Silicon Carbide Devices and Applications: Gate Turn-Off Devices Hybrid Si/SiC Inverter Power Systems Applications

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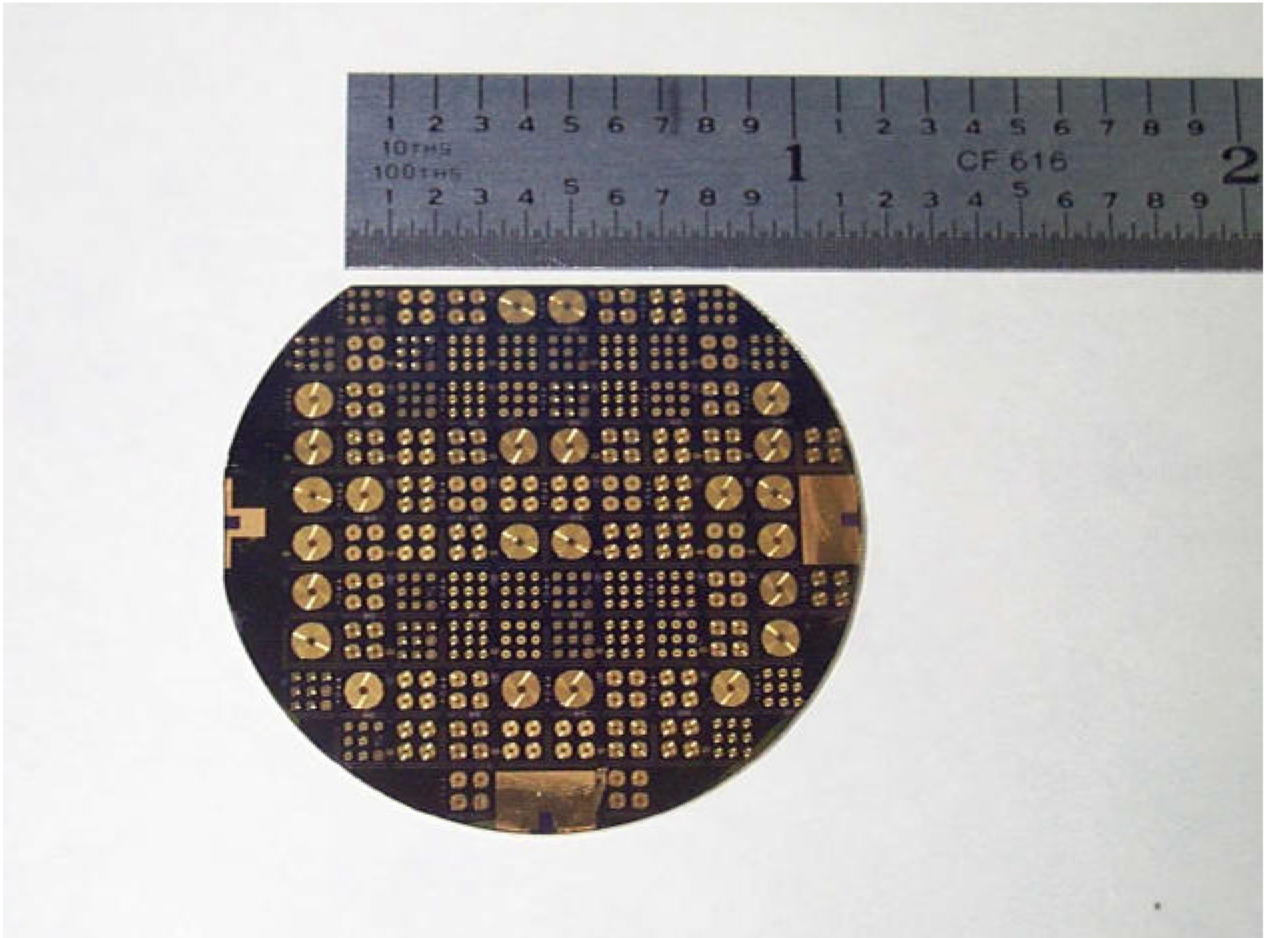
Outline

- SiC GTOs: Dynamic Testing
- Hybrid Si/SiC PWM Inverter:
    - Experimental Results
    - Comparison with an All Si Inverter
- Power Systems Applications for SiC
- Next Steps
- Summary

