WBGlobalSemi, Inc.

Double Pulse Switching Test Inductor (DPTI), Bruce Carsten, CTO Circuits & Systems, WBGS, Inc.

Power America RFI: Focus Area 3: Develop commercial testing device to accelerate industry commercialization of SiC & GaN devices.

BACKGROUND: Commercializing SiC and GaN active switches requires that their switching speed characteristics be established from empirical measurements in test circuits. Of greatest potential application at high power levels are transistors that can be forced both ON and OFF, such as GaN devices and SiC MOSFETs, SiC BJTs, SiC IGBTs, and SiC Thyristors such as the SiC GTO.

<u>This information is essential in predicting a transistor's switching loss under operating conditions of drive, voltage, current, temperature and switching frequency.</u>

As DPT is essential for predicting high power "Wide Band Gap" SiC and GaN devices, this test instrument is based on a new high power inductor design and topology that incorporates SiC Schottky clamping diodes, scaled as necessary to meet the user needs. Based on our proven commercial experience with H and E field probes in use at many US national labs, power electronics companies, and universities we expect design, development, and initial product release could occur within a one year cycle in partnership with interested Power America members.

Resistive load switching tests (Fig. 1) are easiest to perform for a reasonable measure of total switching speed.

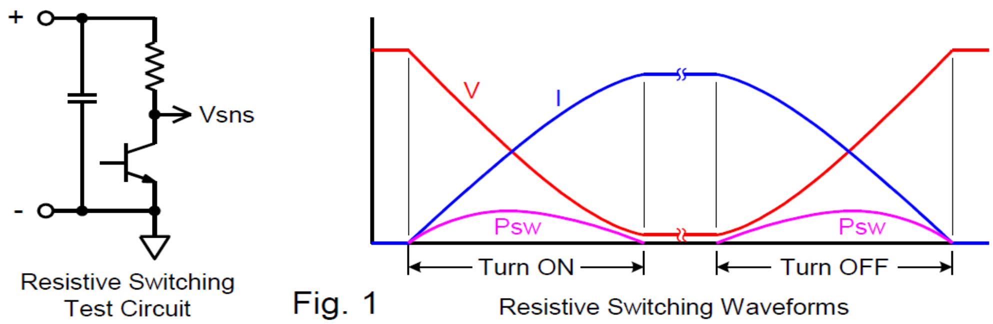


Fig. 1

Clamped inductive switching (Fig. 2) better duplicates real world operating conditions in most power converter applications. When a transistor turns on, the current first rises to the level in an inductor, while the remaining current continues to flow through a 'clamping diode' to a hard voltage source; during this interval the voltage remains high and constant on the transistor.

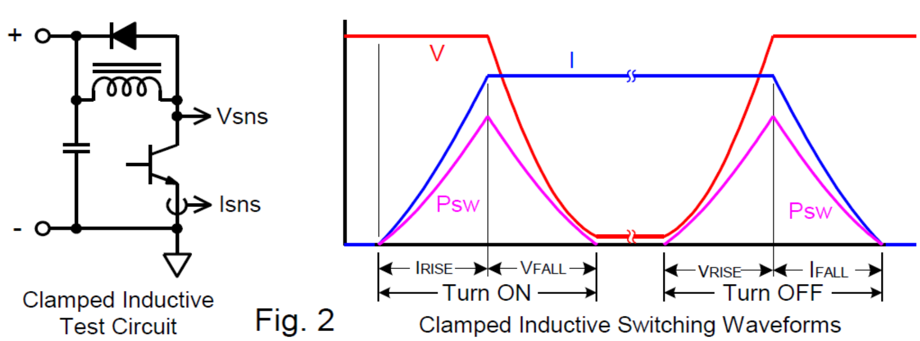


Fig. 2

With an ideal voltage clamping diode, the voltage on the transistor begins to fall when the diode current reaches zero, and the *current* now remains essentially constant as the voltage falls, until the fully ON state is reached. (Some diodes, such as PiN diodes, exhibit a 'reverse recovery', where they continue to conduct for a period after the direction of the current reverses.) SiC Schottky diodes are the closest to ideal diodes in switching behavior above the 60V - 100 V range, and are presently available up to 1.2 and 1.7 kV at current levels up to 50 A. Our current design thinking assumes the use of SiC Schottky diodes.

During turn-off, the voltage first rises while the current remains constant at the inductor's level, until the voltage is again clamped by the diode, after which the transistor current 'tails off'.

This is run as a "double pulse" test (Fig. 3); the transistor is first turned on for an extended period to build up the desired current in the inductor. The transistor is then pulsed OFF to measure turn-off characteristics, back ON for the turn-on test, and finally back OFF again, with the inductor's stored energy dissipated in the diode and the inductor's resistance.

Transistor current now must be measured as well as voltage.

In both types of switching tests an oscilloscope or other digital measurement system stores the information, so that often only a single switching cycle needs to be performed, minimizing self-heating in the transistor and the 'load' components. The product of transistor voltage and current is integrated over time to obtain the energy loss during the turn-on and turn-off intervals.

