Silicon Carbide (SiC) Current Limiting Devices

The Game Changer in Electrical Protection against Energetic and Fast Transients

A known justification for Electrical Protection is to prevent transitory event like lightning, EMI, short-circuit, as well as transitory power-up effects, from disturbing and possibly permanently damage impacted electronic systems.

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Most frequent design approach to Electrical Protection is voltage clamping devices (TVS, MOV, GDT) together with current limiting ones (fuses, resistors, polymeric PTC, inductors). Figure 1 shows a typical schematic of fast surge protection for fast surges combining voltage clamping and current limiting devices mentioned above.

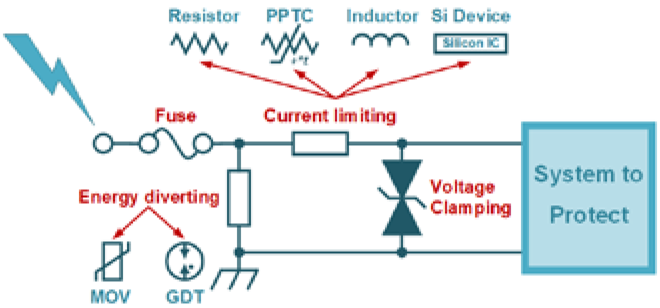

Figure 1: Typical surge protection schematic.

For specific applications, like aircraft lightning protections, tripping speed, reliability and failing mode concerns prevent use of MOV and GDT. This drives aircraft lightning protection designs to use almost exclusively TVS-only structures. To pass Aircraft Lightning Protection Test [1] require sizing up TVS to bulky devices which has cost impact.

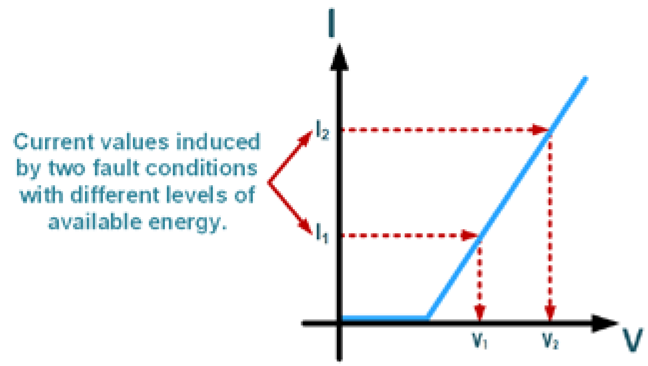

Figure 2: Clamping voltages on a TVS for two current values.

In other cases, standard current limiting devices can be used together with voltage clamping devices.

The following table summarizes drawbacks of standard current limiting devices.

Standard Current Limiting Devices	Drawbacks
Resistors	• Same static and dynamic resistance • Bulky • Unsuitable for high ambient temperature • Reduced bandwidth
PPTC	• Long reaction time • Degradation after repeated tripping • Unsuitable for high ambient temperature
Inductors/Chokes	• Behavior dependent on surge rising/falling times • Bulky • Non compatible with high-speed communication
Silicon Devices	• Low voltage capability • High equivalent resistance (high insertion losses) • Only low nominal currents (low power systems) • Disconnection of protected circuit (turn-off)

The next section introduces Silicon Carbide Current Limiting Devices. Such innovative Silicon Carbide Current Limiting Device (SiC CLD) brings advantages summarized in the following table.

Advantages of SiC CLD	Features
Fast reaction time	<100nsec
Self-resettable behavior	No external action required
Low nominal resistance	From hundred mΩ
High dynamic resistance	Up to several hundred Ω
No Disconnection	Protected circuit always ON
Small footprint	SMB (DO-214AA)
High transient-voltage capability	Above 1600V
Extreme reliability and robustness	1000's operations without degradation
Wide bandwidth	DC to multi GHz

SiC Current Limiting Device in a Nutshell

A Silicon Carbide Current Limiting component is a two-terminal device. When the CLD voltage drop is greater than its threshold voltage, the device clamps the current going through it to a specific value. This maximum current value is set by its internal topology. As shown on Figure 3, SiC CLDs behave like a current source in DC. When CLD voltage is below saturation voltage V_{Sat}, the CLD behaves like a resistor which value is R_{On}. Above this voltage V_{Sat}, the CLD current saturates at I_{Sat} value. Thus, SiC CLDs can be considered as semiconductor non-linear resistors.

