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## MOSFET based dimmer protection

### Introduction

Light dimmer can use either Triac or MOSFET switches. MOSFET requires less power for control than a Triac, but they are less robust against lightning surges, which can appear on mains. Consequently, they need to be protected against lightning and fast transient surges to avoid dimmer failure.

The TVS (Transient Voltage Suppressor) is the first idea to protect MOSFET: however, due to mains voltage, TVS breakdown voltage must be higher than 350 V, which leads to a high power dissipation during lightning surge.

Another solution is to use a thyristor based surge protection (also called crowbar protection, Trisil), which also protects against lightning surge, and provides a lower power dissipation than a TVS: as it acts as a SCR, voltage during surge is low, so power dissipation is low.

## 1 EMC standards for lighting equipment

Equipment connected to the mains must be compliant with:

- IEC 61000-4-5 standard (Testing and measurement techniques – Surge immunity test)
- IEC 61000-4-4 standard (Testing and measurement techniques – Electrical fast transient/burst immunity test)

For lighting equipment, IEC 61547 gives EMC immunity requirements, where following IEC 61000-4-5 levels are specified:

- For input power < 25 W:
  - Line to line (differential mode) surge 1.2/50  $\mu$ s (8/20  $\mu$ s) wave shape: +/-0.5 kV (so 250 A in short circuit)
  - Line to ground (common mode) surge 1.2/50  $\mu$ s (8/20  $\mu$ s) wave shape: +/-1 kV (so 84 A in short circuit)
- For input power > 25 W:
  - Line to line (differential mode) surge 1.2/50  $\mu$ s (8/20  $\mu$ s) wave shape: +/-1 kV (so 500 A in short circuit)
  - Line to ground (common mode) surge 1.2/50  $\mu$ s (8/20  $\mu$ s) wave shape: +/-2 kV (so 167 A in short circuit)

In case of dimmer, where there is no connection to ground, only line to line surge is considered.

For IEC 61000-4-4, following test is specified:

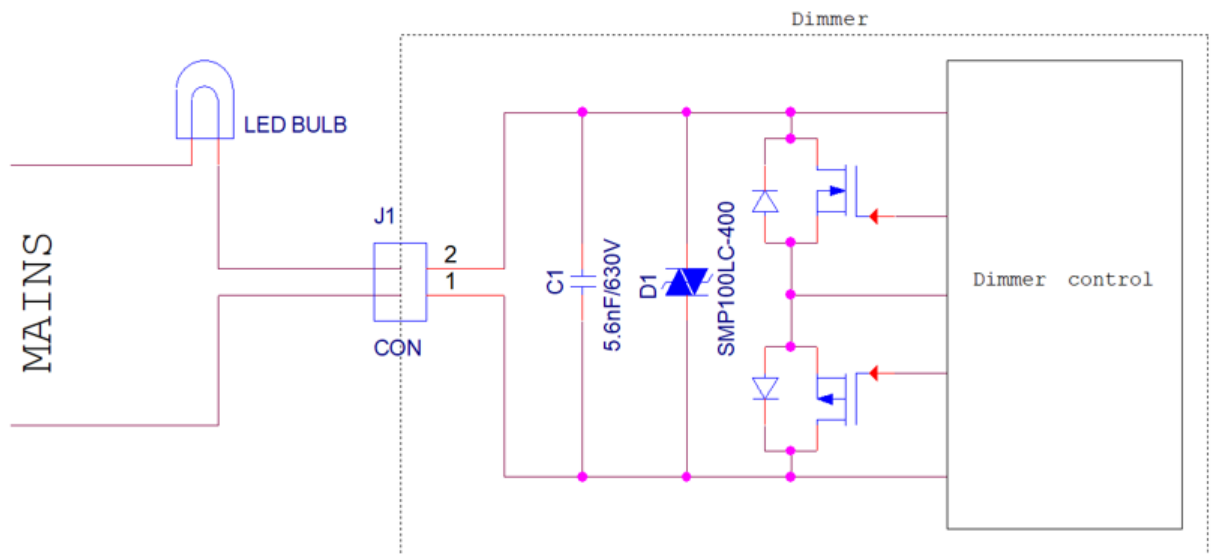
- Test level: 1 kV (peak)
- Rise time / hold time: 5 / 50 ns
- Repetition frequency: 5 kHz

