To: Applications Group

From: Peter Vaughan

Date: 14-Apr-16

Revision: B

Re: Minimum PCB spacing for spark gaps in adapter designs

Summary

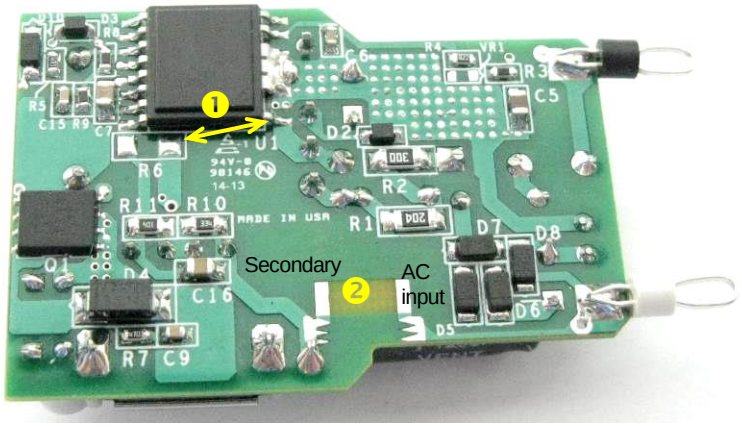
- Minimum spark gap PCB creepage from AC input to secondary side (not primary to secondary where voltages can exceed the AC input)
  - **5 mm** for pollution degree 2 applications with PCB CTI in Material group III, 250 V_{RMS} working voltage
  - **3.6 mm** for pollution degree 2 applications with PCB CTI in Material group II, 250 V_{RMS} working voltage
    - Pollution degree 2 and 2,500 V Transient is appropriate for AC adapters.
    - Material group II PCB material (FR4 variant) is 3-5% more expensive than standard material
- Arcing voltage may be lower when using an in house milled PCB due to sharper edges across the spark gap. Validate critical designs using a production PCBs where etching process results in a smoother surface finish.

Parameter	Spacing (mm)	Pollution Degree	100% Electric Strength Testing	Mains Transient Voltage
Minimum Clearance	4	1, 2 or 3	No	1500 V or 2500 V
	3		Yes	
	6.4		No	4000 V
	6.0		Yes	
Minimum Creepage	5	2 (CTI Group III)	N/A	N/A
	3.6	2 (CTI group II)		
	8	3		

Description

The reliability of the spark gap firing before any other points is so critical this memo was created to record the verification that the spark gap spacing of 5 mm is acceptable for safety or if it could be made smaller.

Testing of InnoSwitch based boards for system level ESD has shown that any primary to secondary arcing must occur away from the InnoSwitch IC. Arcing across the device package, specifically to the drain pin causes destructive failure of the IC.



In the figure above arcing would occur at point 1 for about 2% of applied ESD strikes. This is despite the spacing at (2) being smaller (5 mm) than point (1) (~7.2 mm). This result implies that the spark gap spacing must be at least 2 mm less than spacing from secondary traces and components to the InnoSwitch primary side.

Creepage and Clearance Requirements

All references are to IEC60950 2005 +A1:2009 +A2:2013

Requirements are determined according to IEC60950 Edition 2.2 (2013)

For a spark gap from primary AC to secondary the following assumptions were made:

- AC supply does not exceed 300 V
- The peak voltage across the spark gap during normal operation does not exceed the peak of the AC input voltage
- Pollution degree 2
- Spark gap is required to meet the requirements of reinforced insulation
- PCB falls into Group IIIb (CTI 100 ≤ CTI ≤175) (typical FR4 material)
- Operation to 2000 m above sea level

Clearance in primary circuits (2.10.3.3)

Table 2K provides values for reinforced insulation of **4 mm** (**3 mm** if electric strength test is performed)

2.10.3.3 Clearances in primary circuits

For insulation in PRIMARY CIRCUITS, between PRIMARY CIRCUITS and earth and between PRIMARY CIRCUITS and SECONDARY CIRCUITS, the following rules apply.

