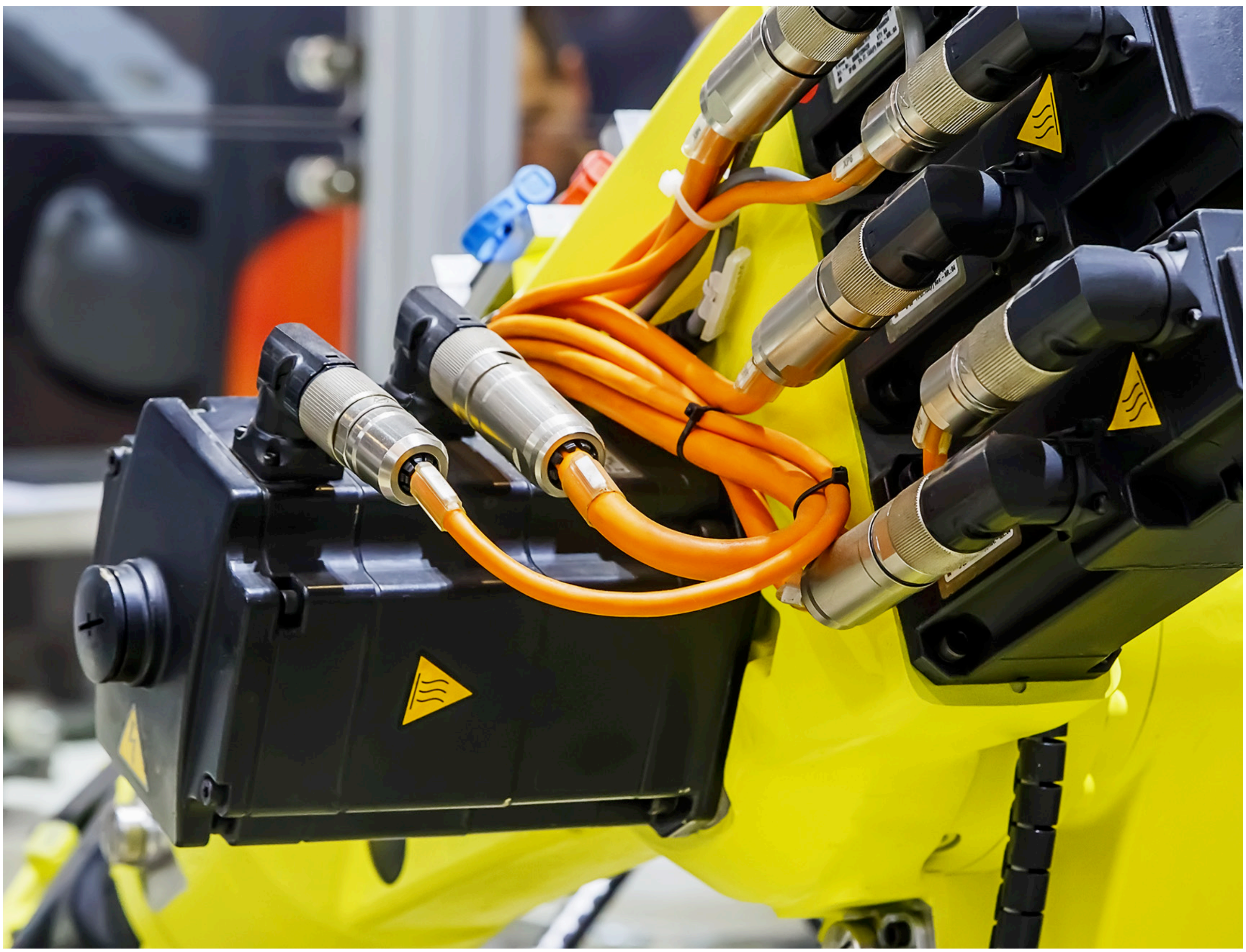
WHITE PAPER

Communication & Isolation Technology for Integrated Gate Driver ICs

Andrew Smith | Director of Technical Outreach



Introduction

New power semiconductors for high density applications require gate driver technologies that support higher working voltages and are reliable across an extended temperature range. The package must also meet international standards for creepage and clearance. This paper presents an innovative communication and isolation technology, integrated in a new industrial package design. An approach to providing comprehensive protection against overvoltage during system short-circuit is also proposed.