Silicon Carbide GTO Wafer

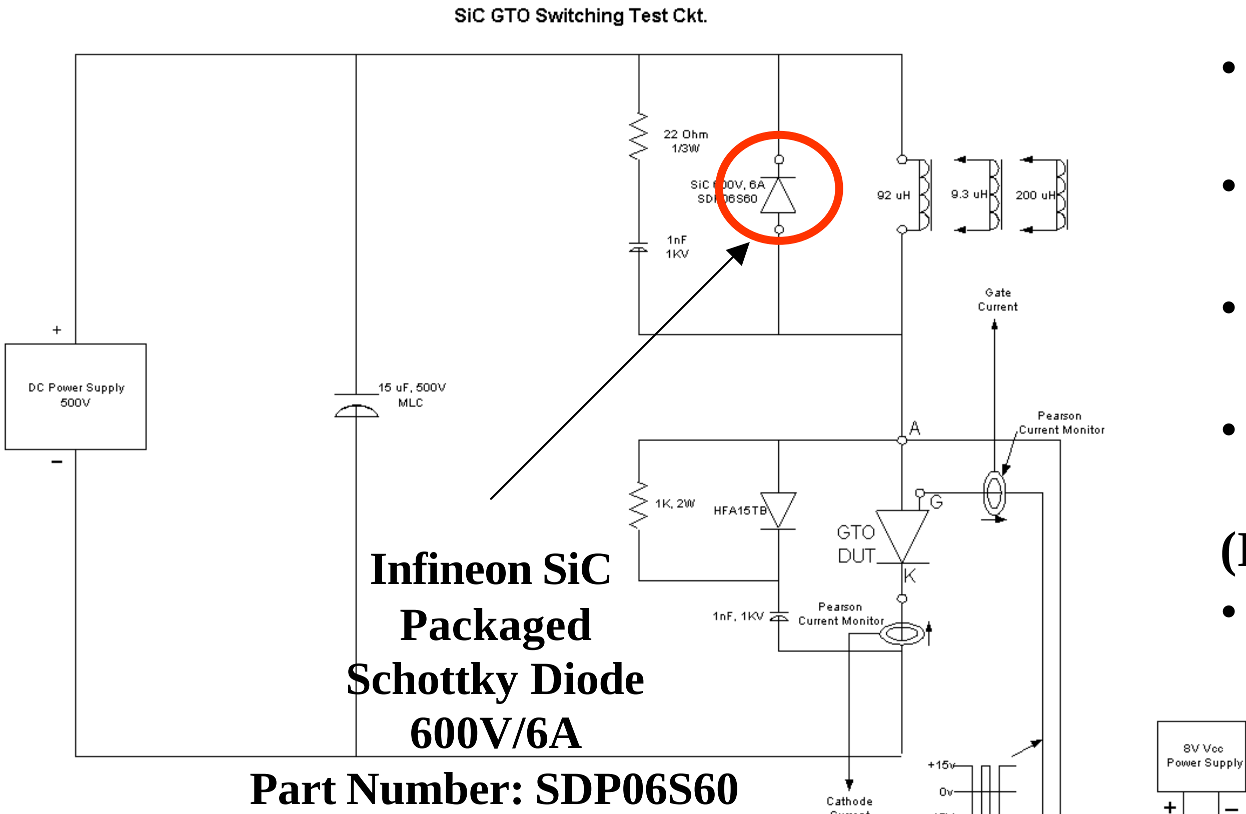
GE Corporate R&D



SiC GTO Wafer: 50mm Epi

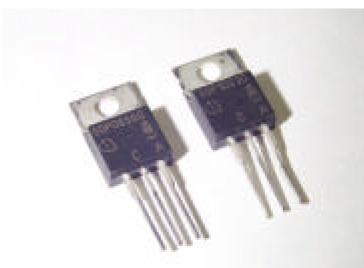
Silicon Carbide GTOs: Dynamic Testing

GE Corporate R&D



Infineon SiC Packaged Schottky Diode 600V/6A

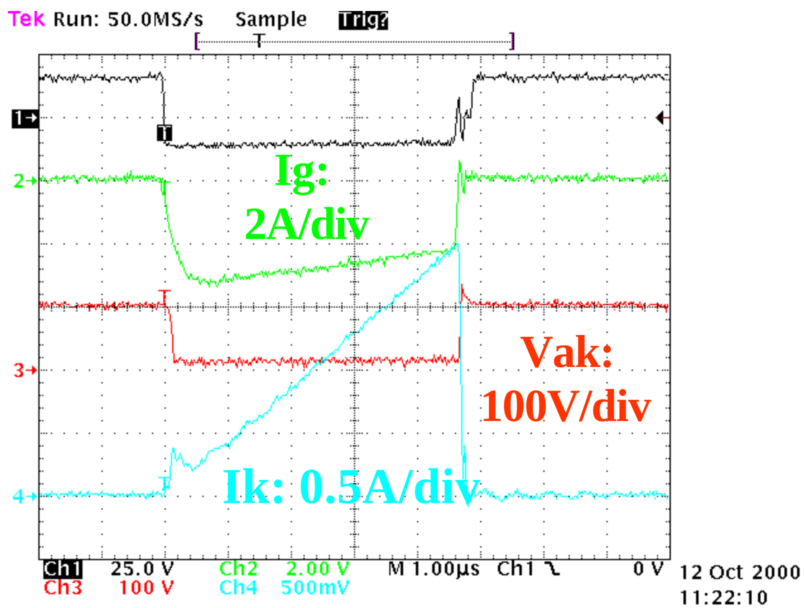
Part Number: SDP06S60



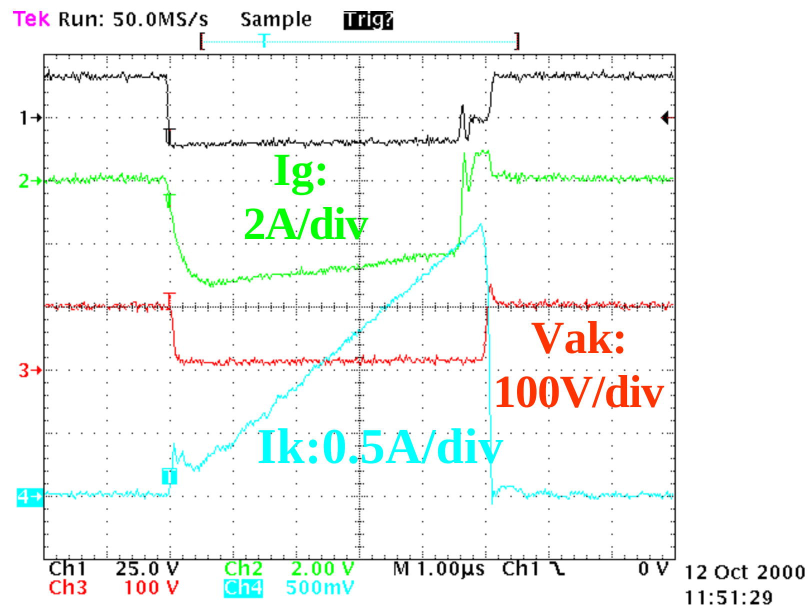
- **Tested 12mm, 30mm, 50mm Epi GTOs**
- **Single and double Pulse Test**
- **Tested at RT and up to 150°C**