For an AC MAINS SUPPLY not exceeding 300 V r.m.s. (420 V peak):

a) if the PEAK WORKING VOLTAGE does not exceed the peak value of the AC MAINS SUPPLY voltage, minimum CLEARANCES are determined from Table 2K;

Table 2K – Minimum clearances for insulation in primary circuits and between primary and secondary circuits

CLEARANCES in mm

PEAK WORKING VOLTAGE [a] up to and including V	MAINS TRANSIENT VOLTAGE														
	1 500 V [c]						2 500 V [c]						4 000 V [c]		
	Pollution degree														
	1 and 2 [b]			3			1 and 2 [b]			3			1, 2 [b] and 3		
	F	B/S	R	F	B/S	R	F	B/S	R	F	B/S	R	F	B/S	R
71 [a]	0,4	1,0 (0,5)	2,0 (1,0)	0,8	1,3 (0,8)	2,6 (1,6)	1,0	2,0 (1,5)	4,0 (3,0)	1,3	2,0 (1,5)	4,0 (3,0)	2,0	3,2 (3,0)	6,4 (6,0)
210 [a]	0,5	1,0 (0,5)	2,0 (1,0)	0,8	1,3 (0,8)	2,6 (1,6)	1,4	2,0 (1,5)	4,0 (3,0)	1,5	2,0 (1,5)	4,0 (3,0)	2,0	3,2 (3,0)	6,4 (6,0)
420 [a]	F 1,5 B/S 2,0 (1,5) R 4,0 (3,0)												2,5	3,2 (3,0)	6,4 (6,0)
840	F 3,0 B/S 3,2 (3,0) R 6,4 (6,0)														
1 400	F/B/S 4,2 R 6,4														
2 800	F/B/S/R 8,4														
7 000	F/B/S/R 17,5														
9 800	F/B/S/R 25														
14 000	F/B/S/R 37														
28 000	F/B/S/R 80														
42 000	F/B/S/R 130														

The values in the table are applicable to FUNCTIONAL INSULATION (F) if required by 5.3.4 a) (see 2.10.1.3), BASIC INSULATION (B), SUPPLEMENTARY INSULATION (S) and REINFORCED INSULATION (R).

The values in parentheses apply to BASIC INSULATION, SUPPLEMENTARY INSULATION or REINFORCED INSULATION only if manufacturing is subjected to a quality control programme that provides at least the same level of assurance as the example given in Clause R.2. DOUBLE INSULATION and REINFORCED INSULATION shall be subjected to ROUTINE TESTS for electric strength.

If the PEAK WORKING VOLTAGE exceeds the peak value of the AC MAINS SUPPLY voltage, linear interpolation is permitted between the nearest two points, the calculated minimum CLEARANCE being rounded up to the next higher 0,1 mm increment.

[a] If the PEAK WORKING VOLTAGE exceeds the peak value of the AC MAINS SUPPLY voltage, ~~use~~ use the peak value of the AC MAINS SUPPLY voltage in this column and use Table 2L in accordance with 2.10.3.3 b) regarding additional CLEARANCES

[b] It is not required to pass the tests of 2.10.10 for Pollution Degree 1.

[c] The relationship between MAINS TRANSIENT VOLTAGE and AC MAINS SUPPLY voltage is given in Table 2J.

Creepage in primary circuits (2.10.4.3)

Table 2N provides **5 mm** (2 x 2.5 mm) for Pollution degree 2, standard PCB material, **3.6 mm** (2 x 1.8 mm) for Pollution degree 2, high CTI PCB material and **8 mm** (2 x 4 mm) for Pollution degree 3.

CREEPAGE DISTANCES shall be not less than the appropriate minimum values specified in Table 2N.

If the minimum CREEPAGE DISTANCE derived from Table 2N is less than the applicable minimum CLEARANCE, that value of minimum CLEARANCE shall be applied as the minimum CREEPAGE DISTANCE.

RMS WORKING VOLTAGE up to and including V	Pollution degree						
	1[a]	2			3		
	Material Group						
	I, II, IIIa, IIIb	I	II	IIIa, IIIb	I	II	IIIa, IIIb (see Note)
10	0,08	0,4	0,4	0,4	1,0	1,0	1,0
12,5	0,09	0,42	0,42	0,42	1,05	1,05	1,05
16	0,1	0,45	0,45	0,45	1,1	1,1	1,1
20	0,11	0,48	0,48	0,48	1,2	1,2	1,2
25	0,125	0,5	0,5	0,5	1,25	1,25	1,25
32	0,14	0,53	0,53	0,53	1,3	1,3	1,3
40	0,16	0,56	0,8	1,1	1,4	1,6	1,8
50	0,18	0,6	0,85	1,2	1,5	1,7	1,9
63	0,2	0,63	0,9	1,25	1,6	1,8	2,0
80	0,22	0,67	0,9	1,3	1,7	1,9	2,1
100	0,25	0,71	1,0	1,4	1,8	2,0	2,2
125	0,28	0,75	1,05	1,5	1,9	2,1	2,4
160	0,32	0,8	1,1	1,6	2,0	2,2	2,5
200	0,42	1,0	1,4	2,0	2,5	2,8	3,2
250	0,56	1,25	1,8	2,5	3,2	3,6	4,0
320	0,75	1,6	2,2	3,2	4,0	4,5	5,0
400	1,0	2,0	2,8	4,0	5,0	5,6	6,3
500	1,3	2,5	3,6	5,0	6,3	7,1	8,0
630	1,8	3,2	4,5	6,3	8,0	9,0	10
800	2,4	4,0	5,6	8,0	10	11	12,5

he values in the table apply to FUNCTIONAL INSULATION if required by 5.3.4 (a) (see 2.10.1.3), BASIC INSULATION and SUPPLEMENTARY INSULATION. For REINFORCED INSULATION the values are twice those in the table.