The main purpose of the gate drive unit is the galvanically isolated transmission of command and status feedback signals between microprocessor (primary side) and power semiconductor (secondary side), as depicted in Figure 1.

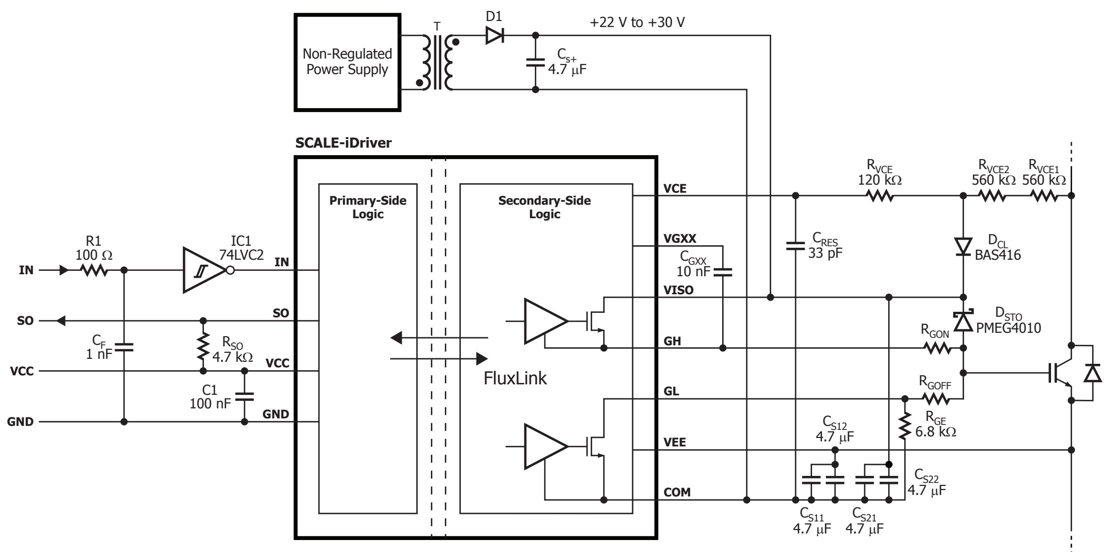


Figure 1: Gate driver [1].

The galvanic isolation must meet creepage and clearance distances described in the safety and isolation requirements outlined in various international standards.

Typical standards for clearance and creepage distances are:

1. IEC 60664-1: Insulation coordination for equipment within low-voltage systems
2. IEC 62109-1: Safety of power converters for use in photovoltaic power systems
3. IEC 61800-5-1: Adjustable speed electrical power drive systems
4. UL61800-5-1 and UL840: Isolation coordination clearances and creepage

The clearance and creepage distances, as shown in Figure 2, must be fulfilled by the layout of the gate driver IC. For creepage distances, the Isolation Group of the IC material is also important. As CTI (Comparative Tracking Index) for the IC material increases, blocking voltage for a given creepage distance also increases.

The distance between primary and secondary side (Distance Through Insulation – DTI, see Figure 2) within the IC must also meet international standards:

1. VDE0884-10: Semiconductor devices - Magnetic and capacitive couplers for safe isolation [2]
2. IEC60747-17: Magnetic and capacitive coupler for basic and reinforced isolation
3. UL1577: Standard for optical isolators

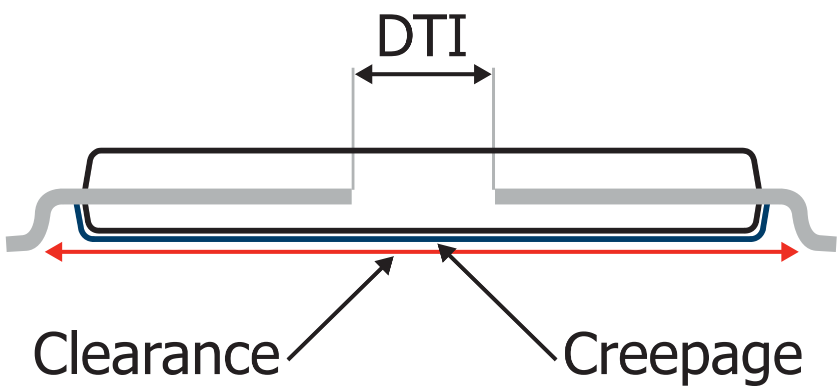


Figure 2: Short overview of the isolation distances.