- **Tested Various Configurations (Involute, Concentric,..)**
- **Tested Various Sizes (800mm, 1200mm, 2400mm) Diameters**

SiC GTOs Pulse Tester

SiC GTO Inductive Switching Tests
Medium Involute Gate, 1200mm Diameter, 30mm Epi



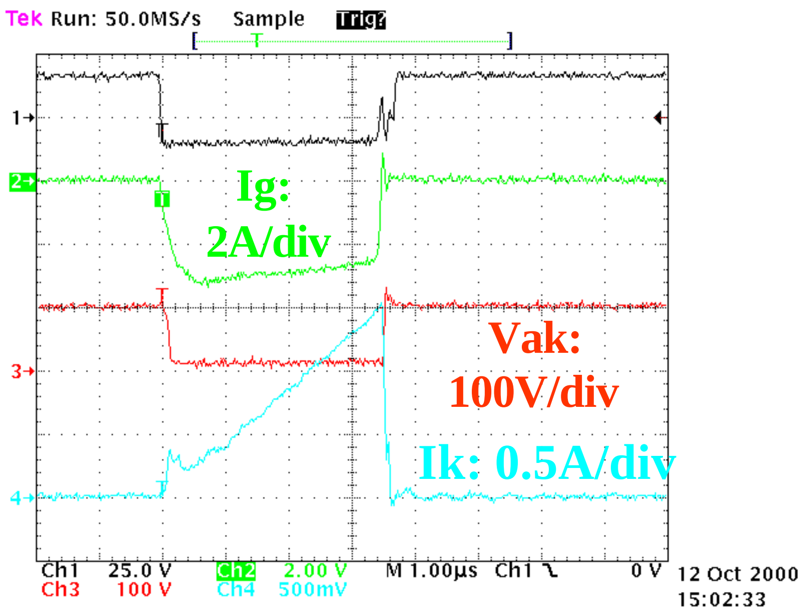
RT



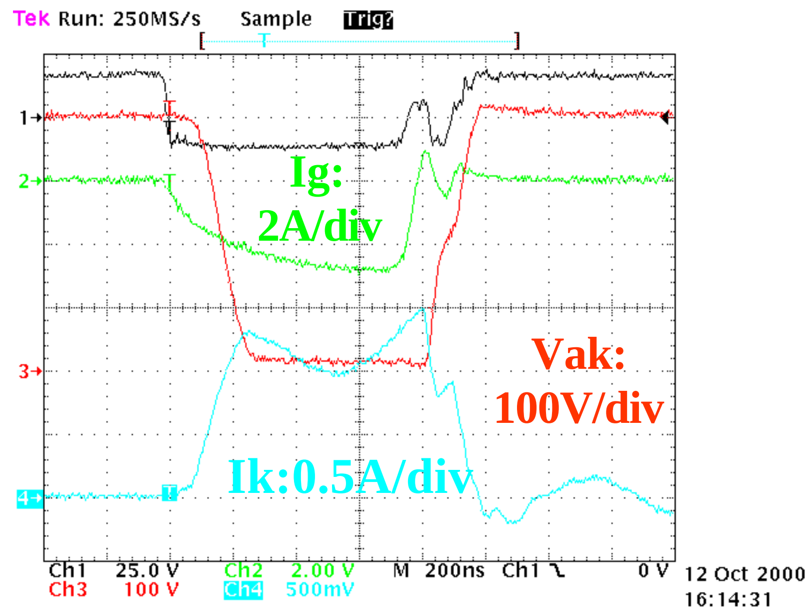
T=100°C

Toff=600ns, Igoff=680mA Toff=720ns, Igoff=920mA

SiC GTO Inductive Switching Tests
Medium Involute Gate, 1200mm Diameter, 30mm Epi

