Gate Drive Optocoupler Provides Robust Insulation in IGBT Destructive Tests

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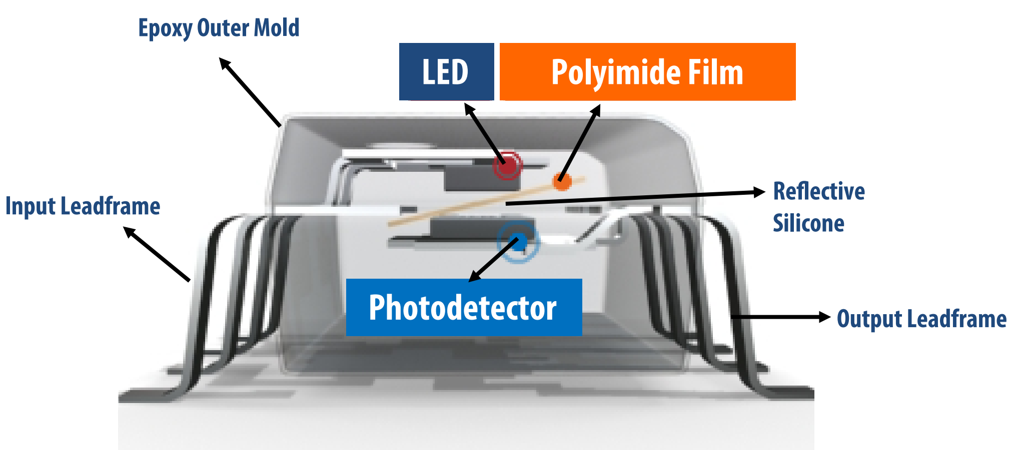
White Paper

Introduction

Avago Technologies gate drive optocouplers are used extensively to drive IGBTs in applications such as motor drives and solar inverters. Optocouplers are a proven technology to provide reinforced galvanic insulation for high voltage protection between IGBTs and control circuits. They are also used to reject high common-mode noise (CMR) and prevent erroneous driving of the IGBTs.

But in order not to compromise the optocoupler insulation barrier, power safety limits must not be exceeded in the event of component failure by protective circuits in application. This can be extremely difficult if catastrophic failures like IGBTs short circuit induce higher energy power into the optocoupler. This paper discusses the impact of unprotected IGBT destructive tests on the insulation barrier of an Avago gate drive optocoupler.

Optocoupler's Structure with Three Layers of Insulation Barrier



Optocoupler's Structure and Regulation

Avago Technologies optocouplers provide reinforced insulation by wide Distance Through Insulation (DTI) between the LED and detector and three layers of insulation barriers. The three layers of insulation are made up of silicone, polyimide film, and silicone. Polyimide film is developed specifically to withstand the damaging effects of partial discharge, which can cause ionization and breakdown of insulation material. Polyimide's unique properties of high dielectric strength and a wide temperature range allow it to be used extensively for a range of electrical insulation applications, from locomotives to aerospace. The polyimide film used in Avago Technologies optocouplers has a typical dielectric strength of 300 kV/mm and can withstand temperatures as low as –200 °C and as high as 400 °C.

The ACPL-337J smart gate drive optocoupler, for example, has a DTI of 0.5 mm and is compliant to the industrial safety standards, IEC/EN/DIN EN 60747-5-5, with a maximum reinforced working insulation voltage of V_{IORM} = 1414 V_{PEAK}.

The IEC/EN/DIN EN60747-5-5 is recognized in the industry as the de facto standard for optocouplers. The standard subjects optocouplers to a set of rigorous environmental preconditioning-like temperature cycles, vibration, mechanical shock, humidity stress before partial discharge, and surge tests. Optocouplers are also subjected to input LED and output IC overload safety tests for 72 hours before a partial discharge test. This is to ensure that the current, power, and case temperature do not overload beyond an optocoupler's safety limits and compromise the insulation barrier. The overloading of an optocoupler's power supply can be protected by circuits like crowbar, clamping diode, and current limiting resistors. Overloading caused by high-voltage IGBT failures such as short circuit or parasitic-induced Miller current can be protected by the integrated IGBT DESAT detection and active Miller clamping of a smart gate drive optocoupler, ACPL-337J. In addition to these standard protections to meet the safety limiting values, this paper discusses the impact of an unprotected IGBT destructive test on the insulation barrier of an Avago gate drive optocoupler.

