IGBT Drivers – Design for Quality

Heinz Rüedi and Jan Thalheim
CT-Concept Technologie AG
Renferstrasse 15
2504 Biel-Bienne (Switzerland)
Tel +41 – 32 – 341 41 01
Fax +41 – 32 – 341 71 21
E-Mail Info@IGBT-Driver.com

Abstract

The theoretical advantages of new IGBT technologies can be exploited only with optimal driving capability. The complex demands made on IGBT driver circuits, especially in the higher power and voltage ranges, call for an efficient design methodology to optimize reliability, functionality, scalability, costs and time-to-market. This paper describes the design methodology of the SCALE driver family. These drivers are used in large item numbers and have proved highly successful within a broad diversity of applications.

1. Introduction

Gate drivers are the link between system control and power semiconductors. Parasitic effects and electromagnetic compatibility are consequently key issues for driver and system performance. The ongoing optimization of the systems with respect to switching speed, insulation voltage, functionality within innovative system topologies, EMI, degree of integration and costs makes complex and interdisciplinary demands on development and support. In addition, a largely universal gate driver must be compatible with diverse power semiconductors and topologies (e.g. power MOSFETs of the 60V/100A class, parallel connection of high-power modules and series connection of 6.5kV IGBTs.

2. Design and Verification Methodology

Complex power-electronics systems with critical reliability requirements may contain more than a hundred gate drivers. Especially in the sectors of power generation / transmission and public transportation, high system availability is absolutely essential. Any loss of functionality leads to high costs and tarnishes the image of the companies responsible. So gate drivers play a central role as regards reliability.

Some applications require a guaranteed service life of up to 30 years. An advanced design and test methodology is the key to success, especially where components are subject to increased stress due to shocks, vibrations and temperature cycles.

2.1. Design Methodology

The fundamental functionality of IGBT drivers already leads to increasing complexity in development. However, high time and cost expenditures result particularly from the fact that the assured functions must as far as possible be guaranteed in all conceivable applications under all operating conditions. CT-Concept Technologie AG has been a leading supplier of gate-driver components for 18 years. Its success in the development and manufacture of its products is based on the following aspects.

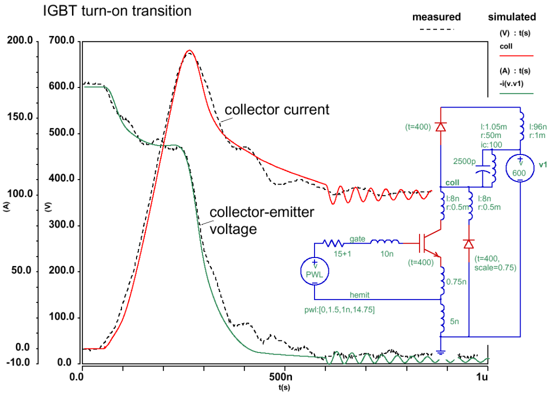

Fig. 1: Turn-on of an IGBT – simulated (solid lines) and measured (dashed).

In-house development of critical components:

- Full-custom ASICs
- Signal and supply transformers
- Printed circuit board layouts
- Test adaptors and software

Highly advanced design tools:

- Analytical verification by means of high-end simulation tools such as Matlab/Simulink/Plecs and Mentor Eldo/ADVance MS
- Advanced modeling (IGBTs and diodes with numerical calculation of excess carrier profile; distributed parasitics extraction within ASIC design, see Fig. 1)
- Rigorous experimental verification against simulation

In-house test and qualification:

- Advanced test procedures for development and production for ASICs and driver boards
- Parameter and reliability statistics

2.1.1. ASIC Design

IGBT gate drivers cover both low-voltage analog and digital as well as high-current and high-voltage circuitry. IGBT drivers are becoming increasingly complex. However, the large number of components has a negative impact on the reliability of the circuits. Cost reduction with simultaneously increased reliability requires a higher degree of integration, which is achieved by implementing all the driver functions in ASICs as far as possible. Depending on the architecture and application, the supply voltage is 15V to 30V and the output currents are several amps. Depending on the application and required signal delay, further operating voltages of between 3.3V to 45V are required in addition to linear-passive and electromagnetic components as well as non-volatile memories. This requires full-custom design, specialized ASIC technologies or even a custom-specific technology.

Design for quality covers the following items:

- Specification and design to a junction temperature of -55 to +140 °C, even when only -40...+125 °C is specified for the end product
- Full-custom ASIC design
- Extraction of the distributed parasitics of the ASICs
- Mixed-mode mixed-language simulation (Spice, VHDL-AMS, C) including ASICs, electromagnetic components, power semiconductors and EMI sources
- Integration of safe operating area (SOA) and reliability checks (i.e. hot-carrier degradation) within the network simulation

The main goals of the SCALE driver chipset (see Fig. 2) development program are reliability and flexibility /1/. Applications range from MOSFET-equipped 48V drives up to drivers for the series connection of 6500V IGBTs.

