TEST REPORT

IEC 60950-1
Information technology equipment – Safety –
Part 1: General requirements

Report Number. .... :	246038
Date of issue .... :	October 28, 2013
Total number of pages	11
CB Testing Laboratory .... :	Nemko A/S
Address .... :	Gaustadalléen 30, NO-0373 Oslo, Norway
Applicant's name........................... :	Power Integrations, Inc.
Address .... :	5245 Hellyer Avenue, San Jose, CA 95138, U.S.A.
Manufacturer's name………………..:	Power Integrations, Inc.
Address .... :	5245 Hellyer Avenue, San Jose, CA 95138, U.S.A.
Test specification:	
Standard.. :	IEC 60950-1:2005 (Second Edition) + Am 1:2009 with CTL Decision, DSH 1080
Test procedure .... :	CB Scheme
Non-standard test method…………..:	N/A
Test Report Form No. .... :	IEC60950_1C
Test Report Form(s) Originator ....:	SGS Fimko Ltd
Master TRF ....:	Dated 2012-08

If this Test Report Form is used by non-IECEE members, the IECEE/IEC logo and the reference to the CB Scheme procedure shall be removed.

This report is not valid as a CB Test Report unless signed by an approved CB Testing Laboratory and appended to a CB Test Certificate issued by an NCB in accordance with IECEE 02.

Test item description ....:	IC including capacitor discharge function (ICX)
Trade Mark...................................... :	CAPZero
Manufacturer .... :	Power Integrations, Inc.
Model/Type reference .... :	CAP002DG; CAP003DG; CAP004DG; CAP005DG; CAP006DG; CAP007DG; CAP008DG; CAP009DG; CAP012DG; CAP013DG; CAP014DG; CAP015DG; CAP016DG; CAP017DG; CAP018DG; CAP019DG; SC1143
Ratings .... :	230V AC

Testing procedure and testing location:		
☒ **CB Testing Laboratory**:	Nemko A/S	
Testing location/ address ....:	Gaustadalléen 30, NO-0373 Oslo, Norway	
☐ **Associated CB Laboratory:**		
Testing location/ address ....:		
Tested by (name + signature) .... :	Ole Morten Aaslund	Ole Morten Aaslund
Approved by (name + signature)...... :	Hans-Eirik Lie	[signature]
☐ Testing procedure: **TMP**		
Testing location/ address ....:		
Tested by (name + signature) .... :		
Approved by (name + signature)...... :		
☐ Testing procedure: **WMT**		
Testing location/ address ....:		
Tested by (name + signature) .... :		
Witnessed by (name + signature) .... :		
Approved by (name + signature)...... :		
☐ Testing procedure: **SMT**		
Testing location/ address ....:		
Tested by (name + signature) .... :		
Approved by (name + signature)...... :		
Supervised by (name + signature) ... :		
☐ Testing procedure: **RMT**		
Testing location/ address ....:		
Tested by (name + signature) .... :		
Approved by (name + signature)...... :		
Supervised by (name + signature) ... :		

List of Attachments (including a total number of pages in each attachment):

CTL Decision, DSH 1080 (2 pages)
Photos (5 pages)
Data sheet (8 pages)
Application note (10 pages)

Summary of testing:

This report covers only tests applicable for IC including capacitor discharge function (ICX). Requirements for such components are covered by CTL Decision, DSH 1080, refer attachment.

The following clauses are not applicable for such components and are removed from this report: 1.5, 1.6, 1.7 (except for 1.7.1 and 1.7.11), 2.1 (except for 2.1.1.7), 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9 (except for 2.9.2), 2.10, 3.1, 3.2, 3.3, 3.4, 3.5, 4.1, 4.2, 4.3, 4.4, 4.5, 5.1, 5.2, 5.3 (except 5.3.7 and 5.3.9) and all Annexes.

However, all relevant clauses must be considered for end products using this ICX.

The following tests were performed as per *DSH 1080:*

- humidity treatment for 120 h at a temperature of (40±2)°C and a relative humidity of (93±3)%

Humidity treatment performed on models CAP002DG, CAP009DG, CAP012DG and CAP019DG, refer also clause 2.9.2 in this report.

- 100 positive impulses and 100 negative impulses between line and neutral using a capacitor with the largest capacitance and a resistor with the smallest resistance specified by the manufacturer of the ICX; and repeated with a capacitor with the smallest capacitance and the resistor with the largest resistance. The time between any two impulses shall not be less than 1 s. The impulse shall be as specified in circuit 2 of Table N.1 (60950-1) / 1.2/50µs in Table K.1 (60065), with Uc equal to the transient voltage.

Impulse tests as described performed on models CAP002DG, CAP009DG, CAP012DG and CAP019DG. Uc = 2500Vpeak. X-capacitor was only mounted during the discharge tests, refer General product information and 2.1.1.7.

- Application of an a.c. voltage that is 110% of the rated voltage for 2.5 minutes.

A voltage of 253V AC applied for 2.5 minutes on models CAP002DG, CAP009DG, CAP012DG and CAP019DG.

- 10 000 cycles of power on and off using a capacitor with the smallest capacitance and a resistor with the largest resistance as specified by the manufacturer of ICX. The power on and off cycles time shall not be less than 1 s.

10 000 cycles of power on and off (cycle time is 1 s) performed on models CAP002DG and CAP012DG.

If any of the associated circuitry components other than those critical for the discharge function fails, it may be replaces with a new component.

No components failed.

Compliance criteria:
Compliance is checked by evaluation of the available data or by conducting the above tests. The capacitor discharge test is conducted after above tests, ensuring the ICX or the EUT provided with the ICX continues to provide the safeguard function.

NOTE: Evaluation of available data should include information of failure of any associated circuitry components keeps the discharge modes in the on/stay mode.

Summary of testing (continued):

After above tests the capacitor discharge tests were performed according to clause 2.1.1.7 on models CAP002DG, CAP009DG, CAP012DG and CAP019DG. The circuit tested continue to comply with 2.1.1.7, refer 2.1.1.7 for details. Note that compliance with 2.1.1.7 must also be checked when the ICX forms part of an end product.

In addition to above tests, evaluation of available data from the manufacturer have been made to prove that the discharge function of the ICX remains the same also during single fault conditions. Refer general product information and clause 5.3.7 for details.

Tests performed (name of test and test clause):		**Testing location:**
1.7.11	Durability (markings)	Nemko A/S
2.1.1.7	Discharge of capacitors in equipment	Gaustadalléen 30, NO-0373 Oslo, Norway
2.9.2	Humidity conditioning	

Summary of compliance with National Differences

Samples tested comply with the applicable requirements covered by CTL Decision, DSH 1080, attached to this report.

Copy of marking plate

The artwork below may be only a draft. The use of certification marks on a product must be authorized by the respective NCBs that own these marks.

(Additional requirements for markings. See 1.7 NOTE)

The following markings are printed on the body of the ICX:

- Power Integrations Logo
- Date code
- Part no.
- Serial no.

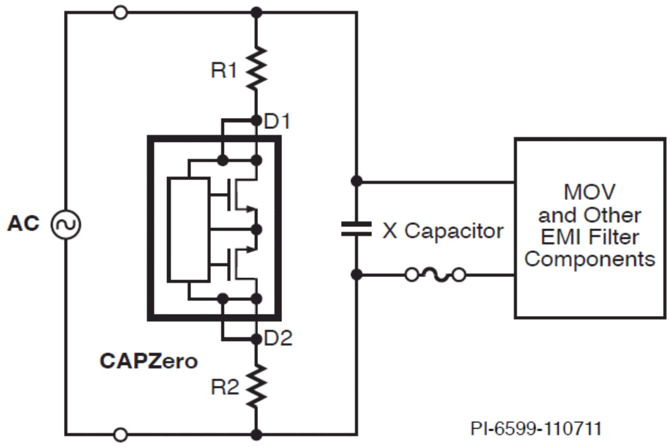
Test item particulars .... :	
Equipment mobility ....:	[] movable [] hand-held [] transportable [] stationary [x] for building-in [] direct plug-in
Connection to the mains ....:	[] pluggable equipment [] type A [] type B [] permanent connection [] detachable power supply cord [] non-detachable power supply cord [] not directly connected to the mains Must be evaluated in the end product.
Operating condition...:	[x] continuous [] rated operating / resting time:
Access location ....:	[x] operator accessible [] restricted access location
Over voltage category (OVC) ....:	[] OVC I [x] OVC II [] OVC III [] OVC IV [] other:
Mains supply tolerance (%) or absolute mains supply values ....:	110% of rated voltage as per DSH 1080
Tested for IT power systems ....:	[] Yes [] No Not applicable for this type of component.
IT testing, phase-phase voltage (V) ....:	230V
Class of equipment ....:	[] Class I [] Class II [] Class III [x] Not classified
Considered current rating of protective device as part of the building installation (A) ....:	N/A
Pollution degree (PD) ....:	[] PD 1 [x] PD 2 [] PD 3
IP protection class ....:	IP20
Altitude during operation (m) ....:	< 2000m
Altitude of test laboratory (m) ....:	< 2000m
Mass of equipment (kg) ....:	< 10g
Possible test case verdicts:	
- test case does not apply to the test object ....:	N/A
- test object does meet the requirement......................:	P (Pass)
- test object does not meet the requirement................:	F (Fail)
Testing..:	
Date of receipt of test item ....:	October 1, 2013
Date(s) of performance of tests ....:	October 4 – October 18, 2013

General remarks:	
The test results presented in this report relate only to the object tested. This report shall not be reproduced, except in full, without the written approval of the Issuing testing laboratory. "(see Enclosure #)" refers to additional information appended to the report. "(see appended table)" refers to a table appended to the report. Throughout this report a ☐ comma / ☒ point is used as the decimal separator.	
Manufacturer's Declaration per sub-clause 6.2.5 of IECEE 02:	
The application for obtaining a CB Test Certificate includes more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided.. :	☐ Yes ☒ Not applicable
When differences exist; they shall be identified in the General product information section.	
Name and address of factory (ies) .... :	Millenium Microtech Shanghai No. 351 Guo Shou Jing Rd., Z.J. Hi Tech Park Pudong New Area, Shanghai, 201203 CHINA

General product information:

The equipment under tests are IC including discharge function (ICX). It is used to cope with environmental issues, as it limits the power consumption in standby conditions. The ICX blocks current through X-capacitor discharge resistor when AC voltage is connected, and it automatically discharges X-capacitor trough discharge resistors when AC is disconnected.

Figure below shows a typical application for the ICX:



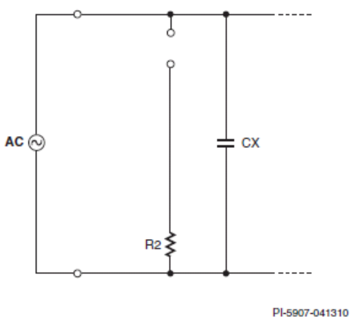
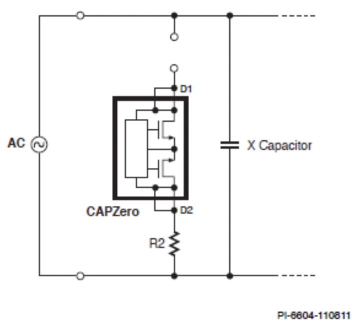
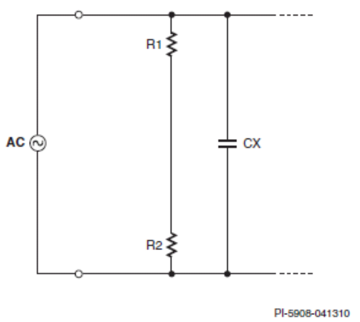
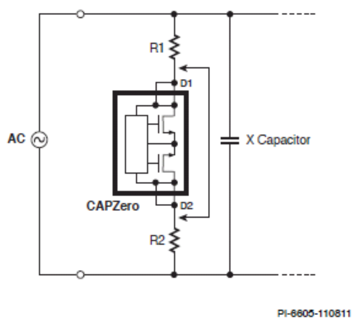
Models covered by this report are listed in table below. Models CAP002DG, CAP009DG, CAP012DG and CAP019DG were chosen to represent all models. During testing the ICX was mounted on a PCB together with a mains fuse (1A) and discharge resistors. Refer attached photos. X-capacitor was only mounted during the discharge tests, refer summary of testing and 2.1.1.7. Values of X-capacitor and discharge resistors are as per recommendation from the manufacturer. Refer table below.