IGBT Failure Modes and Destructive Tests

There are three IGBT failure modes that can induce high energy power into an optocoupler: 1) Desaturation, 2) VCE voltage overshoot, and 3) Induced Miller current. The possible causes of these failures and damages are shown in Table 1.

Table 1 IGBT Failure Modes and Destructive Tests

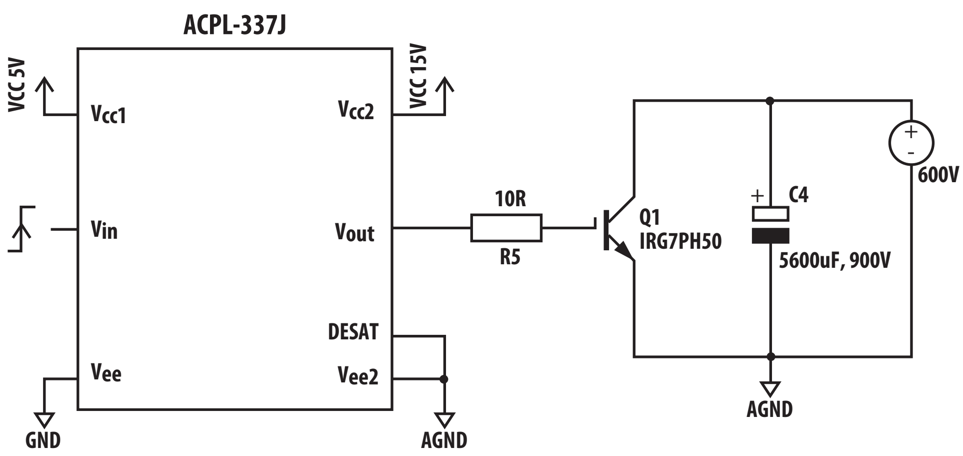
IGBT Failure Mode	Possible Cause of IGBT Failure	Possible Damage	ACPL-337J's Protection	IGBT Destructive Test
1) IGBT Desaturate	Phase of rail supply short circuit	High IGBT current causing thermal overstress	DESAT	IGBT short circuit test with DESAT disable
2) IGBT V_{CE} Voltage Overshoot	Hard shutdown during IGBT shoot through	High overshoot causing IGBT's V_{CE} overstress	Soft shutdown	Repeated IGBT short circuit test with DESAT enable
3) IGBT Induced Miller Current	Induced Miller current during hard shutdown	High current surge into gate driver	Soft shutdown and Active Miller Clamp	Direct current injection from IGBT to optocoupler

The three failure modes can be protected by the ACPL-337J's features of DESAT detection, soft shutdown, and active Miller clamp. These protection features will be disabled to simulate unprotected IGBT destructive tests by:

- IGBT Short circuit test with DESAT disable
- Repeated IGBT short circuit test with DESAT enable
- Direct current injection from the IGBT to an optocoupler