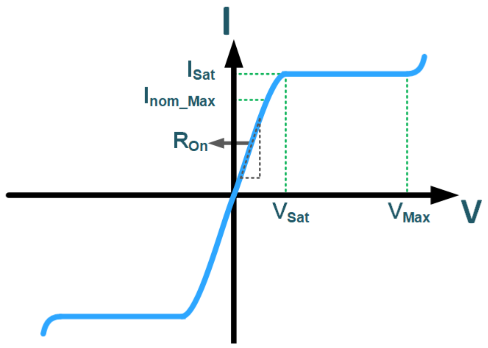

Figure 3: Typical DC behavior of a SiC CLD.

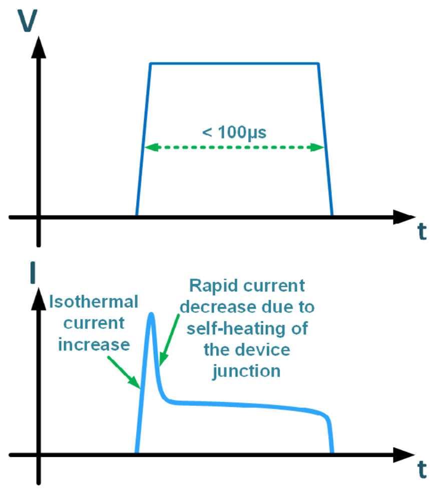

Figure 4: Typical dynamic response of a SiC CLD.

In dynamic behavior, current through CLDs decrease as the junction temperature increases. This is due to self-heating (i.e. junction power dissipation) which increases the equivalent CLD resistance (Figure 4). This resistance increase limits the current inside the device and constrains the self-heating. Therefore, by default the device remains in a safe area of operation. Figure 9 shows the dynamic response of a typical SiC CLD to a short square pulse.

SiC CLDs are described by four principal parameters:

- R_{On}: ON-state resistance
- I_{Sat}: saturation current
- I_{Nom_Max}: Maximum nominal current before saturation
- V_{Max}: maximum use voltage before breakdown.

Parameter	Typical values for available SiC CLDs
R_{On}	from 500mΩ to 10Ω
I_{Sat}	from 1A to 30A
I_{Nom_Max}	From 400mA to 3A
V_{Max}	up to 1.7kV

CLD design took care to comply with 1.2/50µs from IEC 61000-4-2, 40/120µs from DO-160 section 22 making CLD a remarkable fit to it. To ease design with CLD datasheet provides a simple-to-use accurate Safe Operating Area (SOA) graph to assess quick suitability of the CLD device to a specific application. To manage the CLD electrothermal performances a SPICE simulation model is available (Figure 5). More information can be found at application notes of [2].

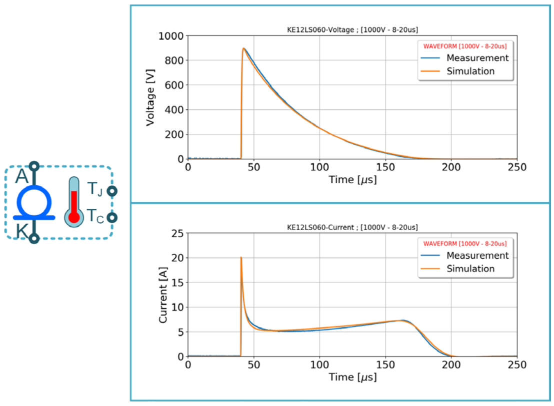

Figure 5: Model of a SiC CLD and measured and simulated dynamic response to a normalized 1000V/1000A, 8-20µs waveform.

Multiple flavors of SiC CLD
SiC CLDs are either unidirectional or bidirectional (see Figure 6). A bidirectional CLD clamps both positive and negative current.

