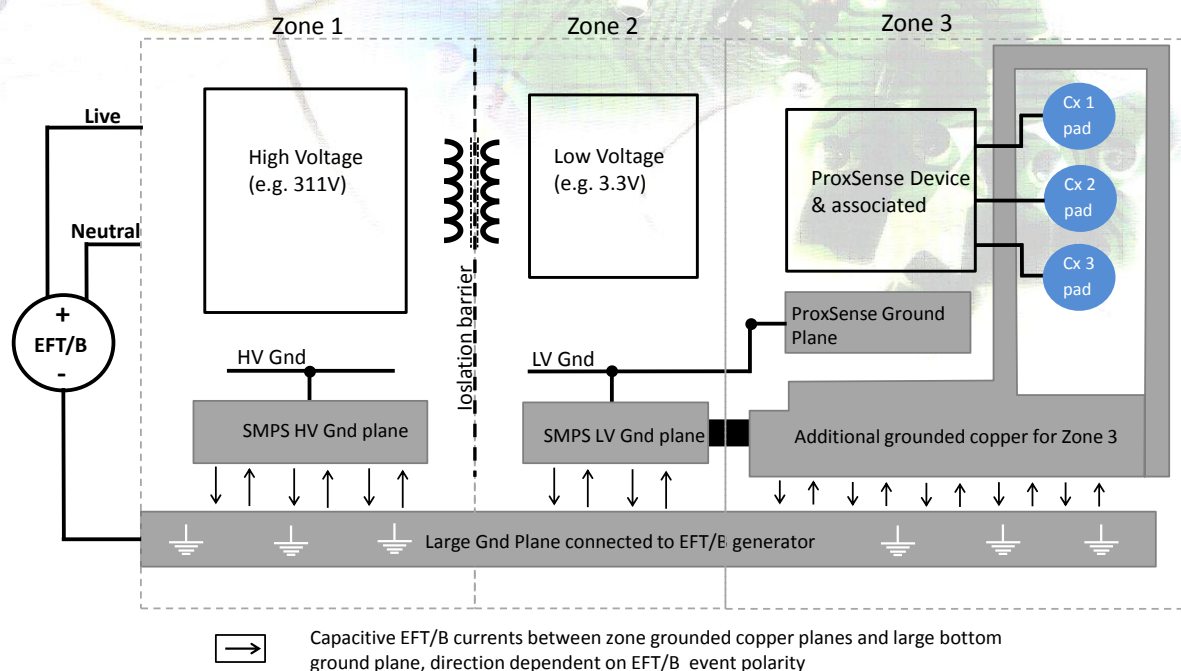


Figure 10: Additional grounded copper to realise sufficient capacitance with bottom plane to reflect EFT/B



3rd Alternative: Dissipate EFT/B transient energy

Although this is the most reliable option to ensure transients do not adversely affect the ProxSense circuit operation, (i.e once the energy is dissipated, it cannot further interfere with operation), it could be difficult or impractical to implement. If allowed by the power budget, one could insert relevant resistors into Zone 1 or 2 / SMPS, after analysing and identifying the transient current path. The obvious drawback of this approach is that power is dissipated at all frequencies, resulting in reduced efficiency of the SMPS.

Another approach is to use lossy filters, ideally with a low or band-pass response, with cut-off above 1MHz. However, most commercial filter offerings are more based on reflection than dissipation, with resistors provided for damping.

For severe cases, where all other alternatives have been exhausted, it may be worthwhile to investigate power cables with frequency selective dissipation. Most vehicles use these already – in the form of the leads to the spark plugs. At low frequencies, these are just normal power leads, but at higher frequencies, become quite lossy due to the magnetic material employed.

Filtering and Decoupling

Blind application of low-pass RC and LC filters, such as those presented in Azoteq application note AZD015, will most likely result in no improvement of EFT/B immunity. Due to the common-mode nature of EFT/B, transient currents tend to flow in the same direction in low voltage (e.g. 5V or 3.3V) power rails. Therefore, current will not be shunted by the parallel element of the filter. In cases where the transient current is much more in one of the two rails, use of such filters may even result in decreased immunity, as the capacitor of the low pass filter provides a parallel path for the current to the other rail, and into the ProxSense device. Figure 11 illustrates these concepts.