Model/Part No. (ICX)	BV_{DSS}	Maximum total X-capacitance	Total series resistance (R1+R2)
CAP002DG	825V	<= 500nF	1.5MΩ
CAP003DG	825V	750nF	1.02MΩ
CAP004DG	825V	1µF	780kΩ
CAP005DG	825V	1.5µF	480kΩ
CAP006DG	825V	2µF	360kΩ
CAP007DG	825V	2.5µF	300kΩ
CAP008DG	825V	3.5µF	200kΩ
CAP009DG	825V	5µF	150kΩ
CAP012DG	1000V	<= 500nF	1.5MΩ
CAP013DG	1000V	750nF	1.02MΩ
CAP014DG	1000V	1µF	780kΩ
CAP015DG	1000V	1.5µF	480kΩ
CAP016DG	1000V	2µF	360kΩ
CAP017DG	1000V	2.5µF	300kΩ
CAP018DG	1000V	3.5µF	200kΩ
CAP019DG	1000V	5µF	150kΩ
SC1143	1000V	5µF	150kΩ

Table on previous page includes tolerances as referred to in the attached data sheet i.e. 5% for resistors and 20% for total capacitance.

Resistors R1+R2 shall be rated for 50% of the system input voltage to allow for the short-circuit of the ICX, D1 to D2 pins, during single fault test.

Evaluation of singe fault conditions (refer also clause 5.3.7):
The ICX has two dedicated pins for the D1 and D2 terminals which add redundancy during single fault testing (short-circuit or open-circuits). Thus if one pin is physically disconnected from the device or PCB, the ICX will continue to function normally. During a short-circuit the outcome is the same as if the ICX had not been used and results in the discharge resistors being connected in series continuously. Figure below summarizes the results of the worst case single fault tests.

Test	Test With Existing System	CAPZero Equivalent	Comments
Open Circuit: Disconnect one pin of any device to see effect on system			Lifting any one pin of the CAPZero device has no effect as 2 pins are connected to each drain terminal. The only way to create an open circuit is by lifting the leads of one of the discharge resistors. This is therefore equivalent to existing system without CAPZero.
Short Circuit: Short any 2 adjacent pins to see effect on system			Shorting D1 and D2 pins creates a condition equivalent to an existing system not using CAPZero.

Evaluation of maximum ambient temperature:
Extended tests performed by the manufacturer to prove that the ICX is also reliable at the maximum specified ambient temperature (105°C).

Refer also attached data sheet and application note from the manufacturer for further details.

Abbreviations used in the report:

- normal conditions	N.C.	- single fault conditions	S.F.C
- functional insulation	OP	- basic insulation	BI
- double insulation	DI	- supplementary insulation SI	
- between parts of opposite polarity	BOP	- reinforced insulation	RI

Indicate used abbreviations (if any)

IEC 60950-1/Am1			
Clause	Requirement + Test	Result - Remark	Verdict

1.7.1	Power rating and identification markings	The required marking is located on the outside surface of the component.	P
1.7.1.1	Power rating marking	Refer below:	P
	Multiple mains supply connections.........................:	Must be considered when installed in the end product.	N/A
	Rated voltage(s) or voltage range(s) (V) ....:	Rated nominal voltage is declared to be 230V AC.	P
	Symbol for nature of supply, for d.c. only ....:	AC supplied.	N/A
	Rated frequency or rated frequency range (Hz) .....:	Must be considered when installed in the end product.	N/A
	Rated current (mA or A) ....:	Must be considered when installed in the end product.	N/A
1.7.1.2	Identification markings	Refer below:	P
	Manufacturer's name or trade-mark or identification mark ....:	CAPZero	P
	Model identification or type reference ....:	CAP002DG; CAP003DG; CAP004DG; CAP005DG; CAP006DG; CAP007DG; CAP008DG; CAP009DG; CAP012DG; CAP013DG; CAP014DG; CAP015DG; CAP016DG; CAP017DG; CAP018DG; CAP019DG; SC1143	P
	Symbol for Class II equipment only ....:	Must be considered when installed in the end product.	N/A
	Other markings and symbols ....:	The additional marking does not give rise to misunderstandings.	P
	Language(s) ....:	Must be considered when installed in the end product.	—
1.7.11	Durability	The marking withstands required tests.	P

IEC 60950-1/Am1			
Clause	Requirement + Test	Result - Remark	Verdict
2.1.1.7	Discharge of capacitors in equipment	Capacitor discharge tests performed on models CAP002DG, CAP009DG, CAP012DG and CAP019DG after tests described in Summary of testing were perfomed. Refer test results below. Discharge tests must also be performed when the ICX forms part of an end product.	P
	Measured voltage (V); time-constant (s) ....:	CAP002DG: Vpeak: 360V Vpeak, 37%: 133.2V Time-constant: 702ms CAP009DG: Vpeak: 348V Vpeak, 37%: 129V Time-constant: 796ms CAP012DG: Vpeak: 356V Vpeak, 37%: 132V Time-constant: 720ms CAP019DG: Vpeak: 360V Vpeak, 37%: 133.2V Time-constant: 796ms	—
2.9.2	Humidity conditioning	Humidity treatment for 120 h performed.	P
	Relative humidity (%), temperature (°C) ....:	40°C, 91%	—

IEC 60950-1/Am1			
Clause	Requirement + Test	Result - Remark	Verdict
5.3.7	Simulation of faults	The ICX has two dedicated pins for the D1 and D2 terminals which add redundancy during single fault testing (short-circuit or open-circuits). Thus if one pin is physically disconnected from the device or PCB, the ICX will continue to function normally. During a short-circuit the outcome is the same as if the ICX had not been used and results in the discharge resistors being connected in series continuously. Refer also figure in general product information. Extended surge tests performed by the manufacturer to maximize the voltage stress of the ICX. Tests showed that the ICX continued to function as intended even when exposed to surge levels far beyond its intended application.	P
5.3.9	Compliance criteria for abnormal operating and fault conditions	Refer 5.3.7 above.	P
5.3.9.1	During the tests	-	P
5.3.9.2	After the tests	-	P

DSH 1080

Report No. 246038

IEC System for Conformity Testing and Certification of Electrotechnical equipment and Components

CTL DECISION SHEET (DSH)

Standard(s) (incl. year)	Subclause(s)	No.	Year
IEC 60950-1:2005 + A1:2009 (ed. 2.1) IEC 60065:2001 + A1:2005 + A2:2010 (ed. 7.2)	2.1.1.7 9.1.6	DSH 1080	2013
Category			
OFF, TRON			
Subject	**Keywords**	**Developed by**	**Approved at**
Zero loss automatic X cap discharge	IC including capacitor discharge function (ICX) IC, capacitor discharge, Zero loss	ETF2	2013 CTL Plenary Meeting

Question

How should an equipment with IC including a capacitor discharge function be tested?

Decision

Requirements

An ICX and any associated components critical to the discharge function of a capacitor to an accessible part (such as the mains capacitor) are not fault tested if one of the following conditions is met:

– the ICX with the associated circuitry as provided in the equipment complies with the tests below. Any impulse attenuating components (such as varistors and GDT's) that attenuate the impulse to the ICX and the associated circuitry are disconnected.
If discharge components external to the ICX are necessary, they shall not fail during the tests; or

– the ICX tested separately complies with the requirements and tests below. If discharge components external to the ICX are necessary:
  - they shall be included in the test; and
  - they shall not fail during the tests; and
  - the discharge components used in the equipment shall be within the range tested

Tests

Where the ICX is tested by itself, the test set up shall be as recommended by the ICX manufacturer.

– humidity treatment for 120 h at a temperature of (40±2)°C and a relative humidity of (93±3)%

– 100 positive impulses and 100 negative impulses between line and neutral using a capacitor with the largest capacitance and a resistor with the smallest resistance specified by the manufacturer of the ICX; and repeated with a capacitor with the smallest capacitance and the resistor with the largest resistance. The time between any two impulses shall not be less than 1 s. The impulse shall be as specified in circuit 2 of Table N.1 (60950-1) / 1,2/50 μs in Table K.1 (60065), with Uc equal to the transient voltage.

– Application of an a.c. voltage that is 110 % of the rated voltage for 2,5 minutes.

DSH 1080

Report No. 246038

IEC System for Conformity Testing and Certification of Electrotechnical equipment and Components

– 10 000 cycles of power on and off using a capacitor with the smallest capacitance and a resistor with the largest resistance as specified by the manufacturer of ICX. The power on and off cycles time shall not be less than 1 s.

If any of the associated circuitry components other than those critical for the discharge function fails, it may be replaced with a new component

Compliance criteria

Compliance is checked by evaluation of the available data or by conducting the above tests. The capacitor discharge test is conducted after the above tests, ensuring the ICX or the EUT provided with the ICX continues to provide the **safeguard** function.

NOTE: Evaluation of available data should include information of failure of any associated circuitry components keeps the discharge mode in the on/stay mode

Explanatory notes

An ICX is introduced to cope with environmental issues. It limits power consumption in standby conditions.

Product Highlights of ICX

- Blocks current through X-cap discharge resistor when AC voltage is connected
- Automatically discharges X-cap through discharge resistors when AC is disconnected

Single fault condition (open circuit conditions) of the IC and associated circuitry components critical for the discharge function is the concern related to safety, when AC power is disconnected. If the capacitance of X-capacitors connected in the equipment is above a certain value, it would result in a noncompliance with the requirements for plug discharge in IEC 60950-1 Clause 2.1.1.7 / IEC 60065 Clause 9.1.6.

IEC TC108 HBSDT agreed to include requirements for IC including capacitor discharge function (ICX) to the FDIS for IEC 62368-1 ed2.0. The Decision above is in accordance with this.

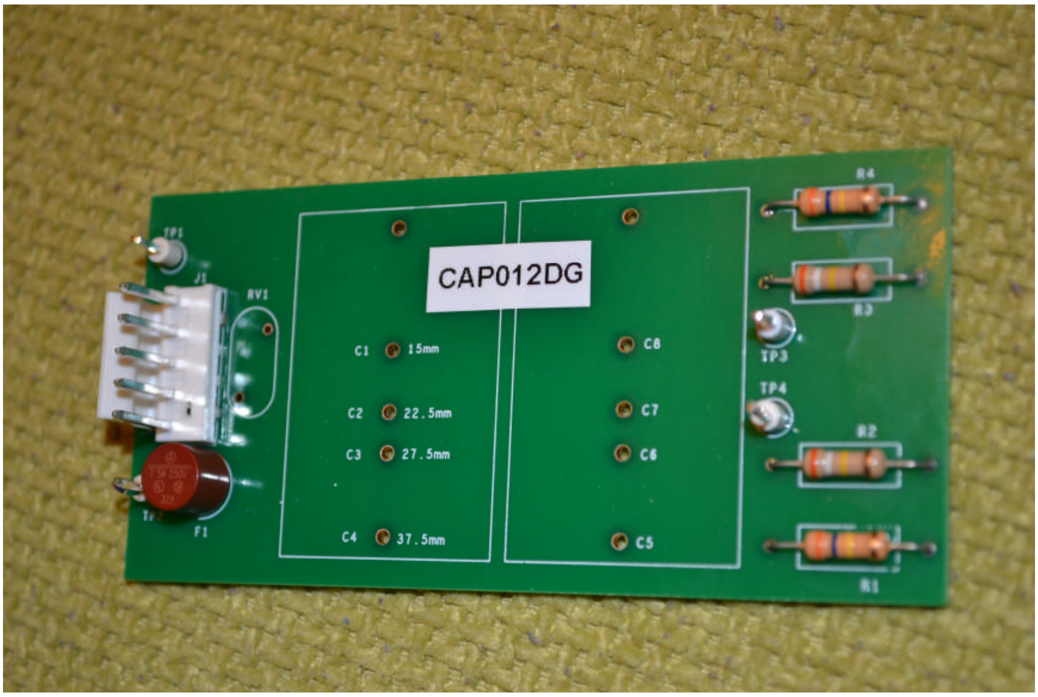
Amd.2 to IEC 60950-1 ed2.0 and IEC 60065 ed8.0 (assumed to be the last updates to these std.) do not include these requirements. IEC TC108 MT1/MT2 has therefore been asked to confirm this CTL proposal.