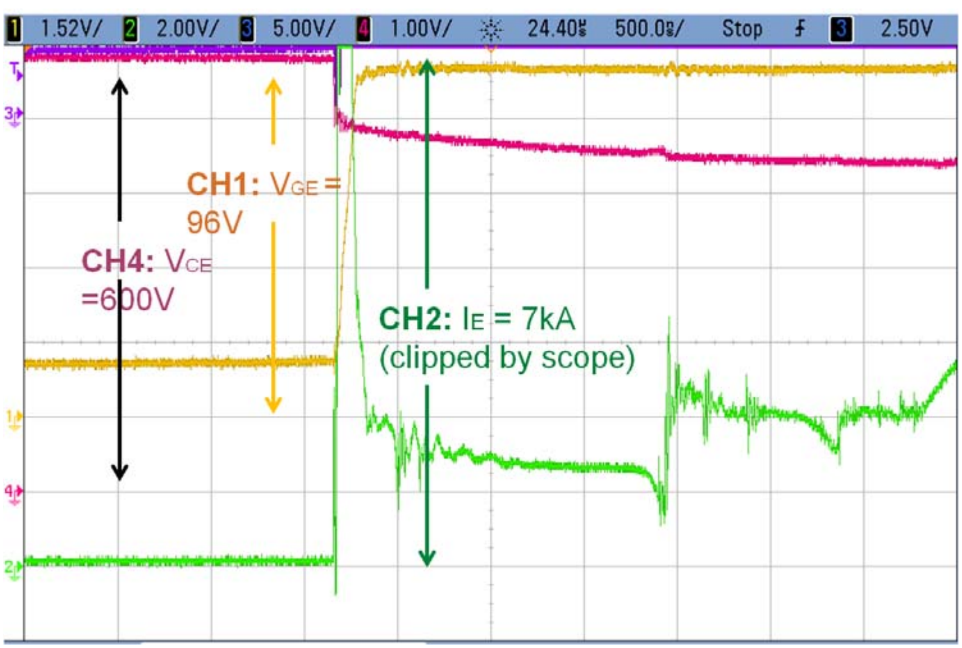
IGBT Short Circuit Test

Figure 1 IGBT Short Circuit Test Setup



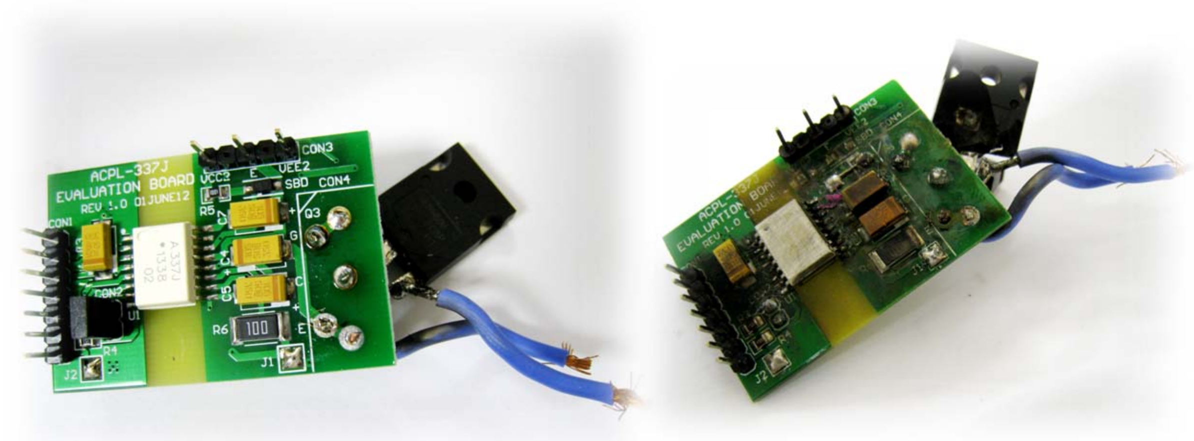
The ACPL-337J was used to drive the gate of a 1200-V/150-A IGBT. The ACPL-337J provided galvanic isolation between the high voltage and logic power supply and was supplied by a unipolar 15-V supply. The IGBT was connected to 5600-µF DC-link capacitor at a bus voltage of 600 V to create high current short circuit when turned on. The DESAT pin of ACPL-337J was grounded to disable the DESAT protection feature and prevent automatic shut down of the IGBT during short circuit. The clamping diode was not used to mitigate the impact of the destructive energy to the gate driver.

Figure 2 IGBT Short Circuit Waveforms



When short circuit occurred, the IGBT was driven into shoot through and an emitter current, I_E of 7 kA was recorded as shown Figure 2. The IGBT did not saturate (V_{CE}) and the gate emitter voltage (V_{GE}) increased tremendously, driving itself into thermal overload. This voltage was fed back to the ACPL-337J under test.

Figure 3 The ACPL-337J Gate Driver Board Before and After Short Circuit Test



Before Short Circuit Test

After Short Circuit Test

The case of the ACPL-337J remained intact except from the burns of the IGBT blast. Many discreet components were damaged, and the gate driver board was not functional.