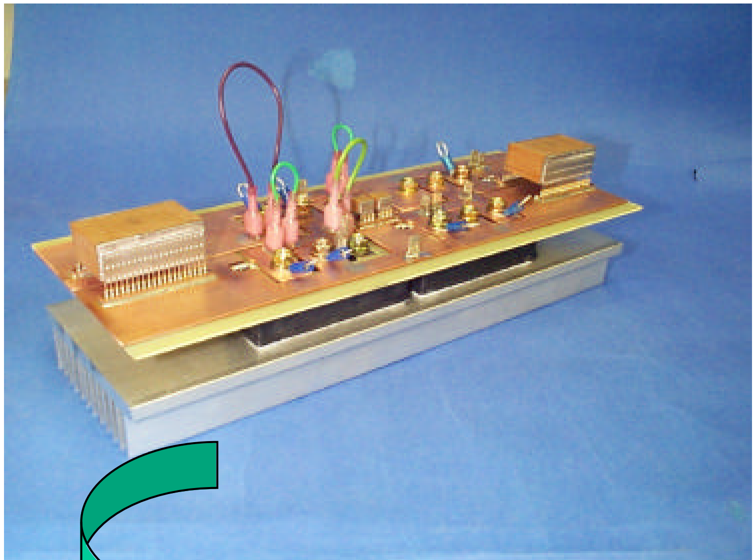


RT,V_{dc}=100V



RT, V_{dc}=400V

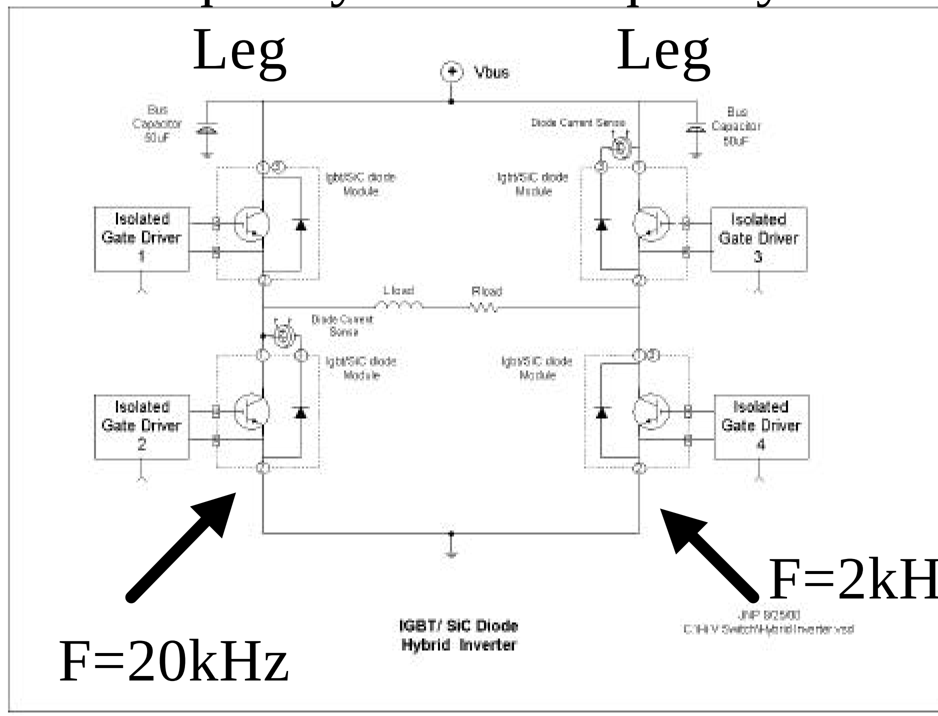
Toff=640ns, Igoff=800mA Toff=400ns, Igoff=880mA



- **Four Single IGBT Modules (Si IGBT/SiC Diode)**
- **Laminated Low Inductance Bus**