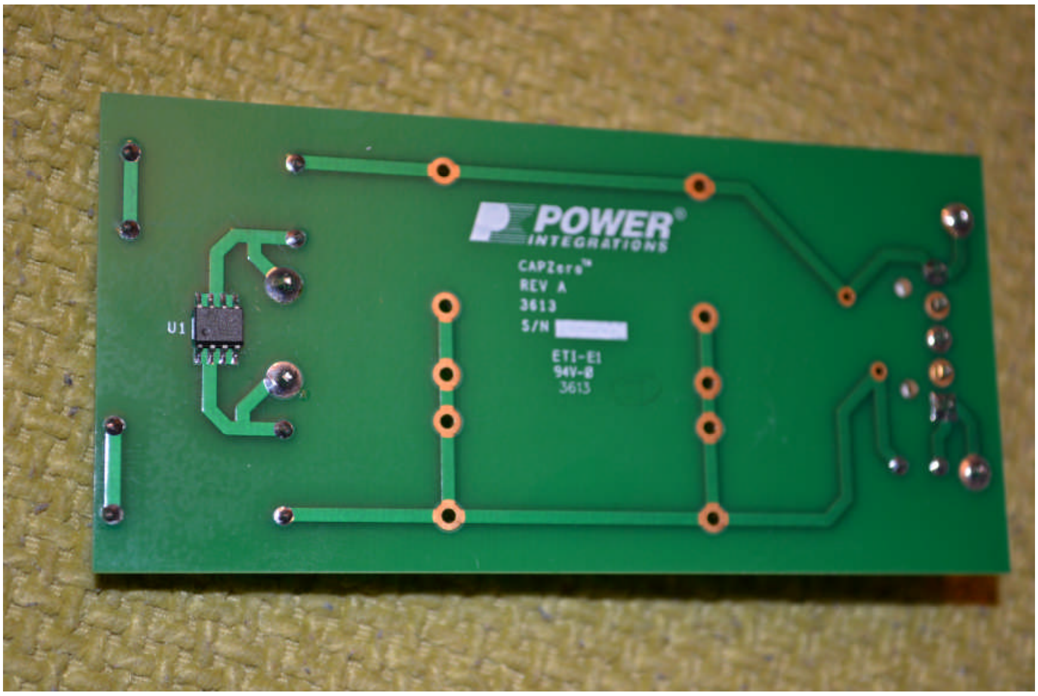
Recommendation by IEC TC108 MT1/MT2, 10 May 2013

The TC108 management discussed the issue and feels that the approach to use the requirements from the latest draft IEC 62368-1, edition 2 is very reasonable. It is also in line with the statements in the drafts of IEC 60065 and IEC 60950-1 that allow components and subassemblies to be used that are evaluated according to IEC 62368-1.