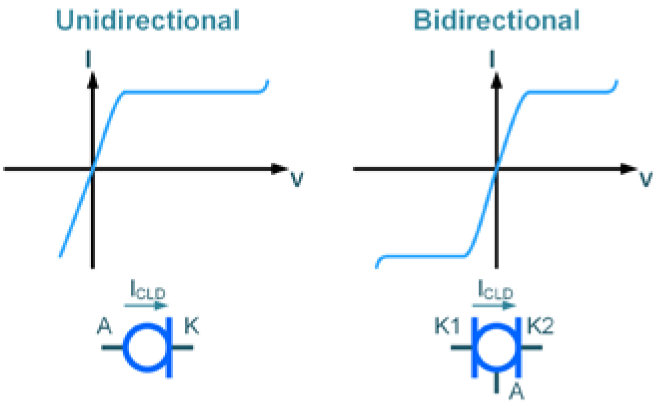

Figure 6: Unidirectional and bidirectional behavior, with corresponding device symbols.

Application benefits of SiC CLDs
SiC CLDs are well suited for many different types of applications such as (Figure 7):

- lightning protection on data or power supply lines,
- reduction of inrush current during start-up of converters,
- protection of sensitive equipment against line transients,
- protection of submarine cable communication repeaters against cable short circuits.

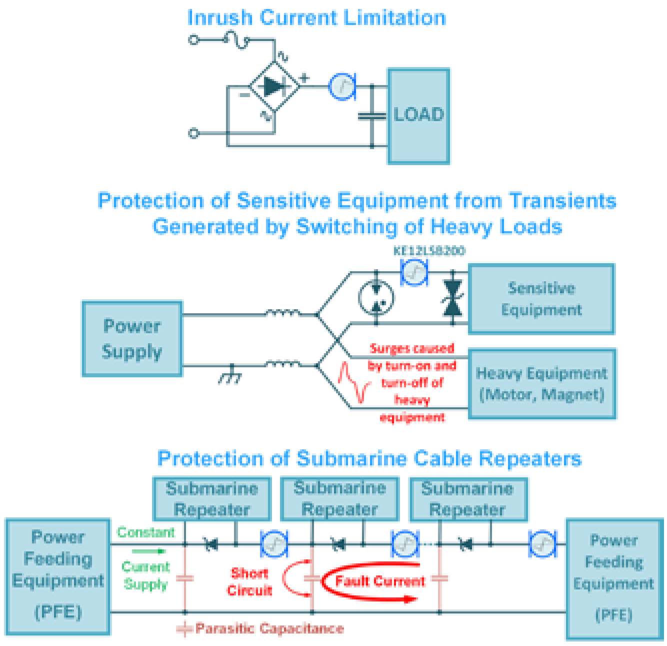

Figure 7: SiC CLD applications in different markets.

SiC CLD is a current-clamping device which is dual to a voltage clamping device such as MOV, TVS or GDT. Combining both in a π (Pi) topology protection circuit ends up with a very compact solution (Figure 8).

In common practice a resistor is implemented in between the GDT and the TVS. Purpose of this resistor is to protect the TVS against current surges. At the same time, this resistor value has to be as low as possible to limit the power dissipation in normal operation. SiC CLDs supplies a new response to deal with this dilemma thanks to its non-linear resistor characteristics. In nominal conditions, SiC CLDs present a low resistance, and this one highly increases when the voltage across the device is high due to a surge condition. This allows using low-power rating TVS, which in turns reduces system footprint and cost. Additionally, for communication lines, SiC CLDs offer lower insertion losses than the needed equivalent resistor, presenting also virtually zero parasitic inductance.

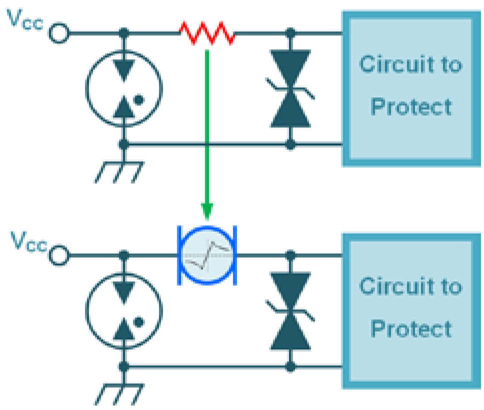

Figure 8: Pi-configuration protection circuit.