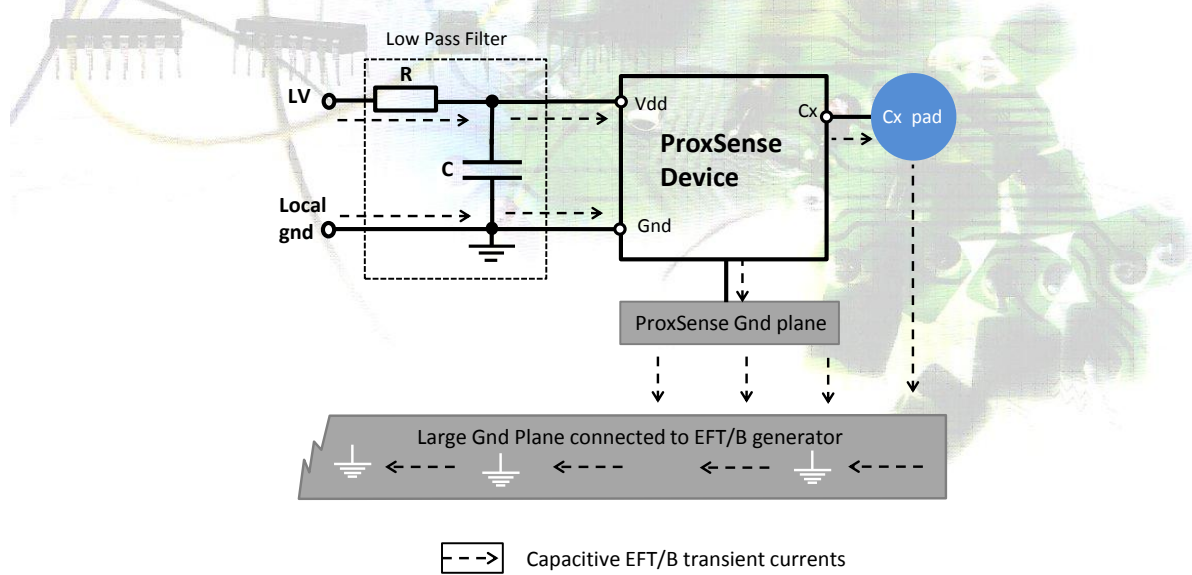


Figure 11: Transient current direction in low voltage power rails, redundancy of classical low-pass filters.

However, careful analysis of possible transient paths could identify instances where filters may improve EFT/B immunity. For instance, if un-filtered, transient currents might flow via communication bus lines, such as SPI, through the ProxSense device towards the local ground, followed by coupling to the large ground plane and back to the generator. By inserting low-pass filters into the SPI lines, transient currents can be



shunted to local ground before the ProxSense device, improving EFT/B immunity. Figure 12 illustrates the concept. To improve immunity, multi-stage low-pass filters may be considered.