## 2 SMP100LC-400 to protect MOSFETs

### 2.1 Schematic

Figure 1. SMP100LC-400 to protect dimmer MOSFET gives a typical implementation of SMP100LC-400 on a MOSFET based dimmer: it is placed in parallel with dimmer MOSFETs, to clamp the voltage during surge, and to keep value lower than MOSFET  $V_{DSmax}$  (generally, 600 V – 700 V MOSFET are used). To avoid triggering of SMP100LC-400 during fast transient/burst test, C1 capacitor acts as a low impedance at fast transient/burst frequencies and keeps the voltage lower than the SMP100LC-400 triggering voltage.

Figure 1. SMP100LC-400 to protect dimmer MOSFET



### 2.2 SMP100LC-400 characteristics

According to countries, mains voltage is not the same. The highest voltage reaches 240 V<sub>RMS</sub>, which gives a peak voltage of 340 V.

SMP100LC-400 V<sub>RM</sub> is 360 V, as shown on Figure 2. SMP100LC-400 electrical characteristics, which is compliant with a max voltage of 340 V.

Figure 2. SMP100LC-400 electrical characteristics

Table 4. Electrical characteristics - values (T<sub>amb</sub> = 25 °C)

Order code	I <sub>RM</sub> @ V <sub>RM</sub>		I <sub>R</sub> @ V <sub>R</sub>		Dynamic V <sub>BO</sub> (1)	Static V <sub>BO</sub> @ I <sub>BO</sub> (2)		I <sub>H</sub> (3)	C(4)	C(5)
	max.		max.		max.	max.	max.	min.	typ.	typ.
	μA	V	μA	V	V	V	mA	mA	pF	pF
SMP100LC-400	2	360	5	400	540	530	800	150	20	45

$$U_{MAINS\ max} = 240 \cdot \sqrt{2} = 340V$$

V<sub>RM</sub> higher than U<sub>MAINS max</sub>

Regarding maximum 8/20 μs current, SMP100LC-400 can withstand 400 A (see Figure 3. SMP100LC-400 absolute maximum rating).

As shown on Figure 1. SMP100LC-400 to protect dimmer MOSFET, bulb is in series with the SMP100LC-400: surge current will be limited, so 400 A is enough to withstand at least 2 kV, as shown on Section 3 Measurements examples.

**Figure 3. SMP100LC-400 absolute maximum rating**

**Table 2. Absolute ratings ( $T_{amb} = 25\text{ }^{\circ}\text{C}$ )**

Symbol	Parameter	Value	Unit	
$I_{PPmax}$ 8/20 $\mu$ s = 400A	Repetitive peak pulse current (see Figure 2)	10/1000 $\mu$ s	100	A
		8/20 $\mu$ s	400	
		10/560 $\mu$ s	140	
		5/310 $\mu$ s	150	
		10/160 $\mu$ s	200	
		1/20 $\mu$ s	400	
$I_{FS}$	Fail-safe mode: maximum current <sup>(1)</sup>	8/20 $\mu$ s	5	kA
$I_{TSM}$	Non repetitive surge peak on-state current (sinusoidal)	t = 0.2 s	24	A
		t = 1 s	15	
		t = 2 s	12	
		t = 15 mn	4	
$i^2t$	$i^2t$ value for fusing	t = 16.6 ms	20	A <sup>2</sup> s
		t = 20 ms	21	
$T_{stg}$	Storage temperature range	-55 to 150	°C	
$T_j$	Operating junction temperature range	-40 to 150		
$T_L$	Maximum lead temperature for soldering during 10 s.	260		

1. In fail safe mode, the device acts as a short circuit.

### 2.3 Thyristor based protection advantages versus TVS

As mains is AC voltage, thyristor based protection can be used, as it will for sure turn-off with current polarity change.