The galvanic isolation in driver ICs today is typically achieved by optical devices, capacitive couplers or silicon-chip-integrated coreless transformer (magnetic) means. Each of these isolation technologies provides benefits, and each has challenges.

Optocouplers are ubiquitous. The structure of the IC package is used to impart isolation, resulting in relatively low cost. This technology also provides very good signal noise immunity, but suffers from long-term reliability issues due to the gradual reduction in signal transmission strength – Current Transfer Ratio (CTR) – over time. Also, the structure has dedicated transmitter and receiver circuits, so it cannot provide bi-directional data transmission through a single channel. High humidity environments can also affect signal accuracy. Capacitive couplers have better longevity and can be made to function bidirectionally, but consume expensive silicon area within the IC (or by adding the expense of an additional chip within the IC) to create the isolating structure – a drawback also encountered with air-cored transformers. Silicon-chip-integrated transformers can also provide bidirectional signal transfer, but tend to be large (a significant drawback if the structure is to be realized in silicon).

The excellence in isolation derived from the transformer (magnetic) coupling has long been understood and is widely used in switch-mode power conversion; however, cost and production repeatability challenges imposed by discrete wound components mean that this technology is not ideal for signal transmission. New technology seeks to combine the performance benefits of a pulse transformer with the size and repeatability afforded by integrated devices like optocouplers.

A New Isolation Technology

Magneto-inductive coupling (FluxLink) is a new approach employed to create a bidirectional data transfer mechanism using the IC lead-frame structure to form the send and receive windings. Isolation is provided by a thick (>0.4 mm, a distance which is comparable to opto IC devices), homogenous layer of mold compound. The concept is shown in Figure 3.

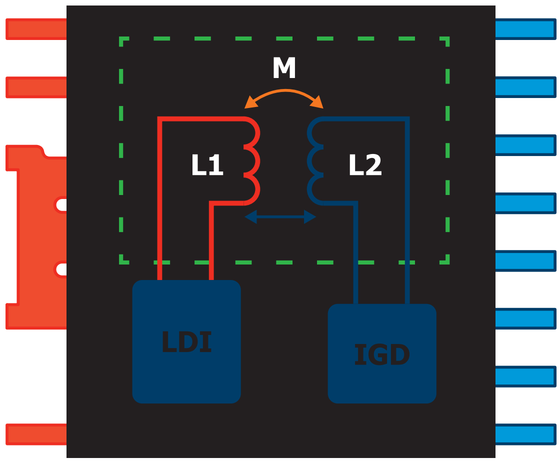


Figure 3: Isolated data transmission technology in new 9.5 mm housing.

Using the performance of established isolation technologies such as optocouplers as a guide, we can measure the relative performance of this new isolation technology to determine its suitability as a gate driver technology. The SCALE-iDriver family of gate drivers from Power Integrations is the vehicle we will use for the examination. A stylized representation of the device cross section is shown in Figure 4.

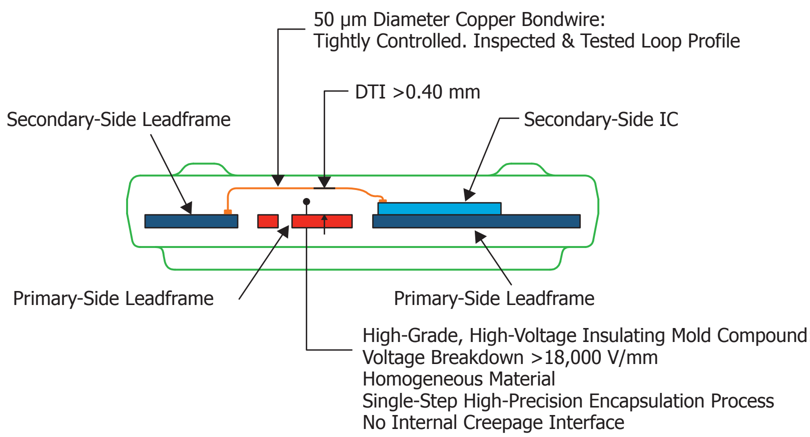


Figure 4: Cross-sectional representation of the SCALE-iDriver device structure showing relative positions of primary and secondary lead frames and bond wires.