Photos

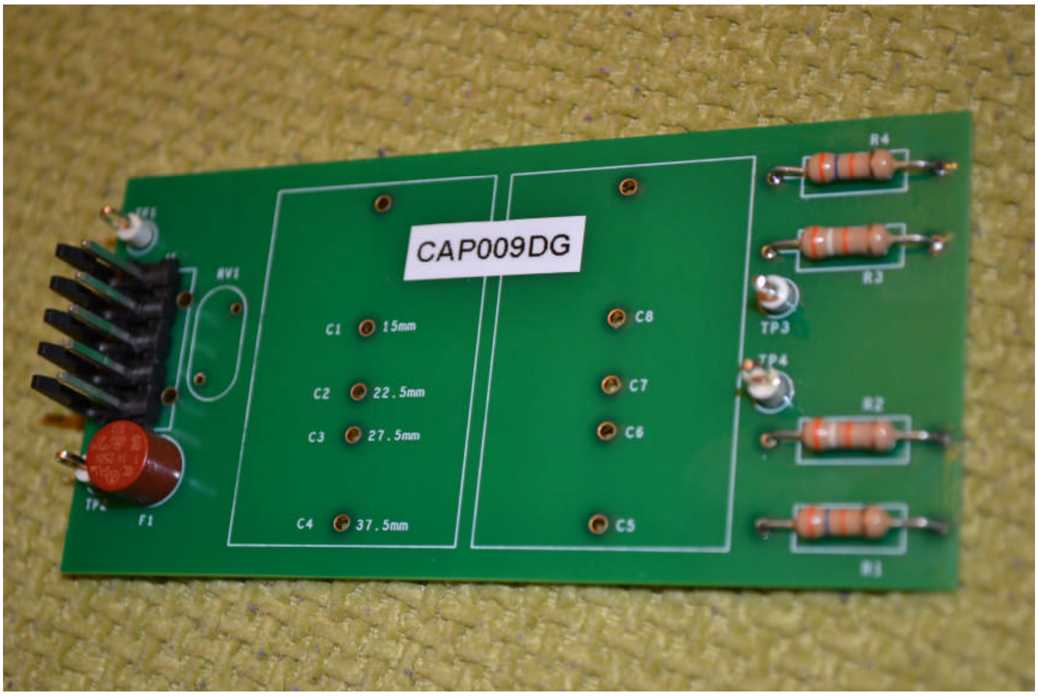
Report No. 246038

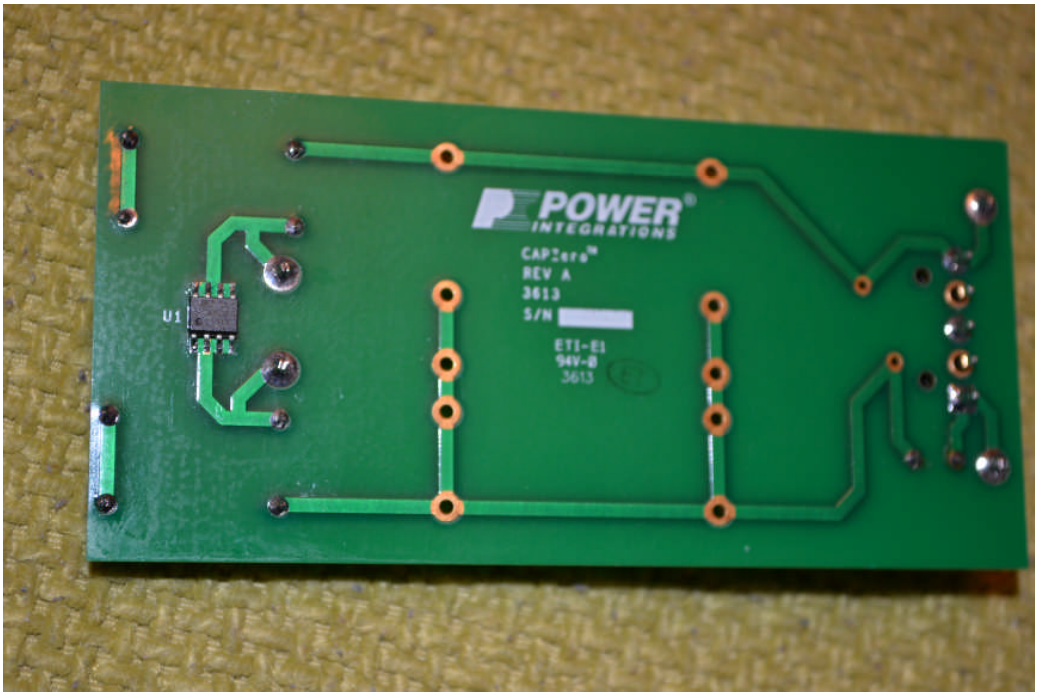




Photos

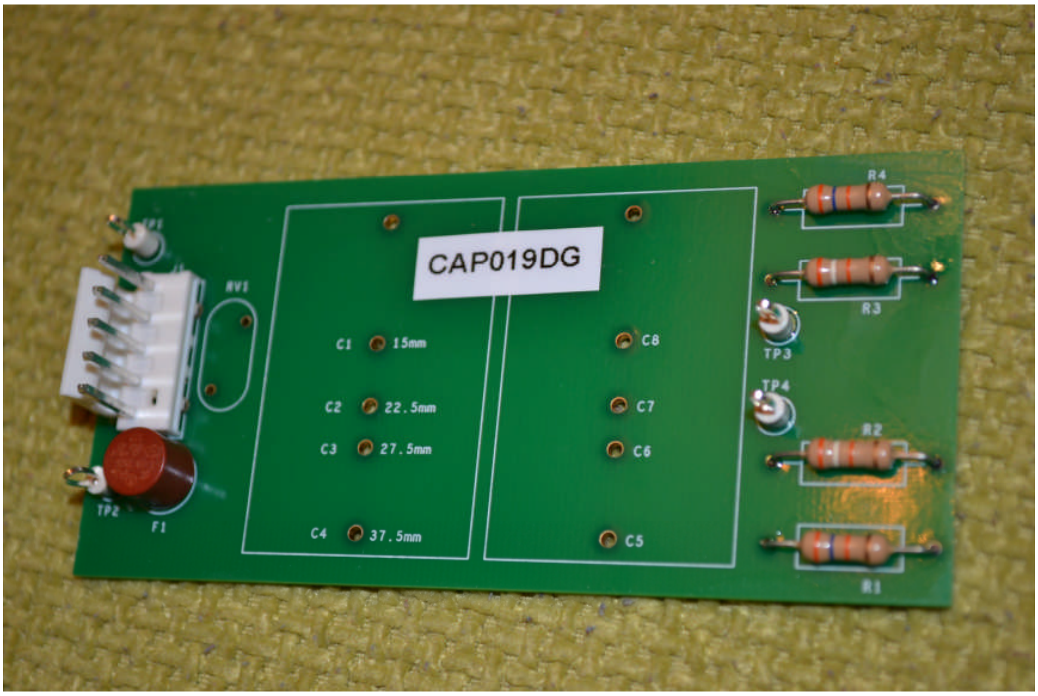
Report No. 246038

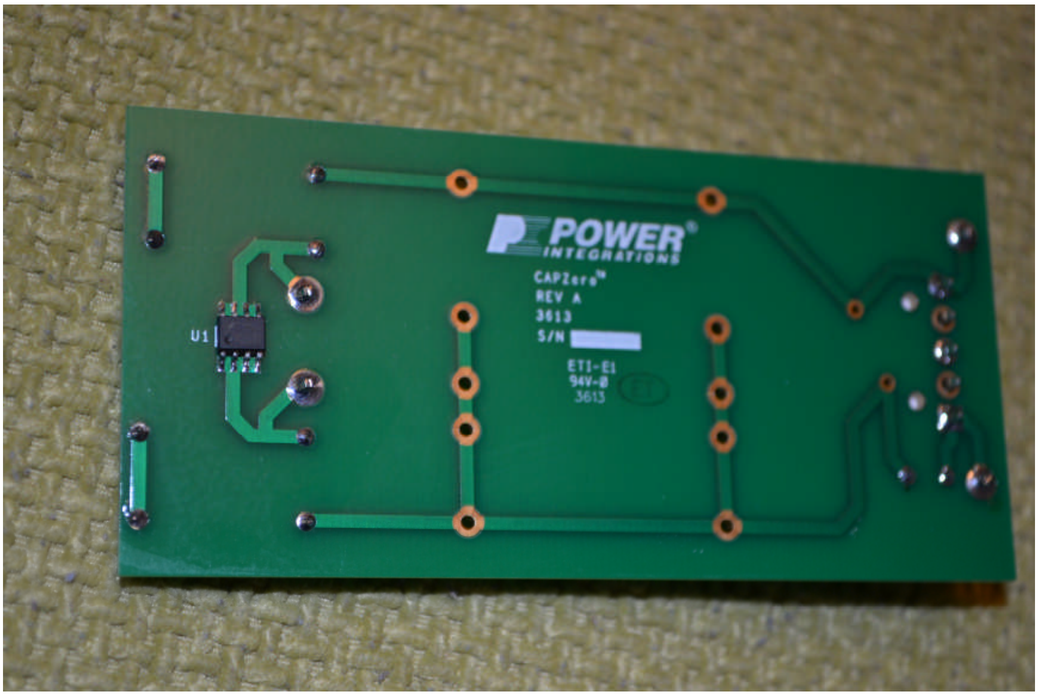




Photos

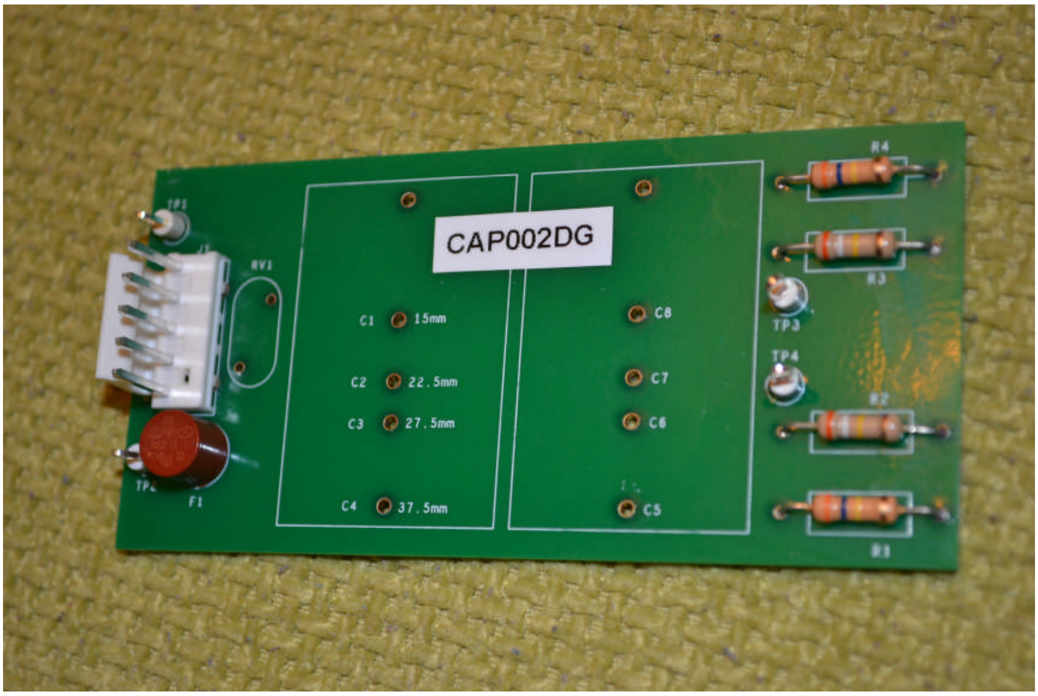
Report No. 246038

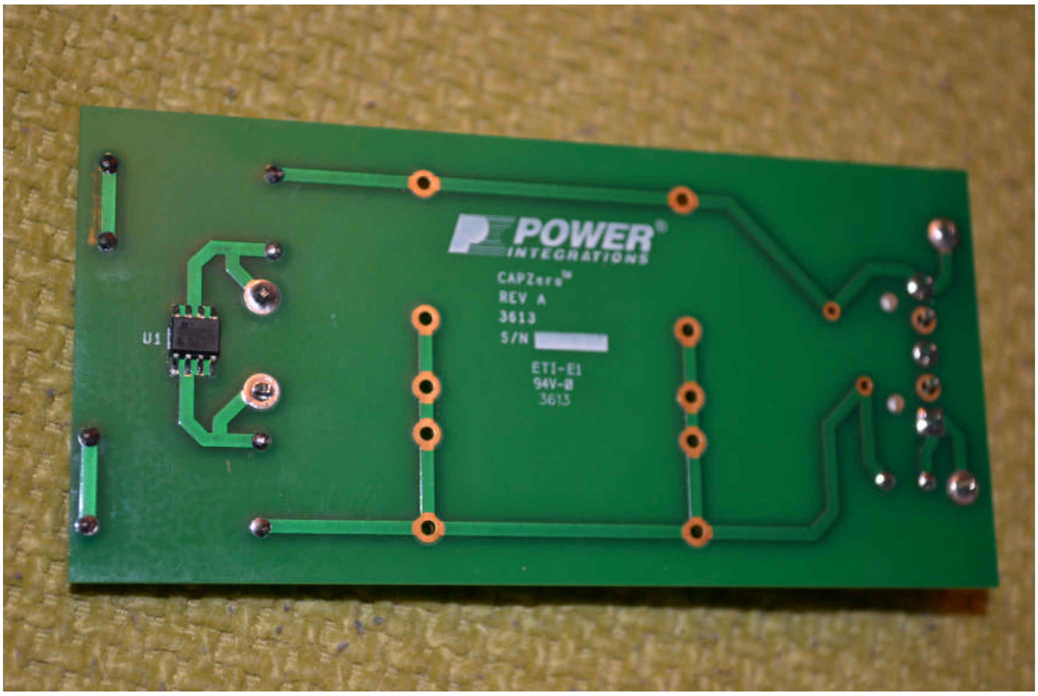




Photos

Report No. 246038

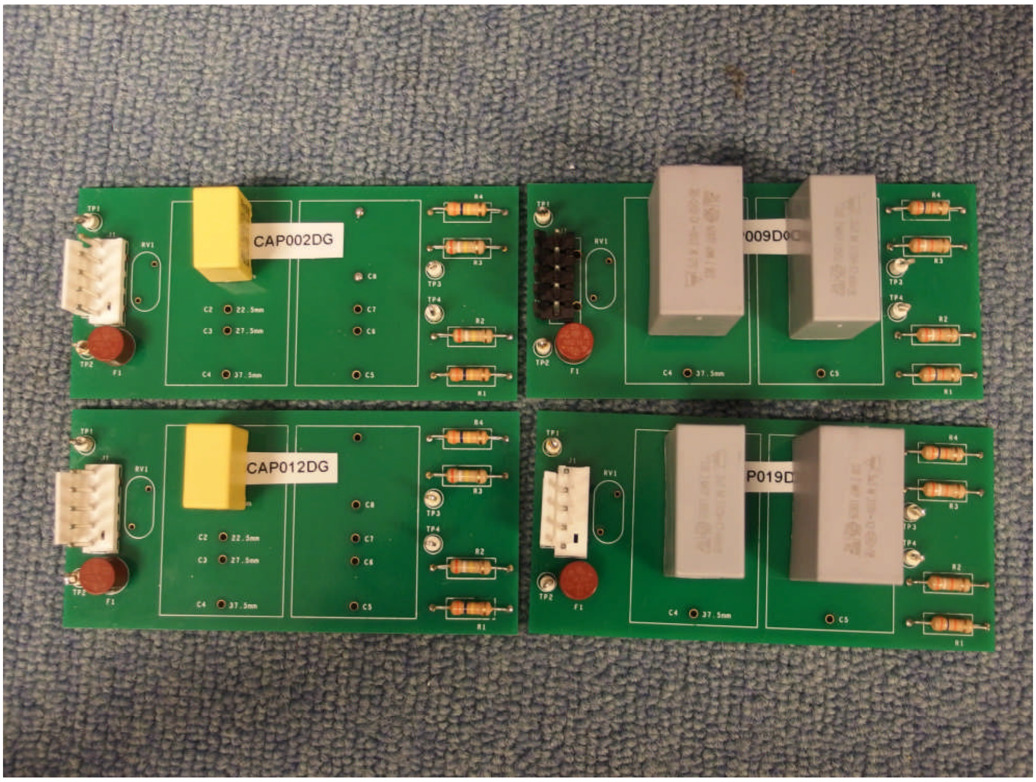




Photos

Report No. 246038

X-capacitors mounted during discharge tests:



Data sheet

Report No. 246038

CAPZero™ Family

POWER INTEGRATIONS

Zero[1] Loss Automatic X Capacitor Discharge IC

Product Highlights
- Blocks current through X capacitor discharge resistors when AC voltage is connected
- Automatically discharges X capacitors through discharge resistors when AC is disconnected
- Simplifies EMI filter design – larger X capacitor allows smaller inductive components with no change in consumption
- Only two terminals – meets safety standards for use before or after system input fuse
- >4 mm creepage on package and PCB
- Self supplied – no external bias required
- High common mode surge immunity – no external ground connection
- High differential surge withstand – 1000 V internal MOSFETs

EcoSmart® – Energy Efficient
- <5 mW consumption at 230 VAC for all X capacitor values

Applications
- All ACDC converters with X capacitors >100 nF
- Appliances requiring EuP Lot 6 compliance
- Adapters requiring ultra low no-load consumption
- All converters requiring very low standby power

Description

When AC voltage is applied, CAPZero blocks current flow in the X capacitor safety discharge resistors, reducing the power loss to less than 5 mW, or essentially zero[1] at 230 VAC. When AC voltage is disconnected, CAPZero automatically discharges the X capacitor by connecting the series discharge resistors. This operation allows total flexibility in the choice of the X capacitor to optimize differential mode EMI filtering and reduce inductor costs, with no change in power consumption.

Designing with CAPZero is simply a matter of selecting the appropriate CAPZero device and external resistor values in Table 1 for the X capacitor value being used. This design choice will provide a worst case RC time constant, when the AC supply is disconnected, of less than 1 second as required by international safety standards.

The simplicity and ruggedness of the two terminal CAPZero IC makes it an ideal choice in systems designed to meet EuP Lot 6 requirements.

The CAPZero family has two voltage grades: 825 V and 1000 V. The voltage rating required depends on surge requirement and circuit configuration of the application. See Key Applications Considerations section for details.

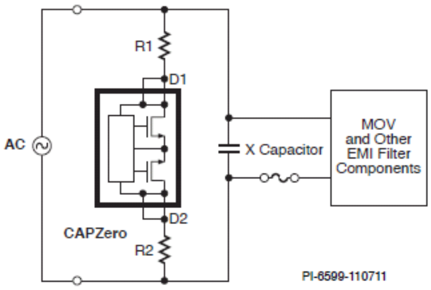


Figure 1. Typical Application – Not a Simplified Circuit.

Component Selection Table

Product[3]	BV_{DSS}	Maximum Total X Capacitance	Total Series Resistance[2] (R1 + R2)
CAP002DG	825 V	≤ 500 nF	1.5 MΩ
CAP012DG	1000 V		
CAP003DG	825 V	750 nF	1.02 MΩ
CAP013DG	1000 V		
CAP004DG	825 V	1 μF	780 kΩ
CAP014DG	1000 V		
CAP005DG	825 V	1.5 μF	480 kΩ
CAP015DG	1000 V		
CAP006DG	825 V	2 μF	360 kΩ
CAP016DG	1000 V		
CAP007DG	825 V	2.5 μF	300 kΩ
CAP017DG	1000 V		
CAP008DG	825 V	3.5 μF	200 kΩ
CAP018DG	1000 V		
CAP009DG	825 V	5 μF	150 kΩ
CAP019DG	1000 V		

Table 1. Component Selection Table.

Notes:
1. IEC 62301 clause 4.5 rounds standby power use below 5 mW to zero.
2. Values are nominal. RC time constant is <1 second with ±20% X capacitor and ±5% resistance from these nominal values.
3. Packages: D: SO-8.

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Pin Functional Description

The pin configuration of Figure 2 ensures that the width of the SO-8 package is used to provide creepage and clearance distance of over 4 mm.

Although electrical connections are only made to pins 2, 3, 6 and 7, it is recommended that pins 1-4 and pins 5-8 are coupled together on the PCB – see Applications Section.

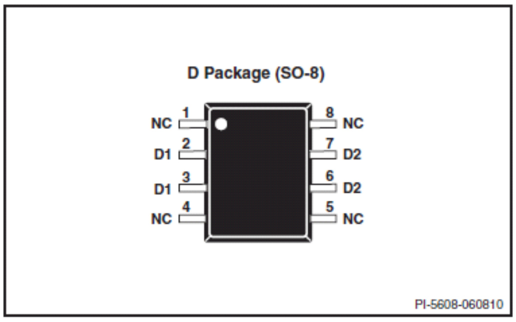

Figure 2. Pin Configuration.