Although total switching times are similar in both tests, the transistor's energy dissipation with clamped inductive switching is several times higher than resistive load switching, so clamped inductive tests need to be run to obtain this essential engineering design information.

DPTI DEVELOPMENT AS CRITICAL COMPONENT IN HIGH POWER DEVICE TESTING

Substantial research and prototyping in the 4.5 kV to 15 kV range for SiC transistors have occurred to date, while Power America members have proposed SiC GTOs to 50 kV, for example the 4th WiPDA IEEE workshop presented results by ABB, et. al. *"The simulation results indicate that the SiC MOSFET has the highest current capability up to approximately 15 kV, while the SiC IGBT is suitable in the range of 15 kV to 35 kV, and thereafter the SiC GTO thyristor supersedes the loss performance from 35 kV to 50 kV. "*

Future transistor test voltages will range to 50 kV, while currents may range from 10s to 1,000s of amps.

We propose that the most important component for clamped inductive switching tests is the inductor itself.

Although conventional inductors can and have been used, high power requirements are sufficiently unique that at high volt-amp product levels special purpose inductors need to be designed and commercialized.

DPTI INDUCTOR DESIGN CONSIDERATIONS:

The high ratio of pulse energy to average power level (nearly zero) mandates the use of an air cored inductor for maximum energy density (i.e., the smallest physical size).

A toroidal inductor may seem ideal, in that it minimizes problematic external magnetic fields, but these are not easy to wind, and the multiple layer windings necessary will have a high parasitic capacitance and voltage breakdown issues. Their greatest drawback is their limited ability to adapt inductance to varying voltage and current levels, which can only be done by connecting multiple windings in series or parallel, which only change the impedance while stored energy remains constant.

The proposed alternative is to design the inductor with two anti-parallel, air-cored solenoidal windings, with the magnetic field returned from one solenoid to the other through ferrite or powdered iron end yokes. It is further proposed that these windings be of modular design, consisting of individual 'discs", as shown in Fig. 4.

In this approach the inductance-current relationship can not only be modified through various series-parallel interconnections, but the total energy can be increased simply by adding more discs to the winding 'stacks'.

An important feature is that each disc can incorporate its own SiC Schottky clamp diode, scaled to the individual disc's voltage and current capability. It is calculated that, with a 1.2 kV, 10 A diode, each disc can be 'rated' for about 1 kV with a peak current of 75 amps, with an inductance of about 1 mH for each disc. The segmented design of the individual winding / clamp diode portions allow very low effective parasitic capacitance of the windings and clamp diodes, and very low reverse recovery time for the clamp diodes, even when testing devices to 6 - 20kV or more. This will allow accurate switching time testing of high speed – high voltage devices such as SiC MOSFETs and BJTs and GaN devices. A focus of this project will be to further reduce the inductor winding capacitance to improve the accuracy of device tests.

WBGlobalSemi is in the process of developing SiC BJTs with switching speeds approaching the best SiC MOSFETS ~ 45ns at VCE of 6 kV at 50 A. Initial test transistors will be available in Q-2, 2019.

Our simulations indicated these can be paralleled to ~ 450A but this is quite challenging. Our company is one of many potential users of the proposed DPTI device.

We are in discussion with potential US customer regarding parallelization on wafer of a number of SiC BJTs to create a single ~ 1800 A module — which will absolutely require 100% testing to meet the ruggedness and reliability requirements for the target application.

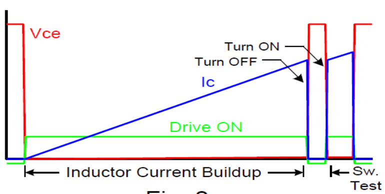
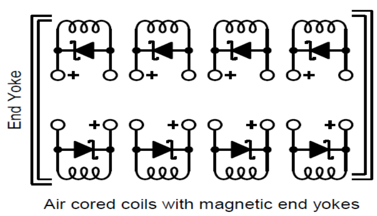


Fig. 3



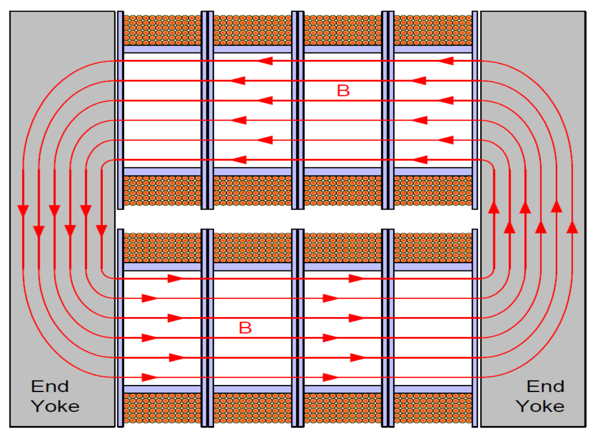


Fig. 4 Stacks of 4 winding 'discs'

With the end yokes the inductance/disc remains constant as more discs are used, and the effective clamp diode's voltage and current capability automatically matches that of the inductor, for any arrangement of series and parallel connections. This test circuit can also be used to measure avalanche energy during the first turn-off, either by removing the clamp diodes, or with clamp voltage set above the transistor's avalanche level.