To provide useful isolation for gate driver applications, FluxLink technology is required to demonstrate its performance, which will be measured using three different criteria:

1. Isolation – structure and resistance to breakdown during normal operation, and after catastrophic failure in high-voltage environments

2. Longevity – ability to operate for long periods under high-voltage stress

3. Noise Immunity – ability to transmit and receive without data loss

Performance of the SCALE-iDriver IC in achieving a safe IGBT shutdown in the event of system short-circuit will also be examined – termed Advanced Soft Shut Down (ASSD).

Isolation: Breakdown Resistance and Dielectric Strength

As described above, FluxLink makes use of primary and secondary lead frames separated by a controlled space filled with a homogenous high-voltage mold compound. The mold compound used is a special material certified by VDE – VDE0303-11.

- Comparative Tracking Index (CTI) rating is 600 – mold compound is in Material Group 1
- Dielectric strength is very high and passes all required qualifications
- High resistivity
  - 1×10^{16} Ω-cm at 25 °C
  - 1×10^{13} Ω-cm at 150 °C

Testing was also performed by VDE on SCALE-iDriver SID1182K parts to determine isolation surge withstand resistance in accordance with IEC 60065, Clause 10.1 test requirements. Isolation resistance was seen to be >109 Ω for all devices tested.

The FluxLink lead frame and bond wire arrangement maintains a minimum separation-through-mold material of greater than 0.4 mm[1]. The mold compound that fills the void is a single material (avoiding the challenges of creepage distances which arise where different materials interface).

In addition to the compliance verification of the FluxLink communication technology, IC package creepage and clearance are critical. The eSOP-R16B package (Figure 5) provides exceptional creepage and clearance (Table 1), which compares well with traditional optocoupler packages.

1) A single layer of insulating material must have a minimum thickness of 0.4 mm to be considered as supplementary insulation -UL60950/EN60950

As noted above, the mold compound for SCALE-iDriver devices has a very high CTI of 600 (Material Group 1), which results in increased breakdown resistance to surface charge creepage.

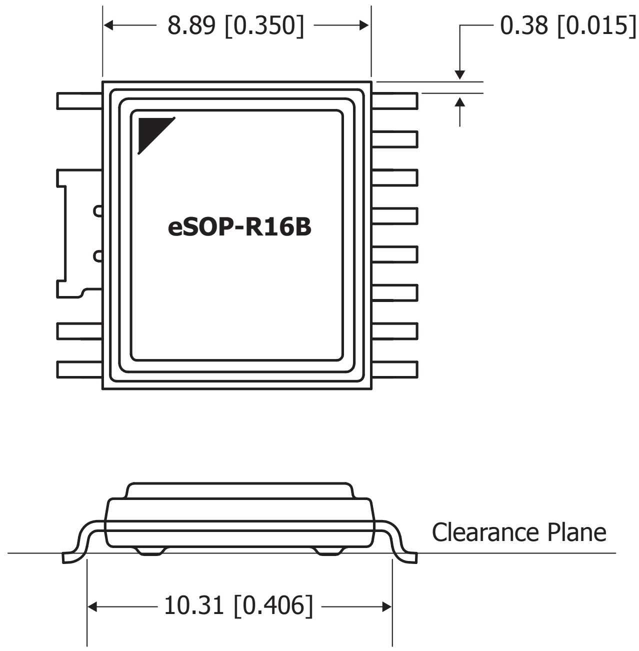


Figure 5: eSOP-R16B showing minimum creepage and clearance paths.

Package	Agency Reporting	Parameter	Distance per TUB Report (mm)	Measured plane distance (mm)
eSOP-R16B	TUV IEC60950	Creepage	9.65	9.65
		Clearance	Not Stated	10.31

Table 1: Package creepage and clearance information (primary–secondary).

Demonstrating Long-Term Integrity of FluxLink Isolation

In addition to the safety compliance testing and 100% production verification hi-pot testing, it is also important to verify the long-term integrity and extended surge lifetime of an isolation barrier.

Effects such as corona erosion and space charge degradation erode isolation capability gradually over time. The destructive effect is increased when the voltage/mm stress across an insulator is increased. Their combined cumulative effect on lifetime cannot be inferred from a single short-event test — either surge or discharge. To verify such long-term performance, device testing was performed as described in the IEC 60747 standard.