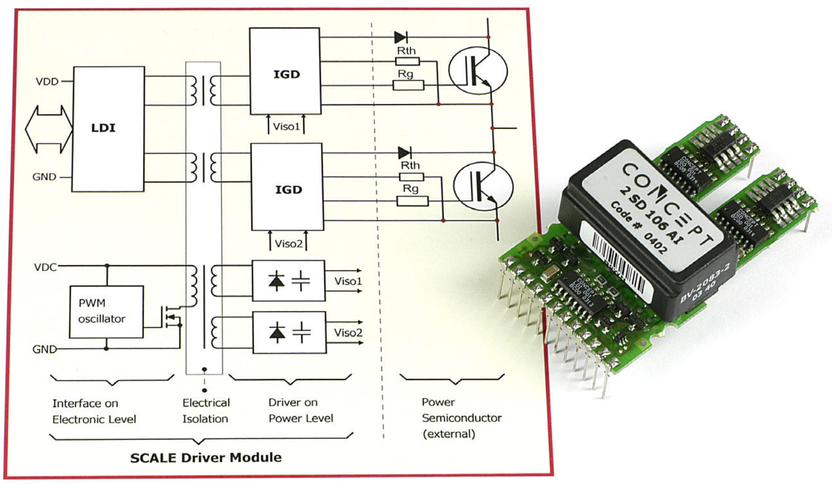

Fig. 2: Architecture of the SCALE driver chipset (left) and dual channel driver core 2SD106AI (right)

2.1.2. System Design

Sustainability is the key to success. Passive components still represent a weak point in terms of reliability. Consequently, any components - including second sources - are qualified in-house to meet customized specifications, taking into account the particular requirements of advanced gate drivers. This means that component selection is primarily based on experience rather than the lowest available price. Furthermore, new products

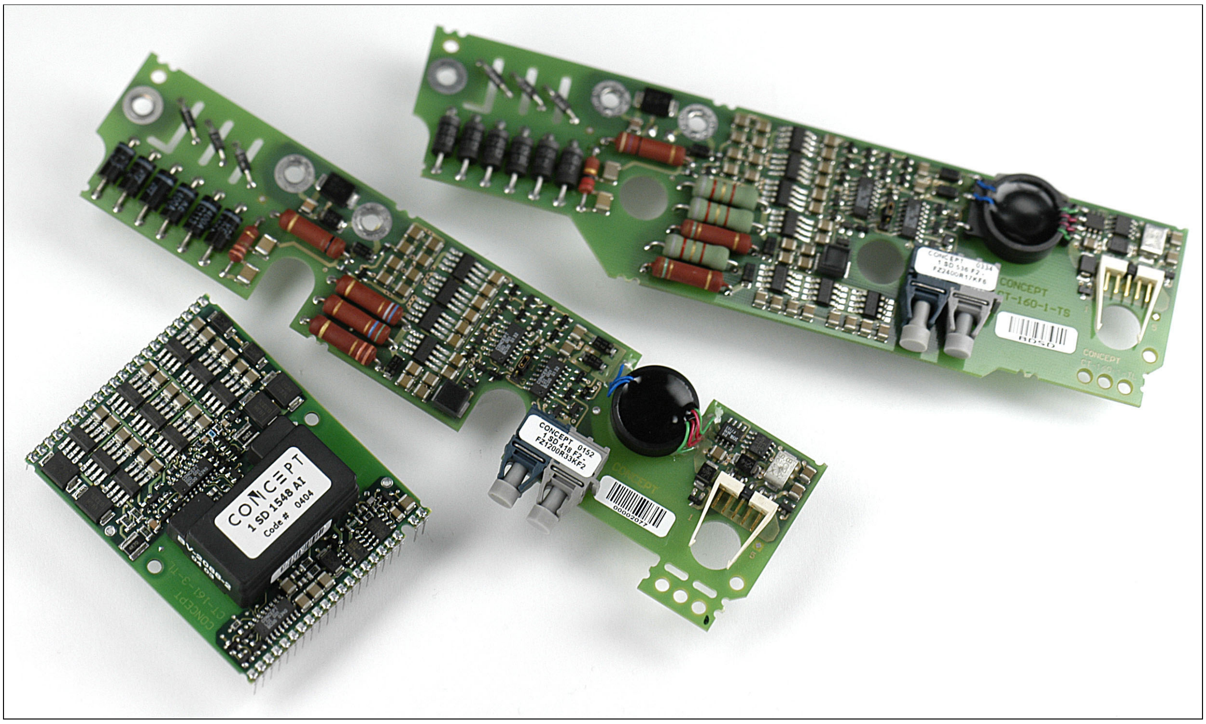

Fig. 3: Plug-and-play drivers for 1200A/3300V IGBTs (1SD418F2, center), 2400A/1700V IGBTs (1SD536F2, top) and a high-power driver core (1SD1548AI, bottom) based on identical circuit cores