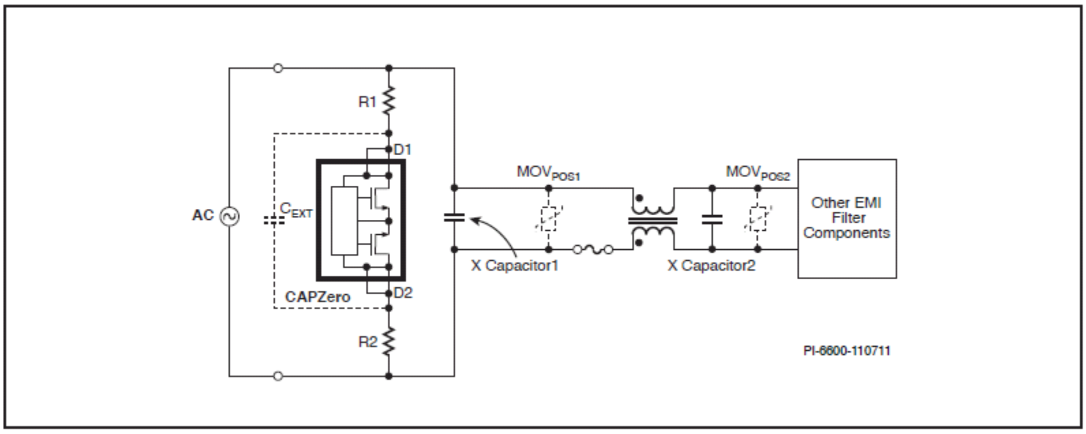

Figure 3. Placement Options of MOV and C_{EXT}.

Key Application Considerations

Breakdown Voltage Selection

Figure 3 illustrates possible system configurations influencing the choice of CAPZero breakdown voltage. The system configuration variables include the placement of the system MOV and X capacitor(s) as well as the differential surge voltage specifications of the application.

As shown in Table 1, each device in the CAPZero family has a 825 V or 1000 V option. For applications where the system MOV is placed in position 1 (MOV_{POS1} in Figure 3), the 825 V option will typically provide adequate voltage withstand for surge requirements up to 3 kV or more. The 1 kV CAPZero would be recommended for higher surge requirements or if additional voltage margin is required.

For MOV placement that is not directly across the X Capacitor1 (for example MOV_{POS2} in Figure 3) the 1000 V CAPZero devices can be used up to a surge specification of 1.5 kV. For differential surge voltage specifications of >1.5 kV it is recommended that the MOV is always placed in the location shown in Figure 3 as MOV_{POS1}.

It is always recommended that the peak voltage between terminals D1 and D2 of CAPZero is measured during surge tests in the final system. Measurements of peak voltage across CAPZero during surge tests should be made with oscilloscope probes having appropriate voltage rating and using an isolated supply to the oscilloscope to avoid ground currents influencing measurement results. When making such measurements, it is recommended that 50 V engineering margin is allowed below the breakdown voltage specification (for example 950 V with the 1000 V CAPZero).

If the measured peak Drain voltage exceeds 950 V, an external 1 kV ceramic capacitor of value up to 47 pF can also be placed between D1 and D2 terminals to attenuate the voltage applied between the CAPZero terminals during surge. This optional external capacitor placement is shown as C_{EXT} in Figure 3. It should be noted that use of an external capacitor in this way will increase power consumption slightly due to the C_{EXT} charge/discharge currents flowing in R1 and R2 while AC is connected. A C_{EXT} value of 33 pF will add approximately 0.5 mW at 230 VAC, 50 Hz.

PCB Layout and External Resistor Selection

Figure 4 shows a typical PCB layout configuration for CAPZero. The external resistors in this case are divided into two separate surface mount resistors to distribute loss under fault conditions – for example where a short-circuit exists between CAPZero terminals D1 and D2. R1 and R2 values are selected according to Table 1.

Under a fault condition where CAPZero terminals D1 and D2 are shorted together, each resistor will dissipate a power that can be calculated from the applied AC voltage and the R1 and R2 values. For example in an application using CAP004 or CAP014, R1=R2=390 kΩ. If CAPZero is shorted out at 265 VAC R1 and R2 will each dissipate 45 mW.

Resistors R1 and R2 should also be rated for 50% of the system input voltage again to allow for the short-circuitry of CAPZero D1 to D2 pins during single point fault testing.

If lower dissipation or lower voltage across each resistor is required during fault tests, the total external resistance can be divided into more discrete resistors, however the total resistance must be equal to that specified in Table 1.

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CAPZero Family

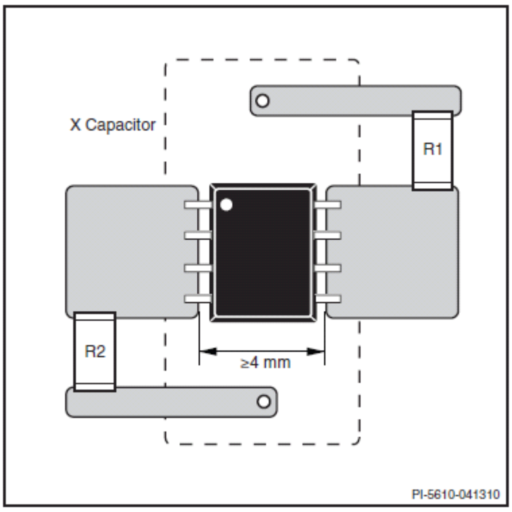

Figure 4. Typical PCB Layout.

Safety

CAPZero meets safety requirements even if placed before the system input fuse. If a short-circuit is placed between D1 and D2 terminals of CAPZero, the system is identical to existing systems where CAPZero is not used.

With regard to open circuit tests, it is not possible to create a fault condition through a single pin fault (for example lifted pin test) since there are two pins connected to each of D1 and D2. If several pins are lifted to create an open circuit, the condition is identical to an open circuit X capacitor discharge resistor in existing systems where CAPZero is not used. If redundancy against open circuit faults is required, two CAPZero and R1 / R2 configurations can be placed in parallel.

Discharge Operation

To meet the safety regulations, when the AC supply is disconnected, CAPZero will discharge the X capacitor to the safety extra low voltage (SELV) levels according to the above functional description. Although there are no specific safety requirements below SELV, CAPZero still continues the discharge until the X capacitor is fully discharged. As such CAPZero can be safely used at low input voltages such as the common industrial 18 VAC and 24 VAC supply rails while retaining X capacitor discharge when the AC source is disconnected.

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Absolute Maximum Ratings[4]

DRAIN Pin Voltage[1]	CAP002-CAP009	825 V
	CAP012-CAP019	1000 V
DRAIN Peak Current[2]	CAP002/CAP012	0.553 mA
	CAP003/CAP013	0.784 mA
	CAP004/CAP014	1.026 mA
	CAP005/CAP015	1.667 mA
	CAP006/CAP016	2.222 mA
	CAP007/CAP017	2.667 mA
	CAP008/CAP018	4.000 mA
	CAP009/CAP019	5.333 mA
Storage Temperature		-65 °C to 150 °C
Lead Temperature[3]		260 °C
Operating Ambient Temperature		-10 °C to 105 °C
Maximum Junction Temperature		-10 °C to 110 °C

Notes:
1. Voltage of D1 pin relative to D2 pin in either polarity.
2. The peak DRAIN current is allowed while the DRAIN voltage is simultaneously less than 400 V.
3. 1/16 in. from case for 5 seconds.
4. The Absolute Maximum Ratings specified may be applied one at a time without causing permanent damage to the product. Exposure to Absolute Maximum Rating conditions for extended periods of time may affect product reliability.

Parameter	Symbol	Conditions T_A = -10 to 105 °C (Unless Otherwise Specified)	Min	Typ	Max	Units
Control Functions						
AC Removal Detection Time	t_{DETECT}	Line Cycle Frequency 47-63 Hz		22	31.4	ms
Drain Saturation Current[A,B]	I_{DSAT}	CAP002/012	0.25			mA
		CAP003/013	0.37			
		CAP004/014	0.48			
		CAP005/015	0.78			
		CAP006/016	1.04			
		CAP007/017	1.25			
		CAP008/018	1.88			
		CAP009/019	2.5			
Supply Current	I_{SUPPLY}	T_A = 25 °C			21.7	μA

Notes
A. Saturation current specifications ensure a natural RC discharge characteristic at all voltages up to 265 VAC pk with the external resistor values specified in Component Selection Table 1.
B. Specifications are guaranteed by characterization and design.

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CAPZero Family

Typical Performance Characteristics

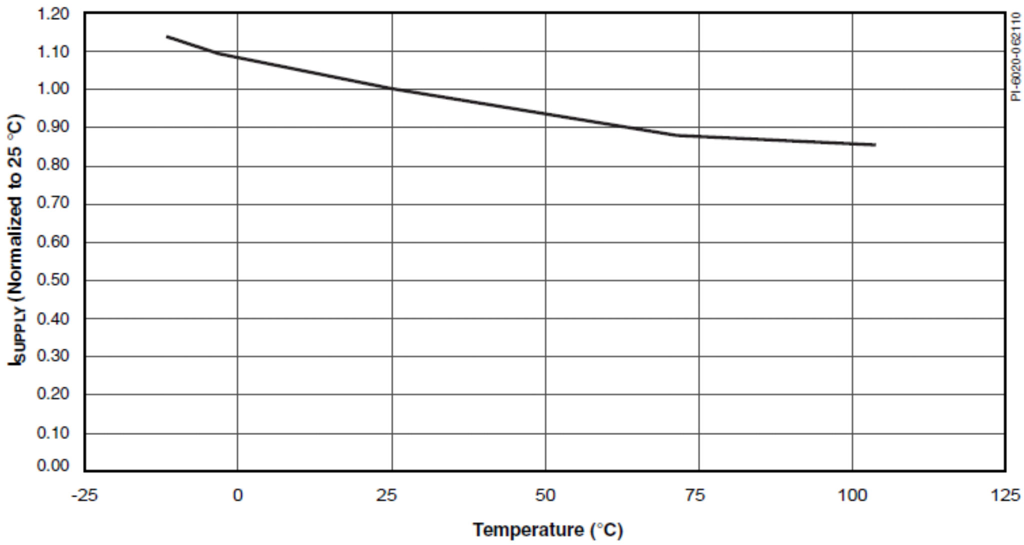

Figure 5. I_{SUPPLY} vs. Temperature.

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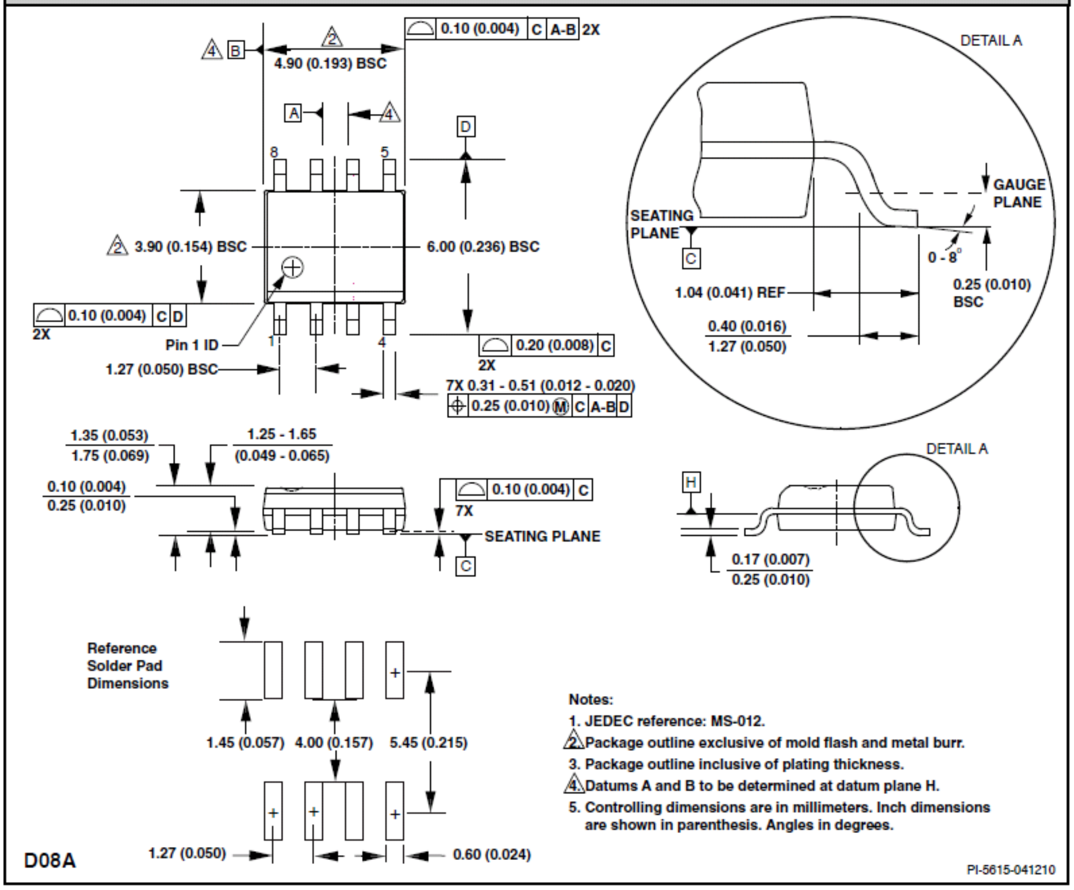
SO-8 (D Package)



Notes:

1. JEDEC reference: MS-012.
2. Package outline exclusive of mold flash and metal burr.
3. Package outline inclusive of plating thickness.
4. Datums A and B to be determined at datum plane H.
5. Controlling dimensions are in millimeters. Inch dimensions are shown in parenthesis. Angles in degrees.