Testing to Meet the IEC 60747-17 Isolation Standard

No degradation in breakdown protection occurred through the test:

> Test performed: Single device suspended in an electrically inert CO_2 environment, 7.3 kV_{RMS} (>10 kV_{PK}) – maximum sustainable with CO_2 environment. Cumulative test time of 250 hours, ambient temperature 25 °C

It is worth noting that 250 hours of a high surge voltage is significantly more than any device can expect to experience over the equipment lifetime, even in the harshest operating environment. The >0.4 mm insulation layer in FluxLink is considered thick, with low-voltage stress sensitivity to the wear-out mechanisms described above. By contrast, thin insulators are perhaps 10 µm thick and are known to be susceptible to long-term degradation.

Optocouplers have a high-stress lifetime of several hundred hours, while some other isolation technologies (using thin polymer coatings/layers such as silicon dioxide) support less than 15 minutes of operation in a UL 1577 dielectric breakdown test [4].

Isolation Integrity in the Event of Highly Energetic Device Failure

To test the efficacy of the isolation barrier after a catastrophic device failure, several devices were made to undergo a highly energetic failure (600 V applied to low-voltage secondary drive pins). Isolation breakdown tests were then applied to measure breakdown. Similar tests were performed on a group of similarly stressed optocoupler devices.

Part Number	Parts Tested	Hi-Pot Test Voltage (kV)	Hi-Pot Failures After Destructive Test
SCALE-iDriver	10	6	0
Optocoupler Technology (3 different device types)	9	3	2
	8	3	4
	8	2	8

Table 2: Post-Failure Breakdown Test – All devices using the FluxLink isolation technology survived a 60 second 5 kV hi-pot test without failure. 56% of the optocoupler parts failed at 3 kV.

The SCALE-iDriver devices retained their isolation integrity even after dramatic package damage. Optocoupler devices fared less well, with more than half of the devices failing to reach even 3 kV in testing. In SCALE-iDriver devices, the die are positioned in the X and Y plane away from the isolation region. In optocouplers, the Z plane is used, with die actually sandwiching the isolation barrier. While this small sample cannot be seen as definitive, the inference as to the additional safety imparted by this die arrangement approach is clear.

Susceptibility – Effect of External Interference on FluxLink Signal

Multiple EMC compliance tests to EN61000 were performed on SCALE-iDriver parts to demonstrate signal integrity when subject to interference. Testing was carried out at Phoenix Testlab (Blomberg) and Trainalytics (Lippstadt), both in Germany. The tests were performed on device part number SID1182K and reference design RDHP-1608.

Test Description	Specification(1)	Performance Criteria Achieved(2)	Compliance	Test Report and Location
Radiated Immunity	EN61000-4-3	A	Compliant	E161901E1 Phoenix Testlab Blomberg
Magnetic Immunity	EN61000-4-8	A	Compliant	E160714E2 Trainalytics Lippstadt
Pulse Magnetic Field Immunity	EN61000-4-9	A	Compliant	E160714E1 Trainalytics Lippstadt

Table 3: Immunity testing and results.

In terms of isolation capability, longevity and immunity to interference, the FluxLink magneto-inductive coupling technique employed in the SCALE-iDriver family of devices is impressive and compares well to the performance of existing gate driver isolation topologies. The breakdown voltage is easily sufficient to support 1200 and 1700 V gate drivers. The extensive creepage and clearance afforded means that reinforced isolation can be claimed for a 1200 V gate driver, while basic isolation is achieved for 1700 V IGBT-based systems, such as those found in traction applications and photovoltaic power generation markets, which require at least 1500 V DC link voltage.

1) Criteria A: 'Normal performance within specification limits'. Means no interruption of normal operation during or after testing.
2) Tests were performed at 1000 A/m and 2000 A/m

SCALE-iDriver Provides Safe IGBT Shutdown and Reports the Failure Event to the System Controller

The schematic for a SCALE-iDriver (SIC1182K) device employed as an IGBT gate driver is shown in Figure 6.