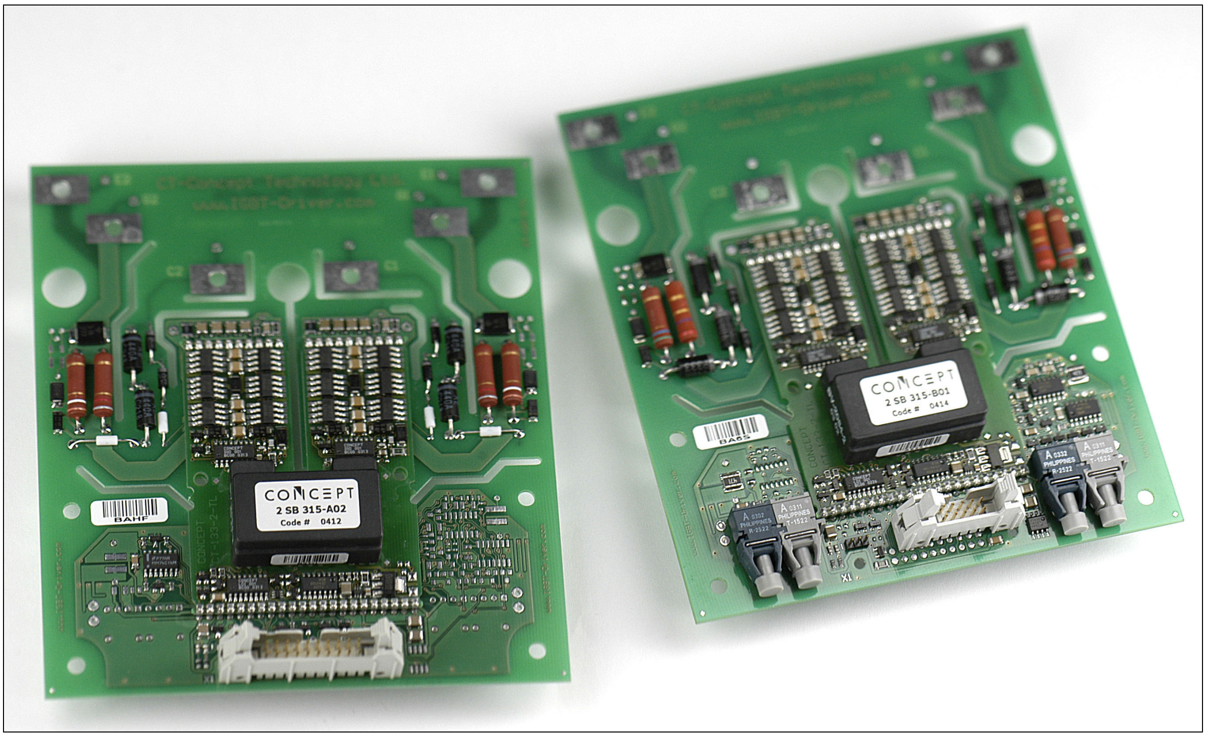

Fig. 4: The 2SB315 generic gate driver with options to provide electrical interfaces (left) or fiber-optical links (right) and others designed to provide for future developments including a reserved test-pad field. Note that the test adaptor and some of the testing-software cores are the same for each driver option.

tend to rely on the re-use of highly approved circuit cores and components rather than on complete new developments and architectures. Although price is also an issue, optimization primarily takes into account the specified MTBF of a product. As a rule, therefore, critical components such as electrolytic capacitors and glass-packaged diodes are strictly avoided. Reliable components based on ceramic substrates, metal film technology and monolithically integrated components are employed whenever possible. Furthermore, integration of passive components (e.g. inductances, capacitances) on the printed circuit board (PCB) is being considered for the future. Recent ASIC designs are driven by the reliability of external components rather than by the area consumed by silicon. Among the results of this approach are fully integrated 6A driver stages and a minimized number and type of board-level components.