near interpolation may be used between the nearest two points, the calculated minimum CREEPAGE DISTANCE being rounded up to the next higher specified increment, or the value in the next row below, whichever is lower. For values:

hot exceeding 0,5 mm, the specified increment is 0,01 mm; and

for those exceeding 0,5 mm, the specified increment is 0,1 mm.

or REINFORCED INSULATION, the calculated value for BASIC INSULATION shall be doubled first before applying the rounding off.

NOTE Material Group IIIb is not recommended for applications in Pollution Degree 3 with an RMS WORKING VOLTAGE above 630 V.

[a] It is permitted to use the values for Pollution Degree 1 if one sample passes the tests of 2.10.10.

PCB Material Feedback

Feedback from PCB vendor (isaac@vectorfab.com). Indicates that a small increase in PCB cost is incurred to use PCB material with a CTI >400, thereby meeting the material group II requirement

Hello Peter,

Regarding your question – Modified FR4 can be a number of variations, including FR4 High Temp, which is the most popular alternative to FR4. The increase in price is ~3% to 5% for High Temp and Halogen Free materials respectively. Both of these materials are available.

Best,

-isaac

Materials group	Tg	CTEz	ε_r(1 MHz/1 GHz/10 GHz)	Proof voltage	Surface resistance	Conductive Tracking Index (CTI)	Water absorption	Cu adhesion
	°C	ppm/K	-	KV/mm	MΩ	V	%	N/mm
Standard FR4	125°C-140°C	<70	4,7/4,3/-	50	10^7	>200	0,06	1,5
Modified FR4	135°C-180°C	<55	4,6/4,2/-	45	10^7	>200	0,06	1,5
FR4 halogen free	150°C-170°C	<40	5,0/4,8/4,6	50	10^8	>500	0,06	1,5
BT epoxy	Approx. 200°C	<40	4,4/4,1/-	70	10^8	>200	0,05	1,6
CE epoxy	Approx. 250°C	<25	3,9/3,7/3,5	65	10^7	>200	0,05	1,6
Polyimide	220°C-260°C	<55	4,0/3,8/3,8	45	10^8	>100	0,3	1
PTFE (pure)	200°C-230°C	<70	2,6/2,4/2,2	45	10^7	>600	0,04	1,3
RO3000	-	<40	3,0/2,8/2,6	30	10^7	>600	0,1	2,5
RO4000	Approx. 280°C	<45	3,3/3,0/2,8	30	10^9	>600	0,04	1,0

Feedback from UL Consultant

1. Our product is classified as Pollution degree 2. This confirms our understanding and concurs with email discussions between you, Mike and Stefan last week.

2. The PCB is assumed to be Group IIIB. Again this is consistent with your original memo. Paul mentioned as long as the PCB manufacturer has their material listed and recognized with the higher CTI, we could use that to lower material group.

3. Clearance distance is specified in Table 2K and using a peak working voltage of 420V, the required reinforced insulation distance is 4mm. This is also consistent with your original memo.

4. Creepage distance which is the most relevant for our concerns is in Table 2N. Paul said that the nominal voltage of 240VRMS is used to determine the RMS working voltage between primary and secondary which is then used to determine the required creepage distance. He said that is it not customary to use 264VAC input for these measurements. He was clear that although the input voltage was 240VRMS, the working voltage can be much higher. He commented that during the safety qualification test the working voltage between two points bridging the isolation barrier is measured with a DVM. In our case he felt relatively safe to say that the since we are not measuring a switching node (like drain of primary HV MOSFET) or a transformer node, the working voltage would fall into the 250VRMS with Material group IIIB. With reinforced insulation the table entry is doubled and results in a creepage distance requirement of 5mm. Paul also commented that in the event the working voltage falls in between two of the entries in the table, linear interpolation is allowed.

Revision History:

Rev A. 18072013	First release
Rev B. 25072013	Second release – after feedback from UL consultant working voltage reduced to 250 V RMS