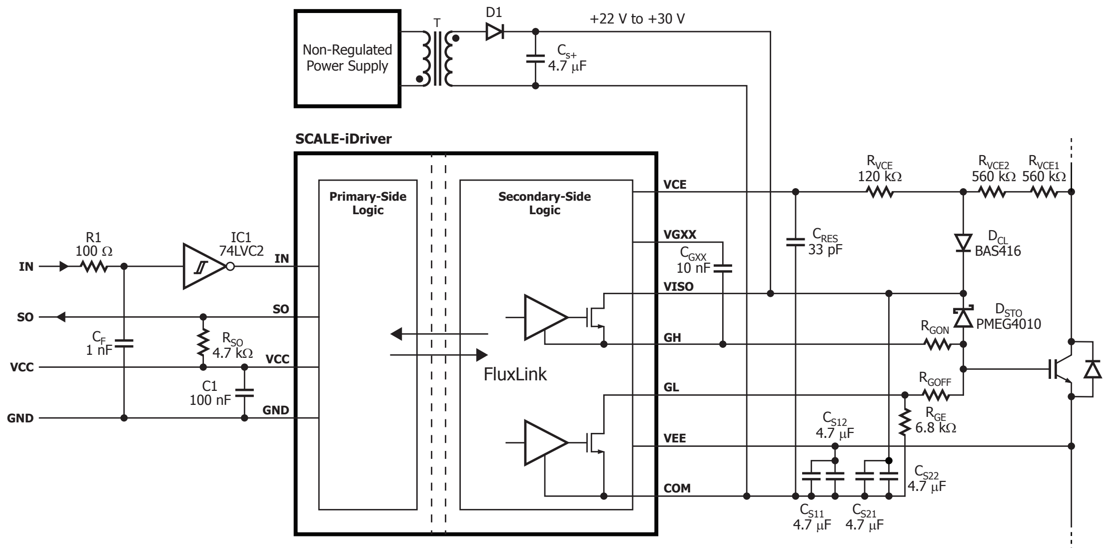


Figure 6: SCALE-iDriver-Based (SIC1182K) IGBT gate driver circuit.

The IGBT is driven by separate GH (Gate High) source and GL (Gate Low) sink pins for turn-on and turn-off, with current limited by R_{GON} and R_{GOFF}, respectively. The collector-emitter voltage (V_{CE}) is monitored on the VCE pin using a novel resistive desaturation detection circuit that detects IGBT short-circuit events (beyond the scope of this paper). In the event that a system IGBT failure occurs, the desaturation monitoring circuit will activate the SCALE-iDriver ASSD function on the secondary side of the SCALEi-Driver device and transmit (via FluxLink) a warning notification to the low-voltage input side of the device. The SCALE-iDriver soft turn-off is independent of the power semiconductor characteristics because gate-emitter voltage reduction depends on gate current alone. It is worth noting that the device is unipolar – being supplied for a single input rail (VISO), internal level-shift and regulation circuits generate the other required voltage rails, reducing component count.

In high-power systems, a rapid shutdown of the switch cannot be allowed to occur. The high rate of collector current change that this would cause, coupled with circuit parasitic inductances, would induce a large V_{CE} overshoot, causing possible device failure. Fortunately, IGBTs are robust – the large mass of the devices and the resulting thermal inertia means that a high short-circuit current can flow for tens of microseconds before damage will occur. To shut down the device safely, the ASSD SCALE technology uses the thermal inertia time interval to turn the IGBT off in stages. Similar protection can also be afforded to SiC and MOSFET devices subject to system short-circuit.

When an IGBT short-circuit is detected, the SCALE-iDriver device sends a notification signal to the primary and begins a staged shutdown sequence. GL provides a current sink and monitors gate current, while the GH pin tracks gate voltage. The shutdown sequence is shown in Figure 7.

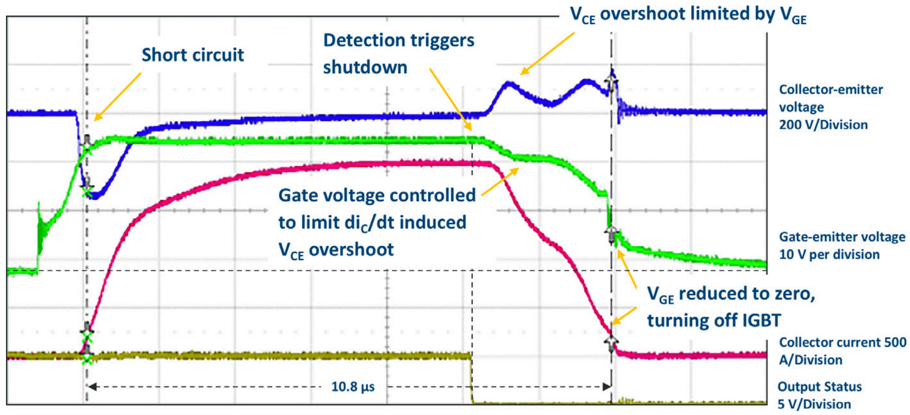


Figure 7: Waveform analysis of ASSD function in operation.