Part Ordering Information

CAP 002 D G - TL

- CAPZero Product Family
- 002 Series Number
- Package Identifier
  - D | Plastic SO-8
- Package Material
  - G | GREEN: Halogen Free and RoHS Compliant
- Tape & Reel and Other Options
  - Blank | Standard Configurations
  - TL | Tape & Reel, 2.5 k pcs.

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Revision	Notes	Date
A	Code A release.	04/14/10
B	Updated I_{SUPPLY} condition. Added figure 5. Parameter T_{DETECT} was updated.	06/08/10
C	Updated Table 1. Updated Note 1 in Table 1. Added "Discharge Operation" paragraph. Updated Absolute Maximum Ratings Table.	02/11
C	Added Maximum Junction Temperature specification.	04/11
D	Updated Figures 1 and 3.	11/07/11

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Application note

Report No. 246038

Application Note AN-48
CAPZero™ Family

Design Considerations

Introduction

CAPZero is a family of self powered ICs designed to reduce the losses associated with the input filter capacitor discharge resistors when the AC voltage is present. Designed to be connected in series with existing discharge resistors each CAPZero device contains an integrated loss of AC detector and back-to-back MOSFETs in an SO-8 package.

When the AC input voltage is present, CAPZero remains in an OFF state, blocking current flow in the discharge path and eliminating power losses. When the AC is removed the CAPZero turns on, thereby switching in the resistors and allowing discharge of the input filter capacitance. CAPZero is self powered from the AC line with a power consumption of less than 5 mW at 230 VAC.

Given the small footprint of the package, it is possible to place the CAPZero IC on the bottom side of the printed circuit board (PCB) directly beneath the X capacitor. This eliminates the need for a major redesign of the PCB allowing existing designs to quickly benefit from reduced power consumption.

Background

Applications that contain off-line switching power electronics, for example motor drives, domestic appliances, industrial equipment and power supplies in general, have high voltage and high current switching waveforms that generate Electro Magnetic Interference (EMI).

To reduce this electro magnetic interference (EMI) a filter stage is included at the AC input (Figure 1). As part of this filter, capacitors are commonly placed directly across the AC input terminals to reduce differential mode EMI. Due to their location safety agency recognized X class capacitors are typically selected. X capacitors are rated to withstand the line surges that appear across the AC line with the numerical suffix indicating the specific voltage rating (X1, X2 or X3).

As the capacitor appears across the input terminals a voltage, up the peak of the incoming AC, can appear across the input prongs of the AC plug. This could potentially cause an electric shock to the user if touched or sparks should the prongs of the AC plug be shorted.

To prevent these risks once the supply is unplugged, safety agencies mandate that capacitance values above 100 nF be discharged automatically with a time constant of <1 second. Typically this is achieved by placing discharge resistors directly across the capacitor. The value of the resistance is selected to meet the 1 second time constant requirement and two resistors are usually connected in series to meet safety agency single point failure testing. Should one resistor become shorted then the presence of the second prevents a short circuit across the AC input.

The presence of discharge resistors results in a constant power loss while AC is applied. With more stringent no-load and standby input power requirements, this power loss has become a significant portion of the overall power budget. For example, a power supply that uses a capacitance of 1 μF across the incoming AC will require a maximum discharge resistance value of 1 MΩ which dissipates 53 mW at 230 VAC independent of the output load. Figure 2 shows typical dissipation in the discharge resistors as a function of the X capacitor value with a 0.75 second RC time constant. The value of 0.75 seconds provides margin to account for capacitor and resistor tolerances such that the maximum time constant is <1 second.

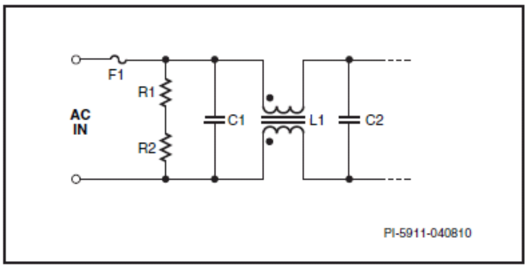

Figure 1. Example EMI Filter Stage of a Switching Power Converter Using Two X Class Capacitors (C1, C2) and Discharge Resistors (R1, R2).

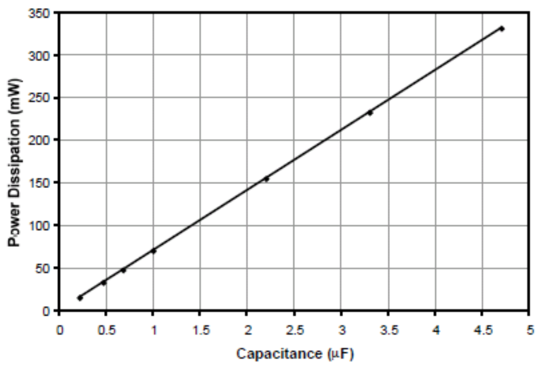

Figure 2. Losses in X Capacitor Discharge Resistors vs Line Voltage. Data Plotted for RC Time Constant of 0.75 Seconds.

Application note

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Quick Start

Step – 1 Selecting the Correct CAPZero Device Size and Discharge Resistor Value

Select CAPZero device and discharge resistors from Table 1 based on the total input stage capacitance. Table 1 accounts for 5% tolerance of resistors and a 20% tolerance of the total capacitance by using a RC time constant of 0.75 seconds.

Component Selection Table

Product	BV_{DSS}	Max Total X Capacitance	Total Series Resistance (R1 + R2)
CAP002DG	825 V	500 nF	1.5 MΩ
CAP012DG	1000 V		
CAP003DG	825 V	750 nF	1.02 MΩ
CAP013DG	1000 V		
CAP004DG	825 V	1 μF	780 kΩ
CAP014DG	1000 V		
CAP005DG	825 V	1.5 μF	480 kΩ
CAP015DG	1000 V		
CAP006DG	825 V	2 μF	360 kΩ
CAP016DG	1000 V		
CAP007DG	825 V	2.5 μF	300 kΩ
CAP017DG	1000 V		
CAP008DG	825 V	3.5 μF	200 kΩ
CAP018DG	1000 V		
CAP009DG	825 V	5 μF	150 kΩ
CAP019DG	1000 V		

Table 1. Component Selection Table.

Step 2 – Selecting the Appropriate CAPZero Voltage Rating

CAPZero is available in two voltage ratings, 825 V and 1 kV. The 825 V rating is ideal for most consumer applications with Metal Oxide Varistor (MOV) located in position 1 (see Figure 5 for MOV_{POS1}), where the differential line surge requirement is up to 3 kV. CAPZero devices with a 1 kV rating are applicable for <1 kV level without MOV, and for >3 kV with MOV at position 1 together with an optional external ceramic capacitor C_{EXT} to lower the surge stress voltage. For applications with no MOV for >1 kV and up to 3 kV level, either a 825 V or 1 kV rated part can be used depending on measured surge voltage across the CAPZero together with an external ceramic capacitor C_{EXT} of up to 47 pF.

Differential Mode	CAPZero Voltage			Comments
	MOV_{POS1}	MOV_{POS2}	No MOV	
<1 kV	825 V		1000 V	C_{EXT} up to 47 pF, 1 kV increases Drain voltage margin
1 to 1.5 kV	825 V	1000 V	825 V or 1000 V with C_{EXT}	
1.5 to 3 kV	825 V	825 V or 1000 V with C_{EXT}		
>3 kV	825 V or 1000 V + C_{EXT} (option)	Not Recommended		

Table 2. Selection of CAPZero Voltage Ratings vs Differential Surge Withstand Requirement. See Figure 5 for MOV position.

Tips for Design

Recommended Circuit Locations for CAPZero

For differential surge levels above 1 kV the use of a MOV is recommended. The presence of the MOV substantially reduces the voltage stress on both the X capacitor as well as the CAPZero. This can be seen from Figure 3 which shows the maximum voltage across the CAPZero device with differential surge voltages ranging from 1 kV to 3 kV.

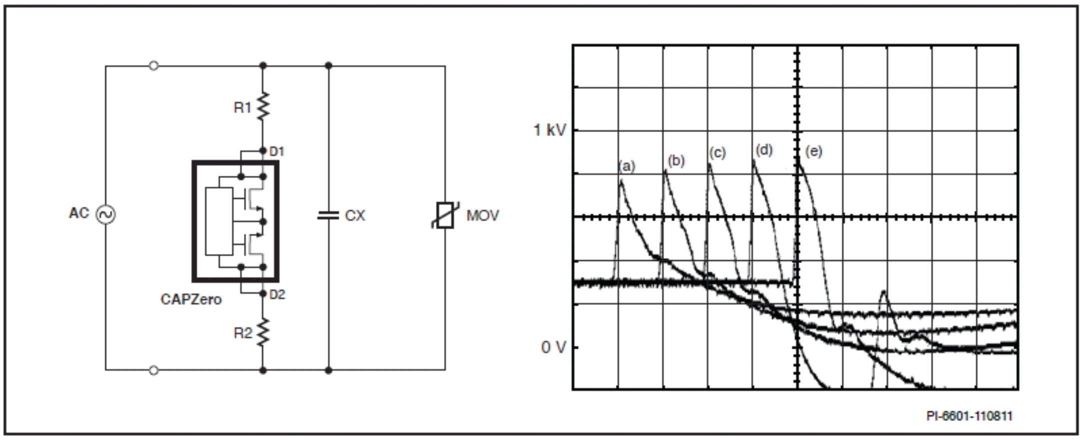

Figure 3. Recommended Position of CAPZero for a Single Stage EMI Filter. Waveforms Show Peak Voltage Across CAPZero in Presence of MOV. 200 V / Division and Time Base = 50 μs / div. Waveforms (a) Through (e) Represent Voltage Measured Across the CAPZero Device Under Differential Mode Input Surge Voltages of 1, 1.5, 2, 2.5 and 3 kV Respectively. MOV Used was 14 mm 275 VAC.

As large currents flow through the MOV when it is clamping there can be significant voltage drops across filter components in the input stage. Therefore it is recommended that the CAPZero be located close to the MOV to minimize the voltage across the device during differential surge events. For designs where the MOV is placed at the input side of the power supply (Figure 3), before any inductive filter components, the CAPZero can be placed directly underneath the X capacitor. For designs where the MOV is placed after a common-mode choke, differential choke or other EMI filter components (Figure 4), it is recommended that if possible the CAPZero also be placed after the common mode choke and be physically close to the MOV allowing the 825 V device to be used up to 3 kV differential surge. If CAPZero cannot be placed after the common mode choke, the 1000 V device is recommended up to a surge level of 1.5 kV. For surge levels greater than 1.5 kV, it is always recommended to have the MOV located on the same side of the common-mode choke as the CAPZero.

One exception is if the X capacitor is on the AC input side of a system input fuse. In these cases if the X capacitor is greater than 100 nF, to meet safety requirements, the CAPZero must typically also be placed before the system input fuse directly across the X capacitor and voltage ratings. CAPZero is designed to meet safety requirements in this position – see 'Safety Considerations' section below.