Advantage of a thyristor based protection versus TVS is the 8/20  $\mu$ s current capability. Indeed, the maximum current is limited by the power handling capability of a device:

- For a thyristor based protection, when triggered, the clamping voltage is low, due to SCR effect
- For a TVS, the clamping voltage is higher than the breakdown voltage, so higher than 340 V
- Consequently, for a same power device, maximum current that a thyristor-based protection can handle is much higher than the current a TVS can handle
- On another way, package to get same current capability is smaller for a thyristor-based protection than for a TVS

Thus, using a thyristor-based protection allows to get a higher current capability than a TVS, with a smaller package.

Withstanding more current is particularly useful with incandescence bulb, as the serial resistances are much lower than a LED bulb. As an example, a 200 W (240 V<sub>RMS</sub>) incandescence bulb serial resistance is 288  $\Omega$  when hot. However, when the bulb is off, so at ambient temperature, the serial resistance is roughly divided by 10, giving 29  $\Omega$ . For 2 kV, (8/20  $\mu$ s) this leads to a current of 69 A. High power TVS, or several in series, are needed to withstand this current, whereas a single SMP100LC-400 is suitable.

### 3 Measurement examples

#### 3.1 IEC 61000-4-5 tests

Measurements have been performed with several LED bulbs, halogen bulb and incandescence bulb.

Figure 4. Surge measurement setup with bulb shows the measurement setup: bulb is in series with SMP100LC-400, same configuration as Figure 1. SMP100LC-400 to protect dimmer MOSFET.

Figure 4. Surge measurement setup with bulb

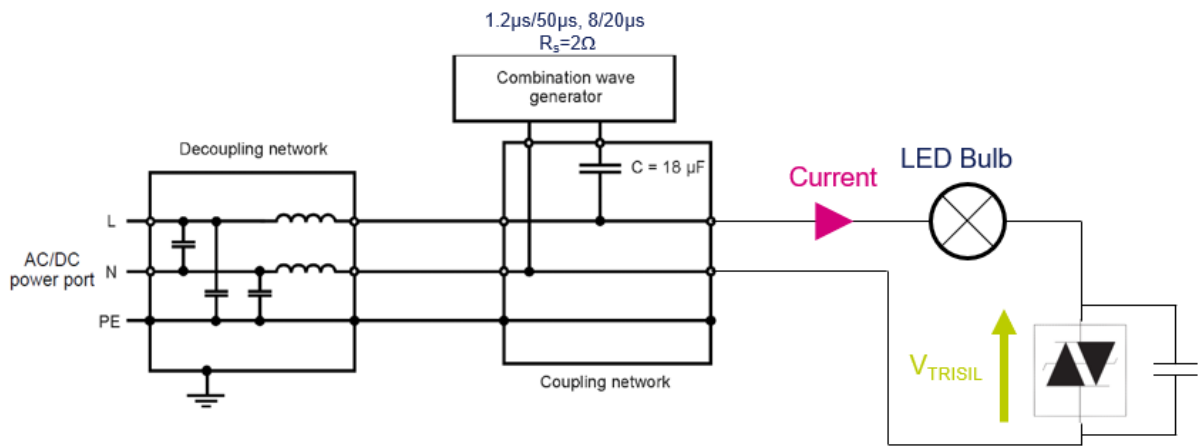


Figure 5. Measurement results for 1 kV surge IEC61000-4-5 gives measurement results for 1 kV surge IEC61000-4-5: peak voltage is 466 V, lower than MOSFET  $V_{DSmax}$