Following an IGBT short-circuit, the SCALE-iDriver control circuit determines whether the V_{CE} change detected on the VCE pin is indeed a short-circuit event. Collector current (pink trace) rapidly increases. After the detection period (time constant set by C_{RES} and the RV_{CE} chain), the desaturation detection circuit sends a shutdown notification to the primary (yellow trace). GL begins to sink current, causing the gate voltage to fall (green trace). Gate current drops and the first V_{CE} spike occurs (blue trace). The ASSD circuit responds by reducing the rate of turn-off of the gate (monitored and controlled by GH voltage and GL current, measurements). The rate of change of gate voltage – controlled by the gate current – decreases and reduces the size of the V_{CE} spike. Once V_{CE} recovers sufficiently, GL again begins a controlled reduction of gate current, causing the rate of drain current change to increase and a second V_{CE} spike to occur. By regulating the rate of change of drain current, the spike is controlled. When V_{GE} is low, the device is finally turned off, causing a final small spike in V_{CE}.

The controlled reduction in gate current, monitored by the GH, GL and VCE pins and regulated by the SCALE technology, limits the V_{CE} overshoot to several small events while rapidly reducing the IGBT drain current to zero. Figure 8 summarizes the turn-off steps.

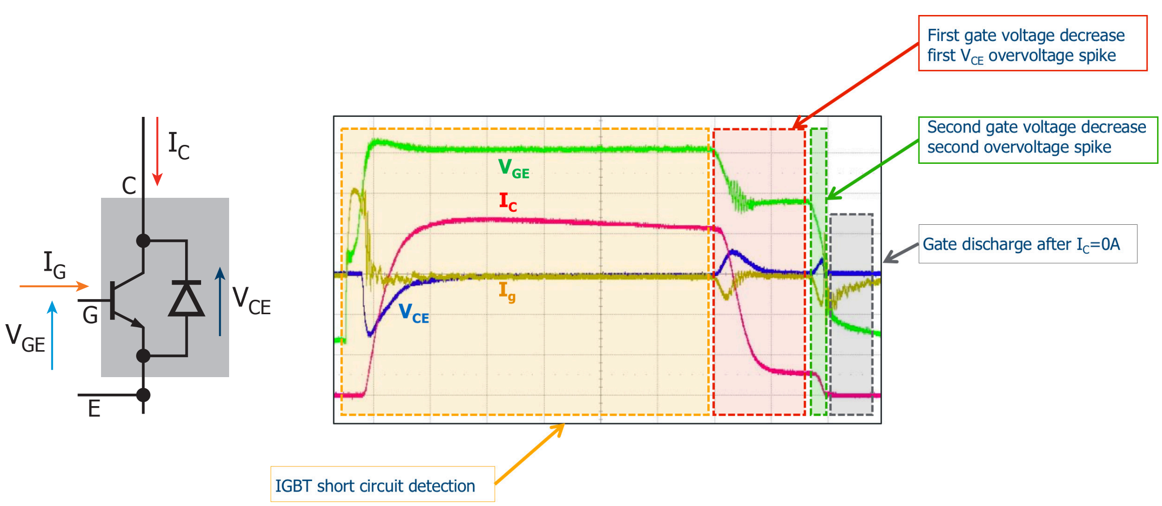


Figure 8: ASSD summary of stages.

Conclusion

The efficacy of the FluxLink pulse transformer employing magneto-inductive coupling between primary and secondary is a safe, robust, and reliable isolation technique that offers definite advantages over conventional barrier crossing technology. The combination of the new technology with advanced control features such as Advanced Soft Shutdown in the SCALE-iDriver device family provides designers with new tools to increase system reliability while reducing size and cost.

References

[1] Datasheet SID11x2K, SCALE-iDriver family

[2] VDE 0884-10, Semiconductor devices - Magnetic and capacitive couplers for safe isolation

[3] Fluxlink Technology, Safety and Reliability (A. Smith, February 2017)

[4] Safety Considerations When using Optocouplers and Alternative Isolators for Providing Protection against Electrical Hazards – Avago Technologies

For more information,
visit **power.com**™

PI-W1021-06