Re-use of approved components and circuitry also applies to the following levels:

1. ASICs – the SCALE driver chipset is designed to meet the requirements of any scale of application, e.g. it is used for an application-specific six-channel driver for 60V MOSFETs with a bi-directional pulse transformer interface, but also for the 6500V single-channel standard driver (1SD210F2) with a fiber-optical link.
2. Driver cores – both the 1700V single-channel high-gate-current driver (1SD1548AI) with a bi-directional pulse-transformer interface and the single-channel high-gate-current driver (1SD536F2) with a fiber-optical link employ the same sub-architectures and partial re-use of circuitry of the highly approved 3300V single-channel medium-gate-current driver (1SD418F2, /2/, /3/), see Fig. 3.
3. Driver boards – recent driver families use large common partitions within the PCB space combined with a driver-specific space, and reserved space including a test-pad field in order to meet reliability and time-to-market requirements, see Fig. 4.
4. Test software – generic and parametric test software cores are re-used for new products to optimize reliability and time to market.

2.2. Test Methodology

Production is largely carried out by subcontractors who are certified to ISO9001:2000. All circuit boards undergo an automated optical inspection (AOI) as well as an in-circuit test and a function test on ATE (automated test equipment, see Fig. 6). Final testing of fully assembled gate driver units is performed in-house by CONCEPT.

Because all test systems as well as the specific test know-how are available in-house, small quantities as well as customer-specific products can be tested under optimized time and cost conditions to the same quality as larger series.

2.2.1. Type Test

As a rule, the following type tests are applied to the gate drivers:

- Verification of all parameters over a temperature range from -40...+85 °C
- Parameter verification within continuous tests at high ambient temperatures up to +135 °C
- Temperature cycles, artificial aging
- Self-heating under various operating conditions
- Integration of temperature distribution measurements (by means of an infrared camera, see Fig. 5) in MTBF calculations
- Experimental verification of dv/dt immunity
- Use under close-to-reality operating conditions in a test bench
- Converter operation on a performance test unit

For transformers, the following type tests apply:

- Partial discharge measurements
- High-temperature storage
- Temperature cycles, temperature shock tests, artificial aging
- Subsequent verification of all parameters

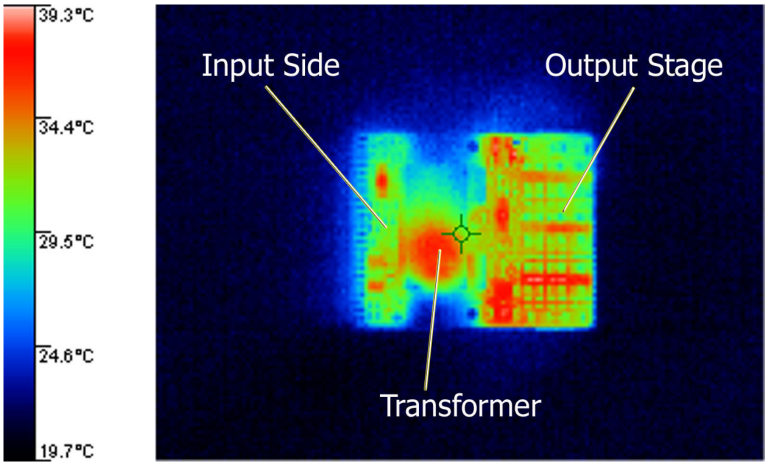

Fig. 5: Thermographic image of a single-channel high-power IGBT driver core (1SD1548AI) in operation under load

- Automatic recording of measured data for statistical evaluation
- Annually repeated type test for every product (product audit)

2.2.2. Series test

All products are 100% tested:

- Partial discharge tests (practically the entire product range)
- dv/dt test (100% when required, i.e. when not covered otherwise)
- ICT (in-circuit test, for all new developments since 1999)
- FT (function test)

2.3. Reliability Field Data

Reliability data are an important criterion for comparing similar products from different manufacturers. Sometimes it is not clear how manufacturers have calculated the MTBF. This means that a product with a lower MTBF could actually be more reliable than one with a higher rating. CONCEPT therefore also checks the reliability data and models against field data. Thus, for the well-established two-channel IGBT driver core 2SD315AI, the calculated MTBF according to MIL217F is 10 million hours, which is state-of-the-art. Field-data statistics over a period of three years show an even higher MTBF of about 40 million hours. This underscores the superior quality of these products based upon our proven design and verification methodology.

Fig. 6: Integrated in-circuit and functional tests with automated test equipment (ATE)

3. Summary and Outlook

High research and development expenditures, implementation of many years of experience and consistent insistence on top quality have made CONCEPT one of the leading suppliers of IGBT drivers with an extensive product range. These IGBT drivers have proved their worth worldwide in practically every conceivable application and represent the state of the art in the sector of mid and high-power applications. This position is confirmed by current developments, which aim at achieving a maximum degree of integration together with high flexibility and functionality, also for series and parallel connection of IGBTs /4/, /5/.

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