Figure 5. Measurement results for 1 kV surge IEC61000-4-5

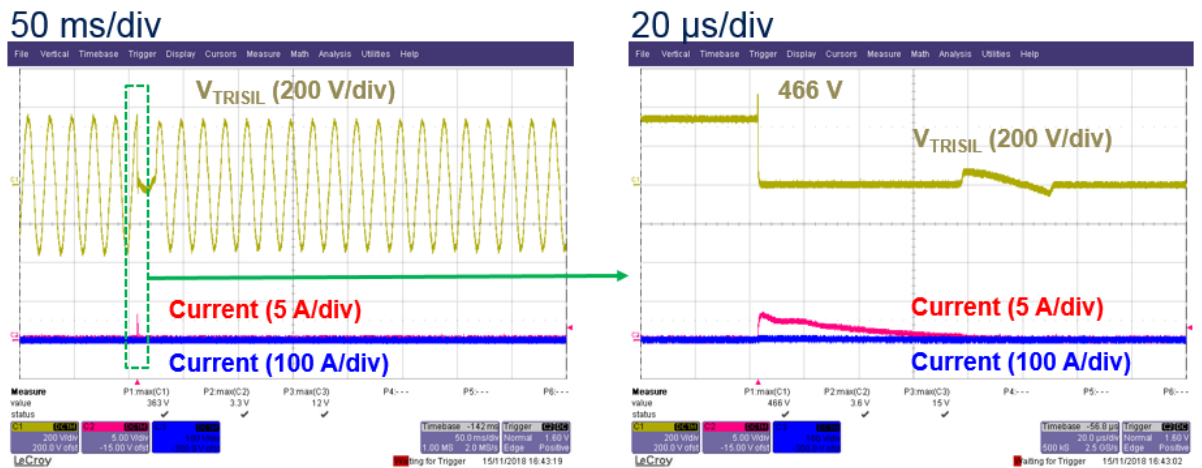


Figure 6. Measurement results for 2 kV surge IEC61000-4-5 gives measurement results for 2 kV surge IEC61000-4-5: SMP100LC-400 still OK, and clamping voltage is 472 V, lower than MOSFET  $V_{DSmax}$ . The current in SMP100LC-400 is 6 A.

Figure 6. Measurement results for 2 kV surge IEC61000-4-5

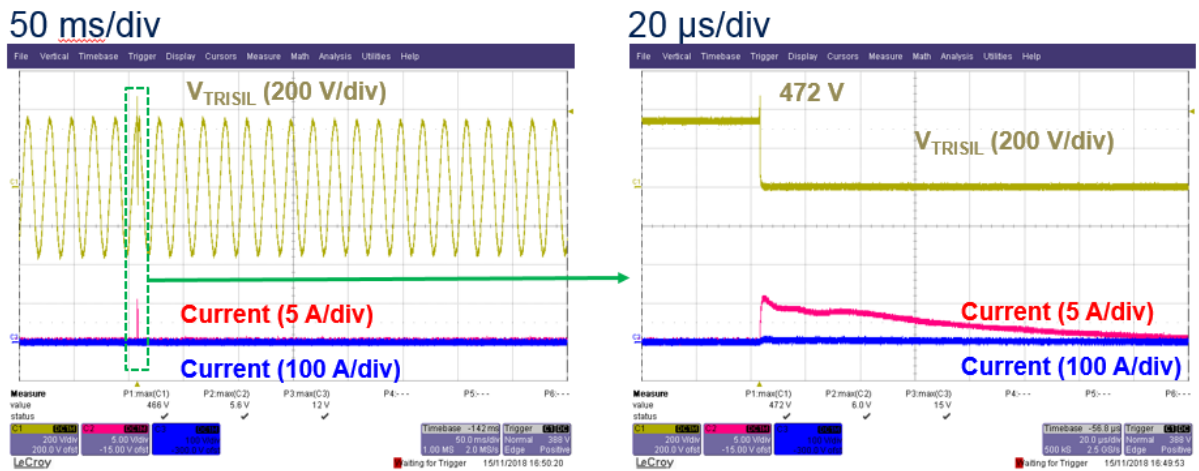
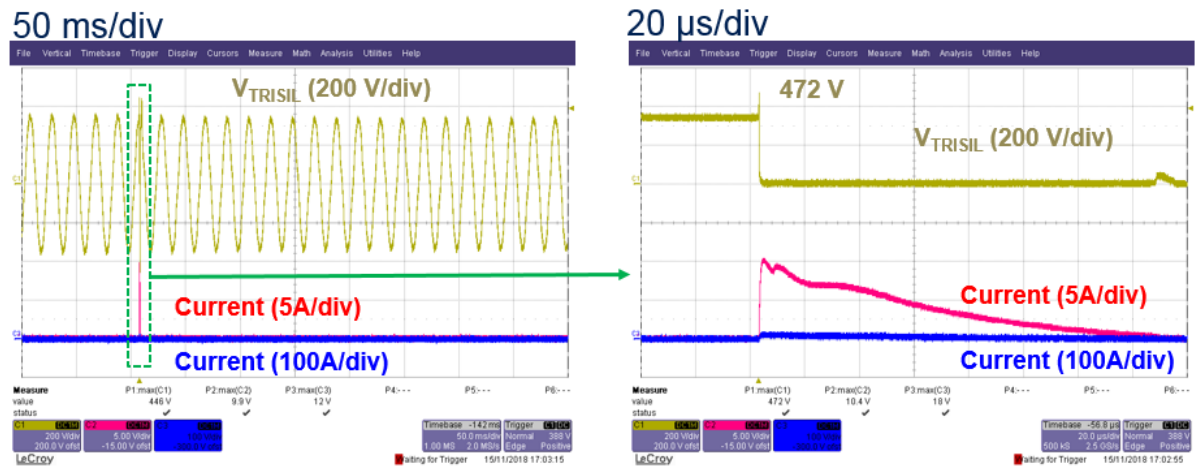