Figure 4 The Destruction of the IGBT After Short Circuit Test

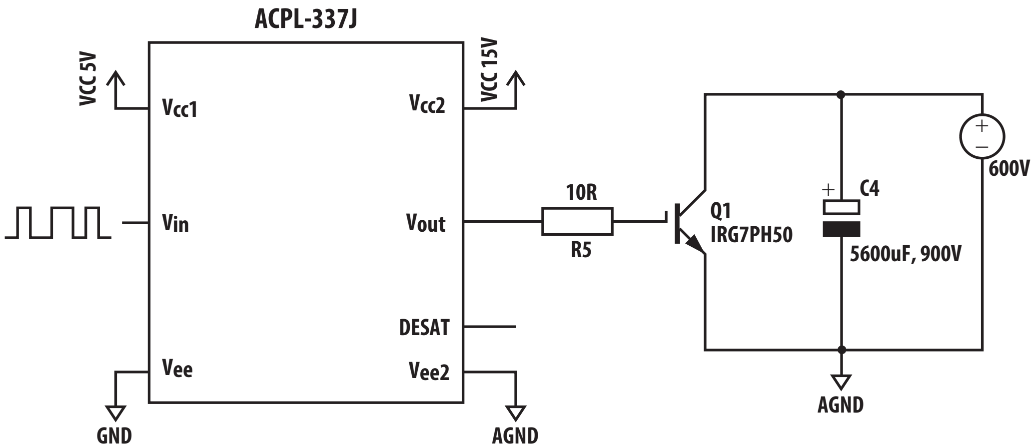
The ACPL-337J was electrically tested, and it passed the rated partial discharge test (1.88 kV_{RMS}/s) and high voltage insulation test (6.2 kV_{RMS}/s). Visual inspection was done externally and internally to determine the degree of damage to the insulation barrier.

Figure 5 The Polyimide Film of the ACPL-337J After Short Circuit Test

Optical inspection of the polyimide film showed no damage and the insulation remained intact.

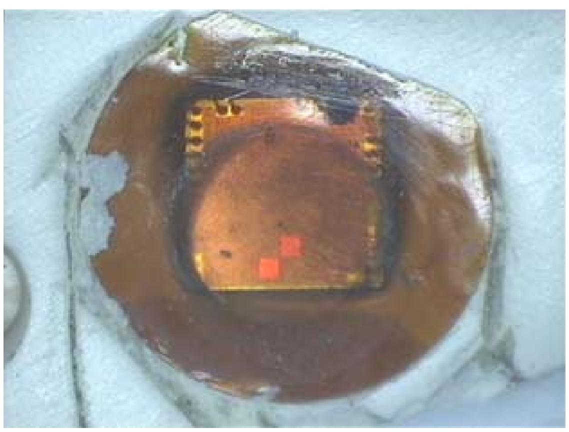
Repeated IGBT Short Circuit Test with DESAT Enable

Figure 6 Repeated IGBT Short Circuit Test Setup



The test setup was the same as the short circuit test, except the DESAT pin of ACPL-337J was left floating. The ACPL-337J will shut down the IGBT at every short circuit cycle after a blanking time of about 1 µs. It would require about 10 to 20 pulses with variable period of about 2 s to cause repeated high IGBT V_{CE} overshoot and burn the IGBT. The ACPL-337J was electrically tested, and it passed the rated partial discharge test (1.88 kV_{RMS}/s) and high voltage insulation test (6.2 kV_{RMS}/s).

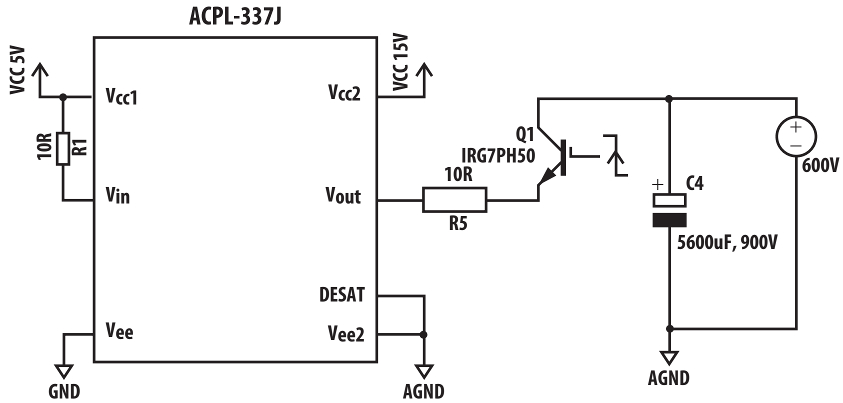
Figure 7 The Polyimide Film of the ACPL-337J After Repeated Short Circuit Test



The gate driver board was not functional, but optical inspection showed no damage to the polyimide film and the insulation remained intact.