High Frequency Leg

Low Frequency Leg

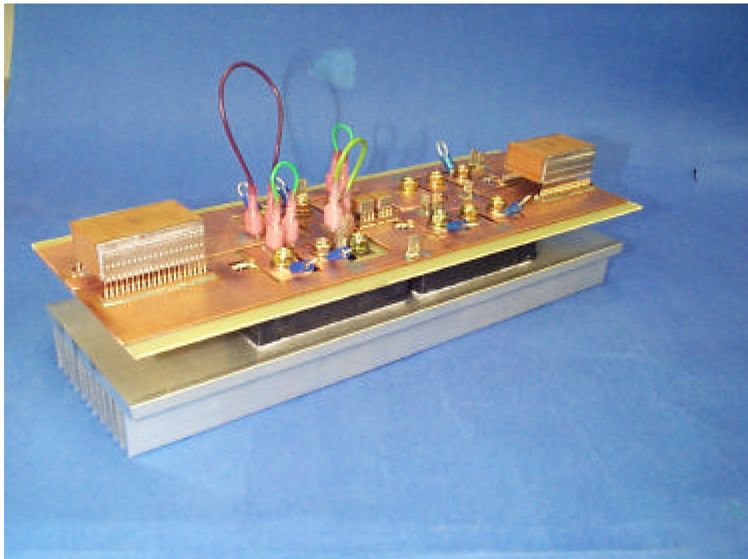


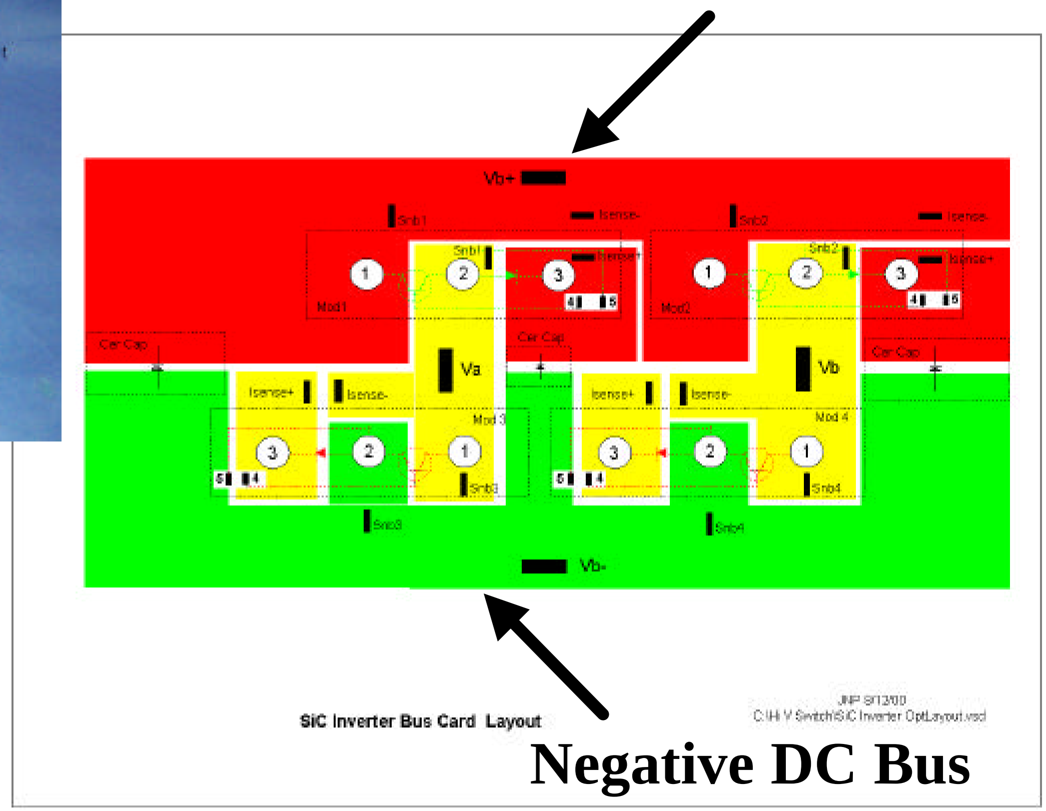
F=20kHz

F=2kHz

Full Bridge Si IGBT/SiC Diodes Hard Switched Pulse Width Modulated Inverter

Hybrid Inverter: Optimal Layout



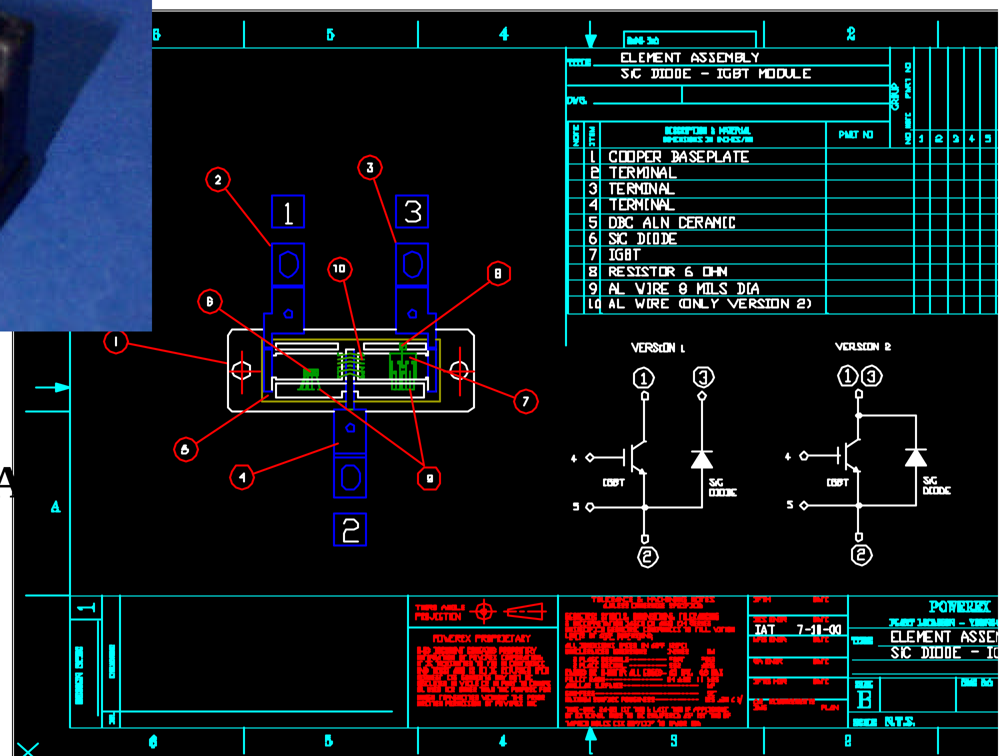


Optimal Layout for the PWM Inverter: Ensures very low inductance, hence reduces overall stress caused by di/dts