Figure 7. Measurement results for 4 kV surge IEC61000-4-5 gives measurement results for 4 kV surge IEC61000-4-5: SMP100LC-400 still OK, and clamping voltage is 472 V, lower than MOSFET  $V_{D_{Smax}}$ . The current in SMP100LC-400 is 10.4 A.

Figure 7. Measurement results for 4 kV surge IEC61000-4-5



Below table shows measurement results on several bulbs, with state of SMP100LC-400 after tests. We can notice that up to 2 kV, the SMP100LC-400 is still OK.

For 4 kV surge, SMP100LC-400 state depends on the bulb state:

- SMP100LC-400 is still Ok if the bulb still Ok, or fails in open circuit after surge
- When bulb fails in short circuit, SMP100LC-400 fails also, as there is no more impedance in series with the SMP100LC-400 (it would have been the same for a TVS)

Conclusion : So as long as the bulb can withstand 4 kV surge, the SMP100LC-400 will efficiently protect the dimmer.

**Figure 8. Measurement results with several bulbs**

IEC61000-4-5 surge voltage		1 kV	2 kV	4 kV
Bulb type	Plug	SMP100LC-400	SMP100LC-400	SMP100LC-400
Dimmable LED bulb A	E27	Ok	Ok	Failed (due to bulb failure in short)
Dimmable LED bulb B	E27	Ok	Ok	Ok
Dimmable LED bulb C	E27	Ok	Ok	Ok
Dimmable LED bulb D	E27	Ok	Ok	Ok
Dimmable LED bulb E	GU10	Ok	Ok	Ok
Dimmable LED bulb F	GU10	Ok	Ok	Failed (due to bulb failure in short)
Dimmable LED bulb G	GU10	Ok	Ok	Ok
Dimmable LED bulb H	E27	Ok	Ok	Ok
Dimmable LED bulb I	E27	Ok	Ok	Failed (due to bulb failure in short)
60 W Incandescence bulb	B22	Ok	Ok	Ok
<u>Halogen Spot</u>	E27	Ok	Ok	Ok

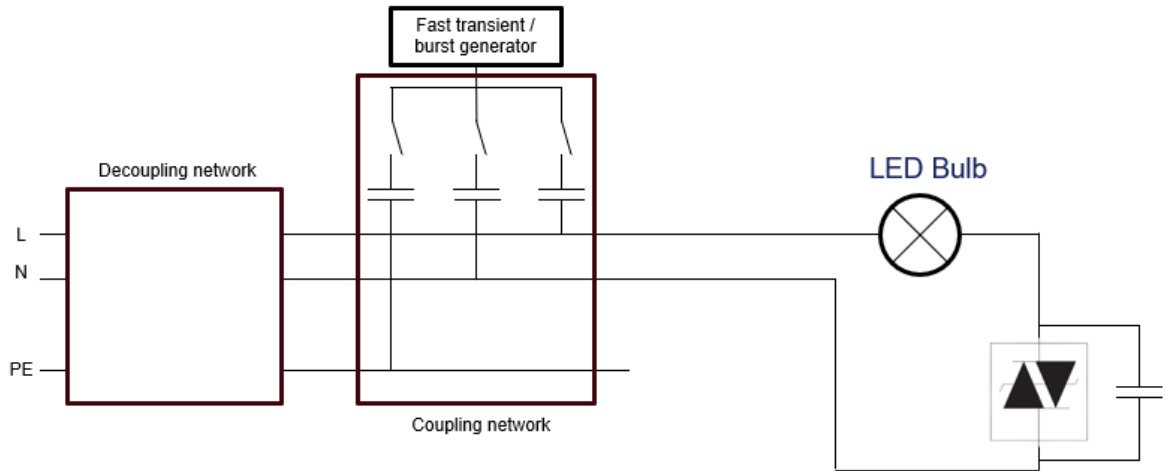
As shown on Figure 5. Measurement results for 1 kV surge IEC61000-4-5, Figure 6. Measurement results for 2 kV surge IEC61000-4-5 and Figure 7. Measurement results for 4 kV surge IEC61000-4-5, when SMP100LC-400 is Ok after tests, this implies that dimmer MOSFET is also Ok, as voltage is limited by SMP100LC-400 to a lower value than  $V_{DSmax}$ .