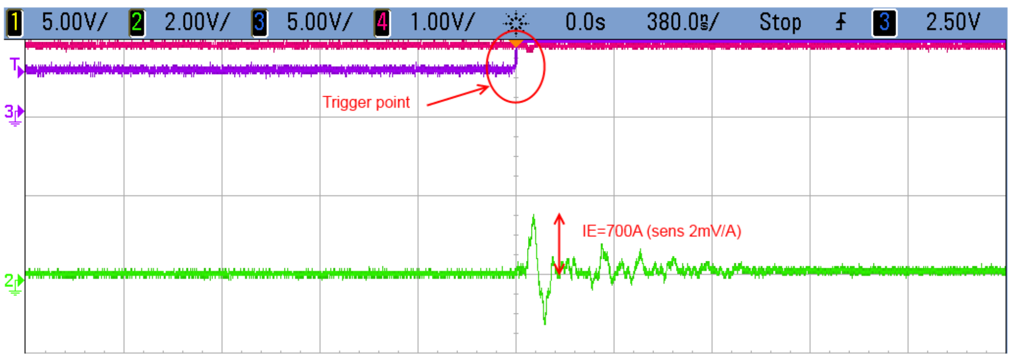
Direct Current Injection from IGBT to Optocoupler

Figure 8 Direct Current Injection Test Setup



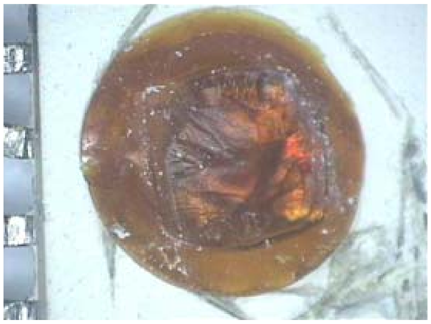
In this test, the IGBT was used to inject high current into the output of the ACPL-337J. The IGBT was triggered with a single 15-V pulse and the gate driver's input was kept at high logic. The IGBT was connected to a 5600-µF DC-link capacitor at a bus voltage of 600 V.

Figure 9 Direct Current Injection Waveforms



When 15 V was triggered at the gate of the IGBT, approximately 700-A emitter current was registered on the scope. This was the worst destructive test as direct energy flowed into the gate driver, causing severe damage to the gate driver board.

Figure 10 The Polyimide Film of the ACPL-337J After Direct Current Injection Test



The ACPL-337J was electrically tested and passed the rated partial discharge test (1.88 kV_{RMS}/s) and high voltage insulation test (6.2 kV_{RMS}/s). There was no damage to the polyimide film and the insulation remained intact.

Summary

Table 2 Summary of IGBT Destructive Tests Impact on Optocoupler

IGBT Failure Mode	External Visual Inspection	Gate Driver Board Functional Test	Partial Discharge Test 1.88 kV_{RMS}/s	High Voltage 6.2 kV_{RMS}/s	Insulation/ Polyimide Film
1) IGBT Desaturate	Pass	Fail	Pass	Pass	Pass
2) IGBT V_{CE} Voltage Overshoot	Pass	Fail	Pass	Pass	Pass
3) IGBT Induced Miller Current	Pass	Fail	Pass	Pass	Pass

The polyimide film and insulation barrier of Avago Technologies gate drive optocoupler is proven robust even during catastrophic failures like the IGBT destructive tests presented in the paper. Although the gate driver boards were damaged, the gate drive optocouplers were able to pass partial discharge and high voltage tests, providing reinforced insulation, protecting the systems and users.

On the contrary, alternative isolators (magnetic and capacitive) with a thin layer of spin-on polyimide or silicon, smaller than 17-µm DTI, might not perform comparably in such destructive tests.

Reference

ACPL-337J 4.0 Amp Gate Drive Optocoupler with Integrated (V_{CE}) Desaturation Detection, Active Miller Clamping, Fault and UVLO Status Feedback, Avago Technologies, AV02-4390EN.

http://www.avagotech.com/products/optocouplers/industrial-plastic/isolated-gate-drive-optocouplers/highly-integrated-smart-gate-drives/acpl-337j-000e

For product information and a complete list of distributors, please go to our web site: www.broadcom.com.

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