Hybrid Modules: Si IGBT/SiC Diodes

This module allows monitoring of:

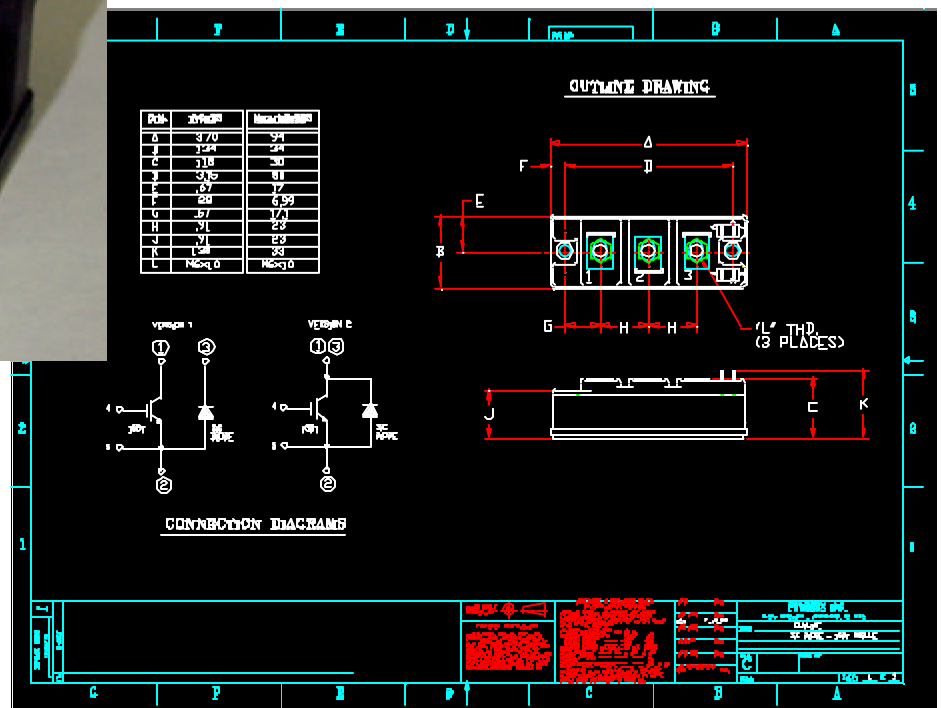
- Si IGBT Current
- SiC Diode Current



GE/Powerex Si IGBT/SiC Diodes:
Si Powerex PT IGBT: 600V/1200V, 75A
Single Chip
SiC GE Diode: 600V, 20A, 6 Dies in ||
Each Die is a 5mm Epi, Medium Size
800mmx800mm

Hybrid Modules: Si IGBT/SiC Diodes

Module with minimum inductance between Si IGBT and SiC Diode



GE/Powerex Si IGBT/SiC Diodes:
Si Powerex PT IGBT: 600V/1200V, 75A Single Chip
SiC GE Diode: 600V, 20A, 6 Dies in ||
Each Die is a 5mm Epi, Medium Size 800mmx800mm