### 3.2 IEC 61000-4-4 tests

Measurements have been also performed with several LED bulbs and incandescence bulb.

Figure 9 show the measurement setup: bulb is in series with SMP100LC-400 + 5.6 nF capacitor, same configuration as Figure1.

Figure 9. IEC 61000-4-4 measurement setup with bulb



Below table shows measurement results on several bulbs, with bulb state during tests: up to 2 kV, no flash observed.

Figure 10. Measurement results on several bulbs

IEC61000-4-4 surge voltage		1 kV	2 kV
Bulb type	Plug	SMP100LC-400	SMP100LC-400
Dimmable LED bulb A	E27	No flash	No Flash
Dimmable LED bulb B	E27	No Flash	No Flash
Dimmable LED bulb C	E27	No Flash	No Flash
Dimmable LED bulb D	E27	No Flash	No Flash
Dimmable LED bulb E	GU10	No Flash	No Flash
Dimmable LED bulb F	GU10	No Flash	No Flash
Dimmable LED bulb G	GU10	No Flash	No Flash
Dimmable LED bulb H	E27	No Flash	No Flash
Dimmable LED bulb I	E27	No Flash	No Flash
60 W Incandescence bulb	B22	No Flash	No Flash
Halogen Spot	E27	No Flash	No Flash

Note: With the MOSFET switching, standard capacitor can generate audible noise. To avoid this, specific capacitor has been developed, for example, FG series from TDK.



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## 4 Conclusion

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Measurement results, on several bulbs, show that the SMP100LC-400 can efficiently protect dimmer MOSFET up to 4 kV (IEC 61000-4-5, line to line surge) as long as the bulb is able to withstand such a surge level. This performance exceeds the IEC 61547 requirements. Anyway, we have shown that all the bulbs part of the measurements performed are able to withstand 2 kV (IEC 61000-4-5, line to line surge).

It can also be efficient for 4 kV surge IEC 61000-4-5, if bulb withstands 4 kV, or failed in open circuit.

Also, fast transient/burst test (IEC 61000-4-4) are compliant with IEC 61547 requirements, as no flash are observed up to 2 kV, exceeding the 1 kV requirement.

In comparison with TVS, thyristor based protection (also called crowbar surge protection, Trisil) offers better performance (8/20  $\mu$ s maximum current is higher), with a smaller package.

The SMP100LC-400 plus capacitor are suitable to well protect dimmer MOSFET, to make it compliant with IEC 61547 standard for IEC 61000-4-5 surge tests and IEC 61000-4-4 fast transient/burst tests.

## Revision history

**Table 1. Document revision history**

Date	Version	Changes
17-Sep-2019	1	Initial release.
20-May-2020	2	Updated Section 1 EMC standards for lighting equipment, Figure 1. SMP100LC-400 to protect dimmer MOSFET, Figure 2. SMP100LC-400 electrical characteristics, Figure 3. SMP100LC-400 absolute maximum rating and Figure 4. Surge measurement setup with bulb. Added Section 3.2 IEC 61000-4-4 tests.
11-Apr-2022	3	Updated Section 1 EMC standards for lighting equipment.

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