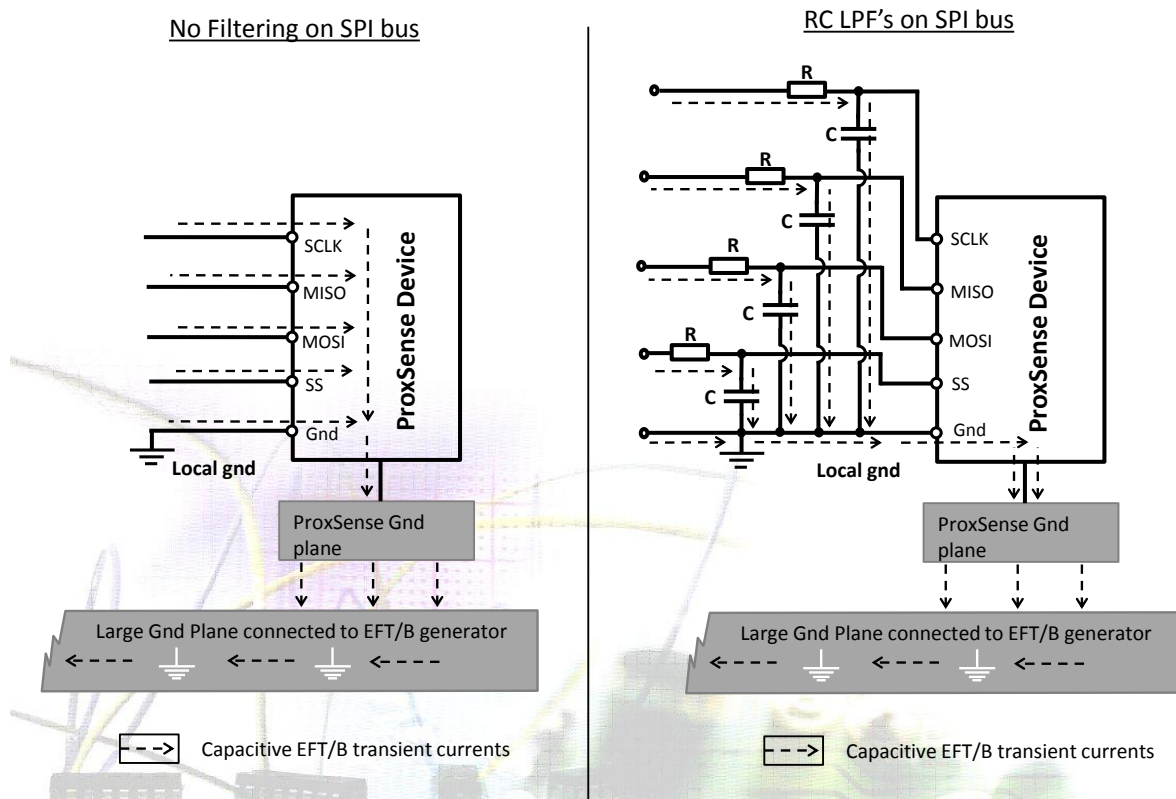


Figure 12: Use of basic low-pass filters on SPI lines to shunt transient currents, and improve immunity

Cx-pad & track guidelines

As observed, with EFT/B typically being a common-mode phenomenon, it is quite likely that capacitive transient currents will try to couple via Cx-pads to the large ground plane underneath the product under test. To avoid this detrimental situation, the following guidelines with regards to EFT/B may be helpful:

- Do not realize a ProxSense design where the total copper area of the local ProxSense ground is significantly less than the total copper area of all the Cx-pads.
- If possible, make the copper area of the local ProxSense ground more than the total copper area of all the Cx-pads.
- If sensitivity allows it, increase the series resistance to each Cx-pad up to 10k Ω , as required by the immunity level pursued.
- If a large local ground area is not possible, and sensitivity allows it, used hashed copper for the Cx-pads. This should reduce the amount of capacitive transient EFT/B currents flowing through the Cx-pads.



- Use thin tracks to the Cx-pads, as these have more inductance, which will help to block high frequency EFT/B currents. The same applies for longer tracks, although this might lead to reduced Radiated Immunity (See AZD015).
- If necessary, place additional, discrete ESD diodes external to the ProxSense device on each Cx pin. This may reduce the amount of EFT/B current internal to the device, and thus improve immunity.

4 Testing alternatives:

Essentially, any mechanical switch that creates sparks when it breaks an inductive current can be used as alternative for EFT/B testing. However, similar with application of a test according to the formal IEC 61000-4-4 standard, and it's relevance for real life transients, one cannot ascertain conformance to IEC 61000-4-4 by establishing immunity of a product to an arbitrary, alternative EFT/B test. But improving immunity to an arbitrary, alternative EFT/B test should in general help with conformance to the formal standard. (But could also result in over-engineering a product, and unnecessary cost.) When using alternative EFT/B tests, observe the following:

- Provide some sort of LC-filtering to the local mains, before the EFT/B injection point. Otherwise other mains powered equipment may fail or be damaged, and the test may even be illegal!
- Inject the EFT/B currents via DC blocking capacitors into Live and Neutral lines.
- Always use a sufficiently sized ground plane.
- It may be sufficient to lay cables containing transient currents alongside power cables of the product under test to recreate failures experienced under a formal IEC 61000-4-4 test.
- Please take heed of the below warnings.

!! Alternative EFT/B tests typically involve hazardous voltages. Basic electrical safety principles should be applied. If unsure, consult a certified professional.


!! In all the above, care must be taken not to exceed local legal limits for RF-radiation. Severe consequences, some fatal, can result if limits are exceeded. If unsure, consult an EMC specialist.



5 Document History

v1.0, Aug 2011	J.D. van Wyk, Sr. Application & Development Engineer	Creation

The following patents relate to the device or usage of the device: US 6,249,089 B1, US 6,621,225 B2, US 6,650,066 B2, US 6,952,084 B2, US 6,984,900 B1, US 7,084,526 B2, US 7,084,531 B2, US 7,119,459 B2, US 7,265,494 B2, US 7,291,940 B2, US 7,329,970 B2, US 7,336,037 B2, US 7,443,101 B2, US 7,466,040 B2, US 7,498,749 B2, US 7,528,508 B2, US 7,755,219 B2, US 7,772,781, US 7,781,980 B2, US 7,915,765 B2, EP 1 120 018 B1, EP 1 206 168 B1, EP 1 308 913 B1, EP 1 530 178 B1, ZL 99 8 14357.X, AUS 761094

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