Adding an External Parallel Capacitor to Reduce CAPZero Voltage Stress

While the use of a MOV is recommended, an external capacitor C_{EXT} (Figure 5) may be placed across the CAPZero to reduce surge voltage stress and may be sufficient in some design. This capacitor does not have to be an X class type, since it is not directly placed across the AC input terminals, but should be rated at or above the CAPZero being used. Figure 6 shows the effect of adding external capacitance directly across a CAPZero device in a design without a MOV. With no external capacitor at

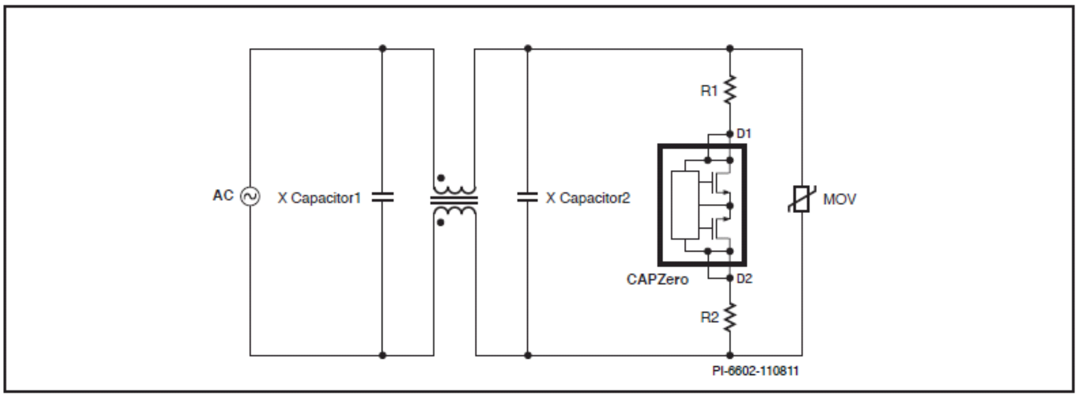

Figure 4. Recommended Location of CAPZero for a Two Stage EMI Filter With a MOV Located After Input Common Mode Choke.

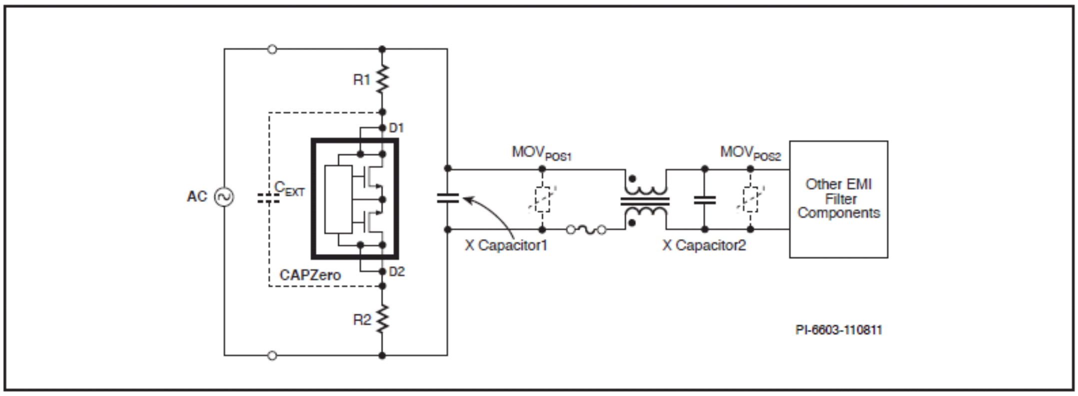

Figure 5. The Addition of an External Capacitor Across the CAPZero can Reduce Voltage Stress Across the Device During a Surge Event.

Application note

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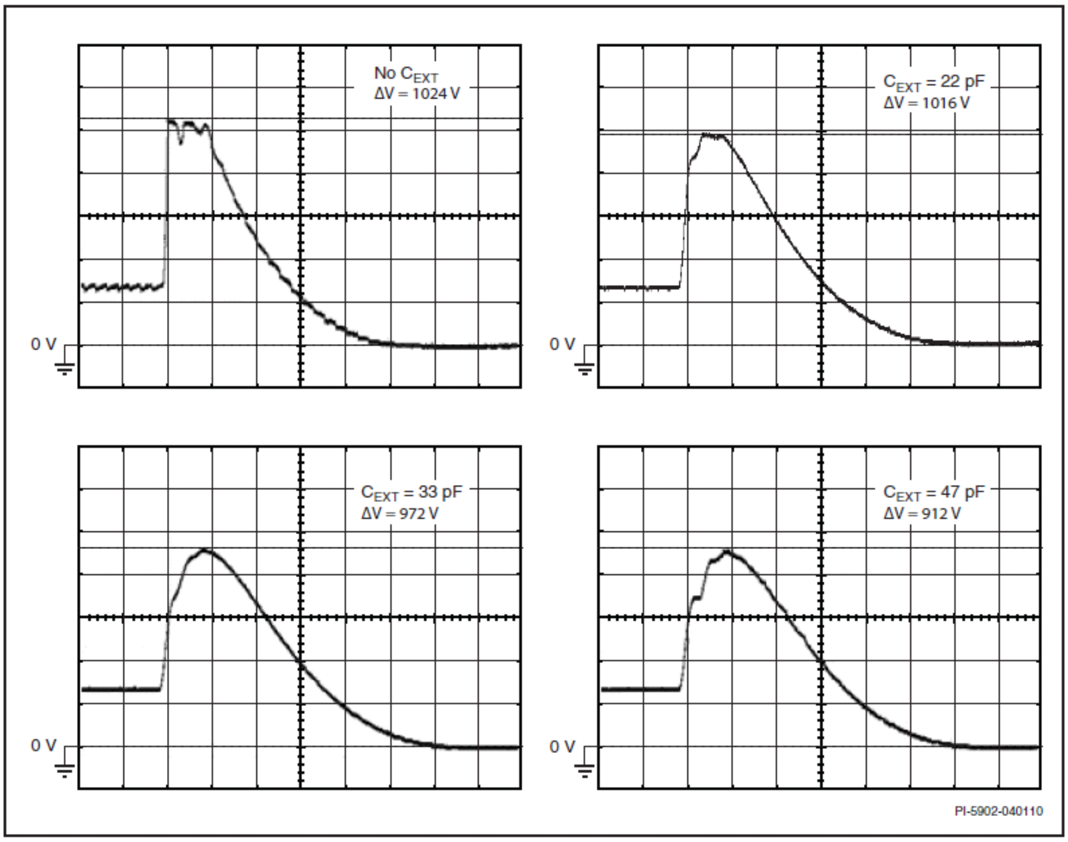

Figure 6. External Capacitor Placed Across CAPZero May Reduce Peak Voltage During Surge Event. No MOV present, 1.5 kV surge. 200 V / div., Time Base = 50 µs / div.

a 1.5 kV surge level, the CAPZero device exceeds its BV_{DSS} rating however as the value of C_{EXT} is increased to voltage level reduces.

Recommended values of C_{EXT} are between 22 pF and 47 pF. The use of 47 pF capacitor is not recommended in applications where the ambient temperature is in excess of 85 °C. Values above 47 pF are not recommended.

The presence of the external capacitor can for example reduce the voltage stress on the CAPZero by up to 100 V with 2 x 390 kΩ external resistors (1 µF X capacitor) and 47 pF C_{EXT}. It should be also noted that the use of C_{EXT} will cause a slight increase in no load power consumption.

Measuring Device Voltage Stress

To measure the voltage stress across the CAPZero IC during differential line surge testing, it is recommended that the CAPZero be placed such that one terminal (D1 or D2) is connected to AC neutral. This reduces any effects due to common-mode noise. The area between the oscilloscope probe tip and the ground lead should be minimized. Finally it is necessary to float the oscilloscope or to use a battery powered oscilloscope while performing the surge tests. Please note that if using a floating scope proper care must be exercised as the scope chassis will assume high potential with respect to earth ground.

Application note

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Class	Differential Mode Surge	Common Mode Surge	Comments
	$Z_{OUT} = 2\ \Omega$	$Z_{OUT} = 12\ \Omega$	
1	No requirement	0.5 kV	Protected environment
2	0.5 kV	1 kV	Electrical environment where cables are well separated
3	1 kV	2 kV	Electrical environment where cables (power and electronic) run in parallel (residential environment)
4	2 kV	4 kV	Electrical environment where cables (power and electronic) run in parallel (industrial environment)
5	>2 kV	>4 kV	Severe surge environment (rural/sparsely populated areas)

Table 3. Surge Voltage Levels.

Ensure that the surge voltage measured across the CAPZero device is less than its BV_{DSS} rating.

Surge Severity

The severity of the surge signal is defined in the IEC61000-4-5 standard published by the International Electrotechnical Commission (IEC). The surge voltage levels are described in Table 3 depending on the operating environment of the power supply.

Certain applications may require surge levels higher than those described in Class 4. For surge voltages greater than 3 kV the use of external capacitors across the CAPZero will help reduce voltage stress across its terminals by a few hundreds of volts as discussed above. It should be noted that at higher surge voltages the energy involved is very high and the MOV should be appropriately selected to handle this excess energy. Varistors have a energy rating which should exceed the applied energy to the system to ensure that this energy can be safely absorbed by the MOV.

Use in DC Input Environments

Since CAPZero relies on detecting the AC voltage at the input, under DC input the CAPZero will remain on all the time. This is a perfectly acceptable mode of operation for CAPZero although this operation will remove any energy savings from the use of CAPZero.

Use with Uninterruptable Power Supplies (UPS)

UPS systems often have a pseudo square wave output waveform, which although AC in nature are not sinusoidal. CAPZero can accept this type of input waveform.

Safety Considerations and Single Point Failure Testing

As with all offline power supplies, all safety requirements must

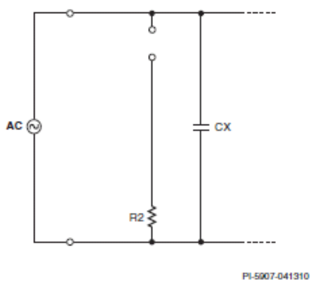
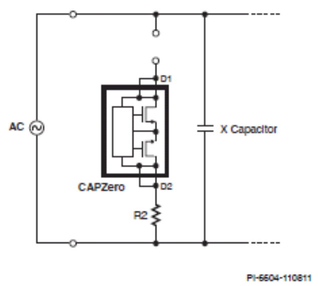
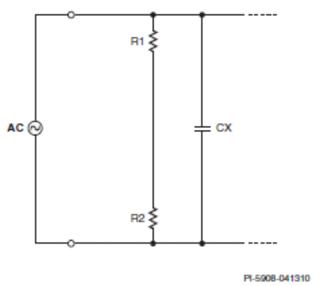
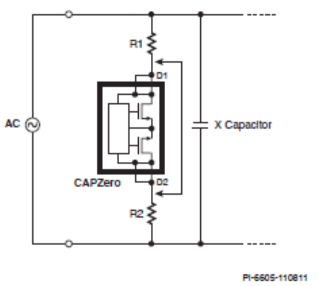
Test	Test With Existing System	CAPZero Equivalent	Comments
Open Circuit: Disconnect one pin of any device to see effect on system			Lifting any one pin of the CAPZero device has no effect as 2 pins are connected to each drain terminal. The only way to create an open circuit is by lifting the leads of one of the discharge resistors. This is therefore equivalent to existing system without CAPZero.
Short Circuit: Short any 2 adjacent pins to see effect on system			Shorting D1 and D2 pins creates a condition equivalent to an existing system not using CAPZero.

Table 4. Single Point of Failure (SPOF) Tests as Pertaining to Failure Modes of CAPZero. CAPZero Passes Both Tests.

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still be met when including CAPZero. To achieve this CAPZero has two dedicated pins for the D1 and D2 terminals which add redundancy during single point of failure testing (pin short / pin open testing). Thus if one pin is physically disconnected from the device or PCB, the IC will continue to function normally. During pin shorting the outcome is the same as if CAPZero had not been used and simply results in the discharge resistors being connected in series continuously; a safe condition. Table 4 summarizes the results of single point fault testing.