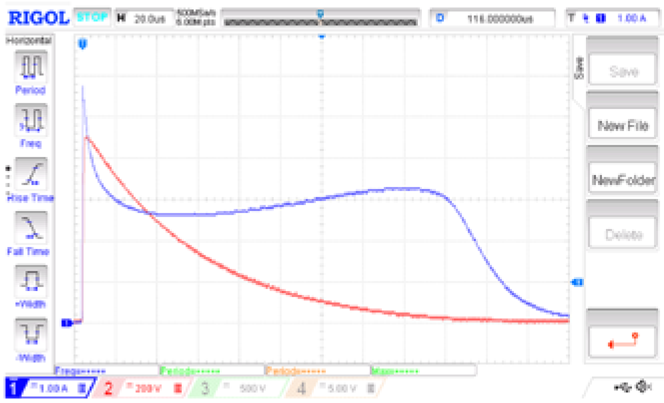

Figure 9: Measured dynamic response (blue) of a SiC CLD (KE12LEB150T20 bidirectional mode) to a normalized 900V/900A, 1.2-50µs waveform (red).

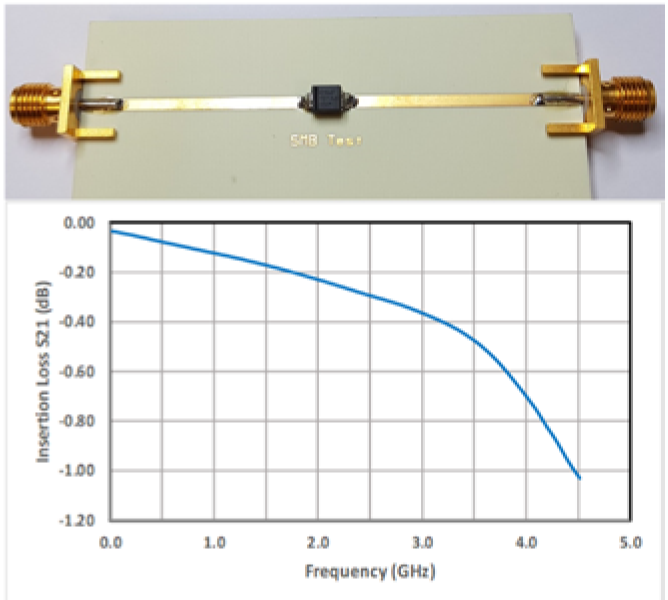

Figure 10: Measured insertion loss S21.

Fast and Safe!

Exhibiting very low parasitic inductance and taking advantage of the SiC material properties, SiC CLD is ideal for ultra-fast current clamping while sustaining high energy. Perfect Fast and safe!

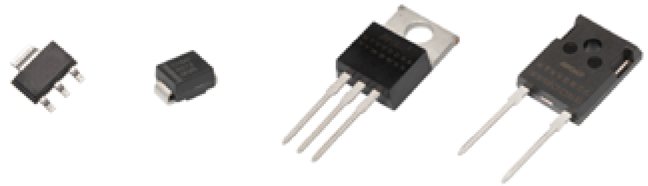

Figure 11: Caly's SiC CLD Packaging options.

Figure 12: Full set of evaluation boards for SiC CLD assessment.

Figure 9 shows Off-The-Shelf SiC CLD (KE12LEB150) real time dynamic response to a normalized 900V/900A 1.2-50µs lightning waveform. At the beginning of the waveform, current through the SiC CLD is clamped almost instantaneously (50-100ns) to I_{Sat} and then it drops quickly per device self-heating.

As mentioned in previous sections, SiC CLD is a perfect fit to high-speed data communication line protection. It brings wide bandwidth performance whilst current clamping is still ensured. Off-The-Shelf SiC CLD insertion losses (S21) up to 4.5GHz is shown on Figure 10.

What does a CLD look like?

Depending upon intended use and targeted market, SiC CLDs are available in diverse forms and packages. Package selection must consider DC power dissipation as much as required AC characteristics. Multiple choices are available to you to fit your need in package size and application requirements.

To facilitate your CLD experimentation various flavors of demo boards are awaiting your call.

References

[1] "Environmental Conditions and Test Procedures for Airborne Equipment", RTCA/DO-160G, RTCA Inc. December 16, 2014

[2] http://www.caly-technologies.com/wp-APPNOTE/AN-00038-17-CLD-Improving Performance of Surge Protection Circuits with Current Limiting Devices.pdf

www.caly-technologies.com