Si/SiC Module Internals

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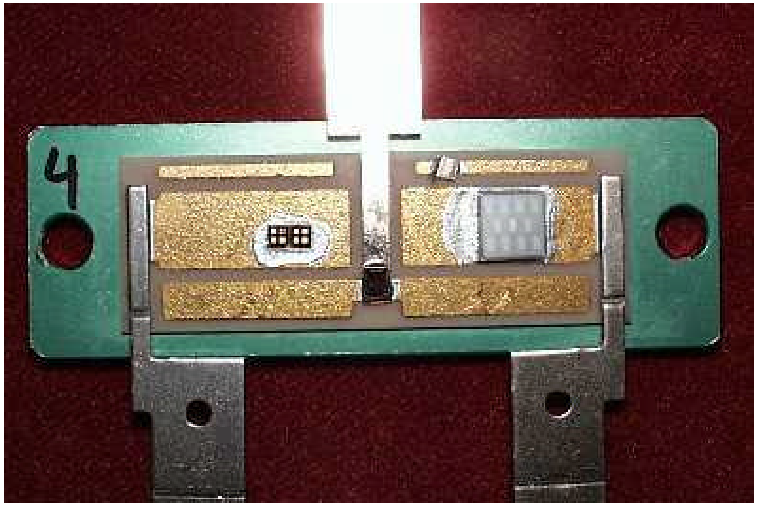
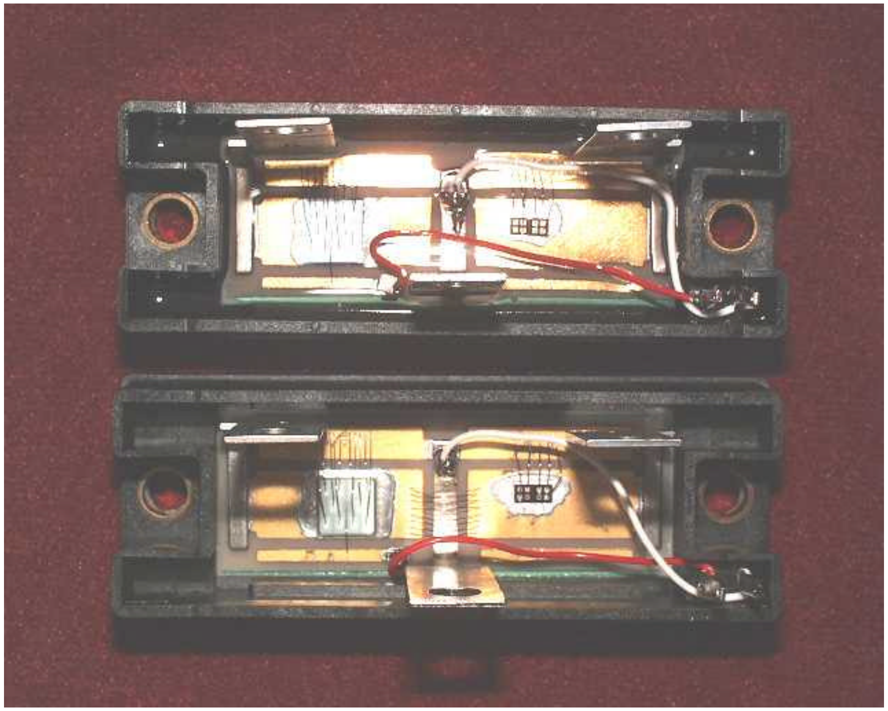
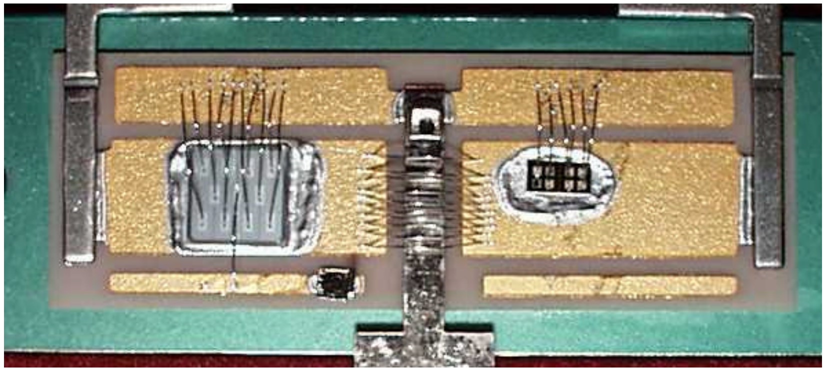