Accurate Measurement of No-load Input Power

X capacitors do not consume real power but they to cause a substantial reactive current to flow from the AC source. This reactive current leads to real power loss in the cables that connect the power supply to the AC source and power meter as shown in Figure 7. This cable loss can cause inaccurate measurements of no-load and light load input power. Normally the consumption of the discharge resistors is much larger as compared to this loss. However when CAPZero is used, and this loss is eliminated, the cable loss may become the most dominant component of no-load losses.

Also, at such low levels of input power, the leakage current of the MOV must also be considered. Typically this leakage current is approximately 10 μA and is large enough to increase no-load consumption by 1 – 2 mW at 265 VAC.

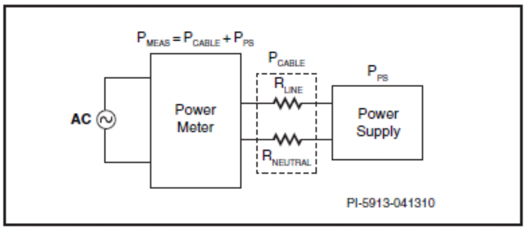

Figure 7. Measured Power can be Misleading Due to Significant RMS Current Resulting in Measurable Power Loss in Cables.

To measure the power consumption of a CAPZero IC, the X capacitor and the MOV (if used) should therefore be physically disconnected from the circuit.

Also ensure that the power meter is configured such that the current drawn by the voltage sensing element is not included in the measurement.

CAPZero Selection for Different X Capacitor Discharge Time Constants

In cases where a faster discharge time constant is required the curves of Figure 8 can be used to the select CAPZero for worst case discharge time constants and X capacitor values ranging

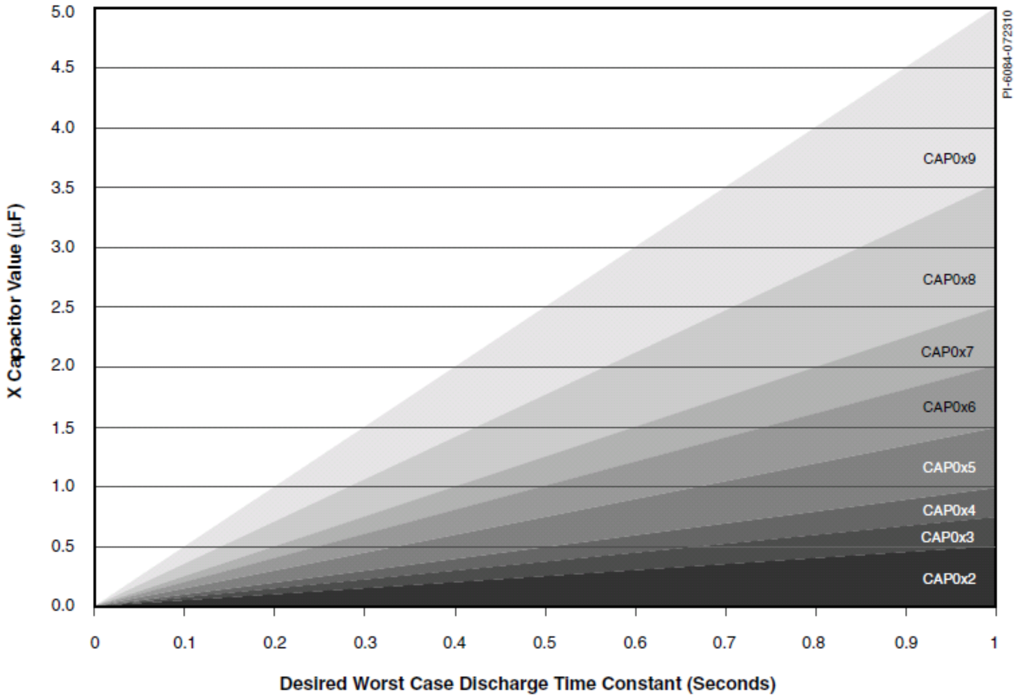

Figure 8. Required Worst Case Discharge Time Constant vs X Capacitor Value.

from 0 to 5 uF. Although safety standards do not generally require discharge resistors for X capacitors values up to 100 nF, data to zero capacitance is included for completeness.

The use of the curves is best demonstrated by an example. Referring to Figure 9, an example is illustrated for a 680 nF X capacitor with a desired worst case discharge time constant of 0.5 seconds. The solid arrows illustrate how the intersection of the 680 nF (on Y axis) and 0.5 seconds (on X axis) provide the CAP0x5 as the correct device. The dotted lines shows the CAP0x3 recommendation as provided on the data sheet which assumes a worst case discharge time constant of 1 second.

The discharge resistor value can be determined from Table 1 based on the required CAPZero. In this example, the CAP0x5 external discharge resistance is 480 kΩ. This choice of external resistance will actually provide a worst case discharge time constant of about 0.45 seconds as illustrated by the dotted arrow in Figure 9. Since this has no impact on the power consumption, it is recommended to use the Table 1 resistor choice for simplicity.

Note that the Y axis of Figures 8 and 9 are the typical X capacitor value. However, the CAPZero recommendations allow for worst case X capacitor and discharge resistor tolerances to provide a worst case discharge time constant as shown on the X axis. Typical discharge time constants will be ~30% lower than this.

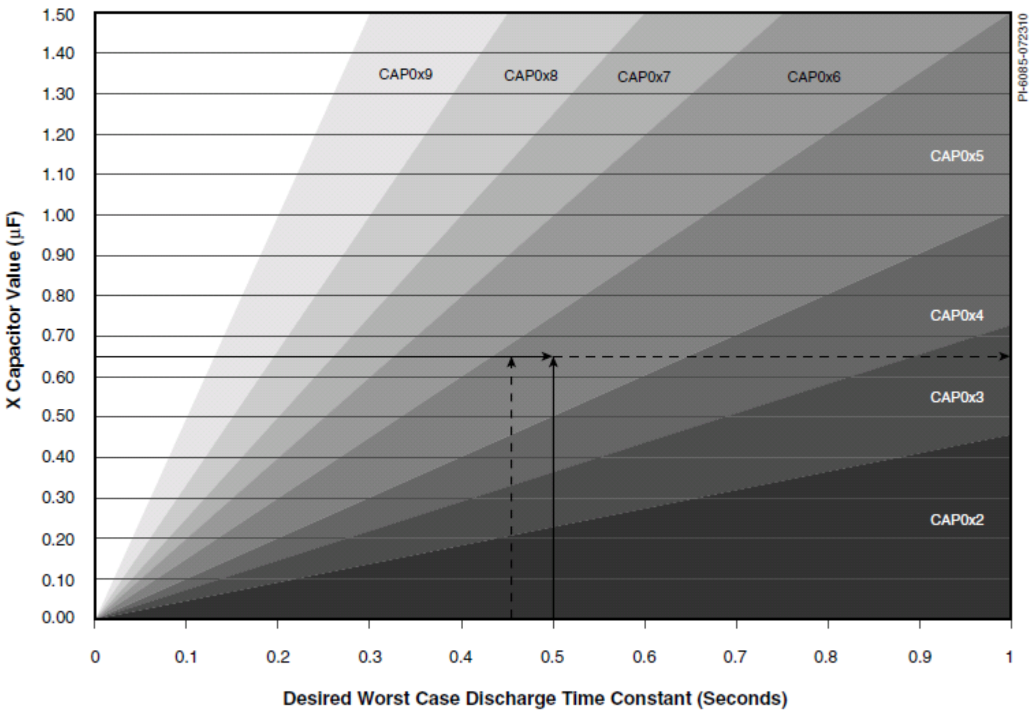

Figure 9. Magnified View of Figure 8 for 0 to 1.5 µF.

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Use of CAPZero for AC Line Voltage Zero-Crossing Detection

Any CAPZero can be used for AC line voltage zero-crossing detection when an AC voltage is present. At the same time it can be used as an X capacitor discharging circuit when the AC voltage is removed. The zero-crossing detection circuit uses CAPZero supply current with no additional power consumption in a non-isolated system (it consumes slightly more power when detector circuit is used in an isolated system).

A simple example of CAPZero used as a zero-crossing detector in a non-isolated application is shown in Figure 10. The zero-crossing signal is generated by a low voltage Zener diode (VR1) which is placed in between the CAPZero device and the AC neutral. The voltage across the Zener is used to drive a small signal MOSFET thereby obtaining the zero crossing signal. Figure 11 shows an example where the zero crossing detection circuit is required with isolation from the input line. While the concept of generating the signal remains the same, an opto-coupler and a bias supply are required for isolation.

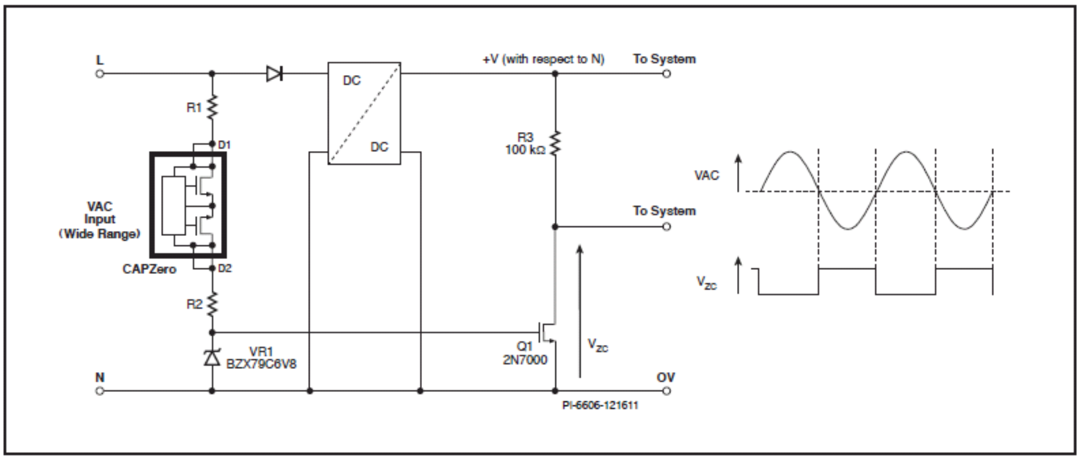

Figure 10. Example of CAPZero for AC Line Voltage Zero-Crossing Detection in a Non-Isolated System.

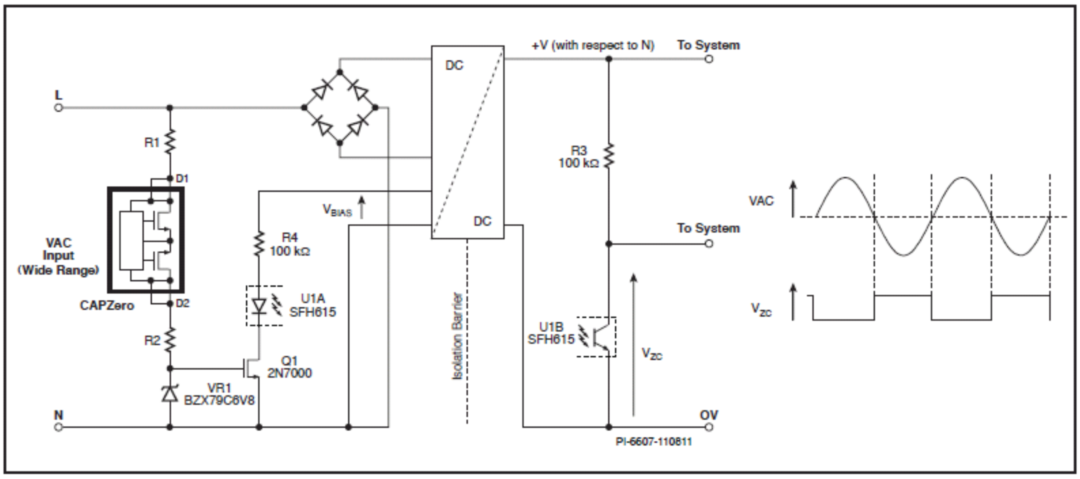

Figure 11. Example of CAPZero for AC Line Voltage Zero-Crossing Detection in an Isolated System.

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Revision	Notes	Date
A	Initial Release	04/14/10
B	Updated Surge Application Information. Added Discharge Resistor Selection Information.	07/28/10
C	Updated Step 2 paragraph and Table 2 on page 2.	9/28/10
D	Updated Figures 3, 4, 5 and Table 4. Added ZCD section.	12/16/11

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