SiC IGBT Module: No Wire Bonds

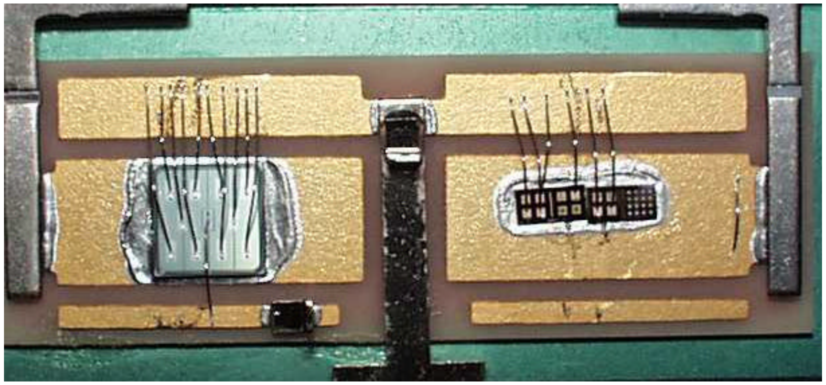


Gelled Modules

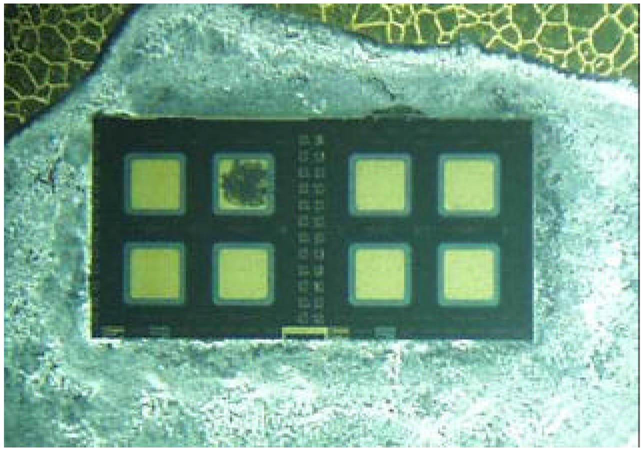
Si/SiC Module Internals



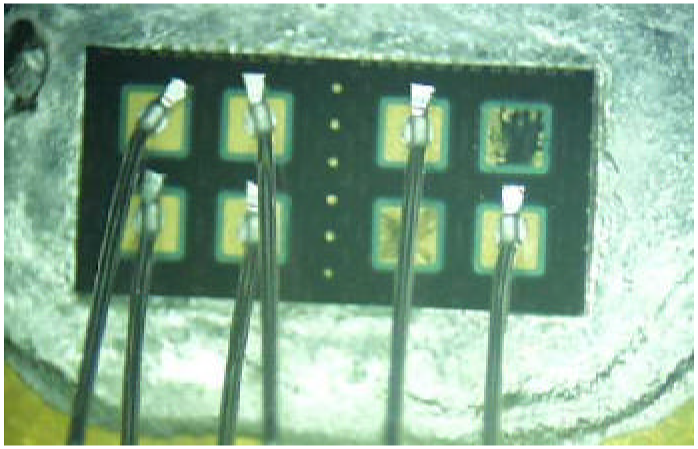
Wirebonded Module (Version 1)



Wirebonded Module (Version 2)

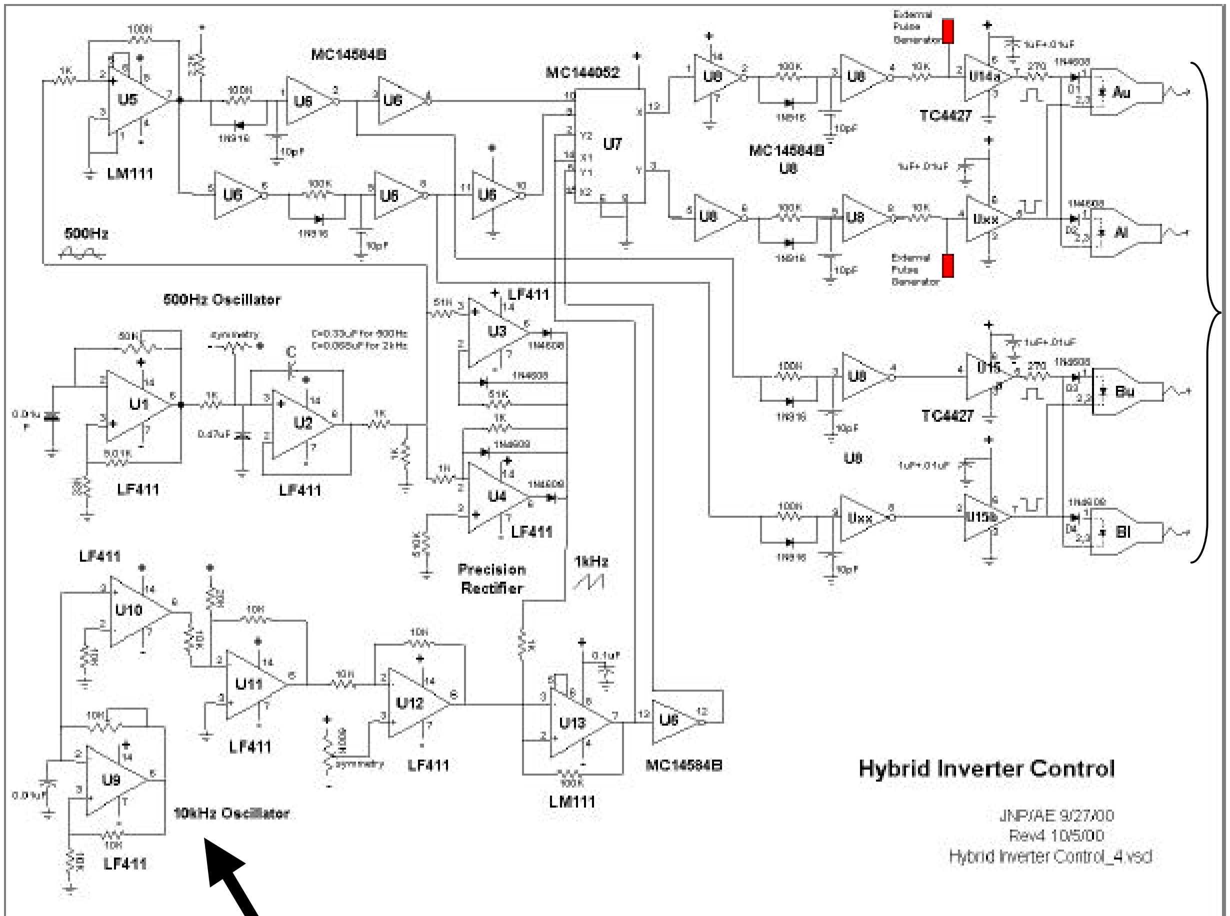


SiC Diode (Soldered)



SiC Diode (wirebonded)

PWM Inverter Control Circuit



Low Frequency Oscillator

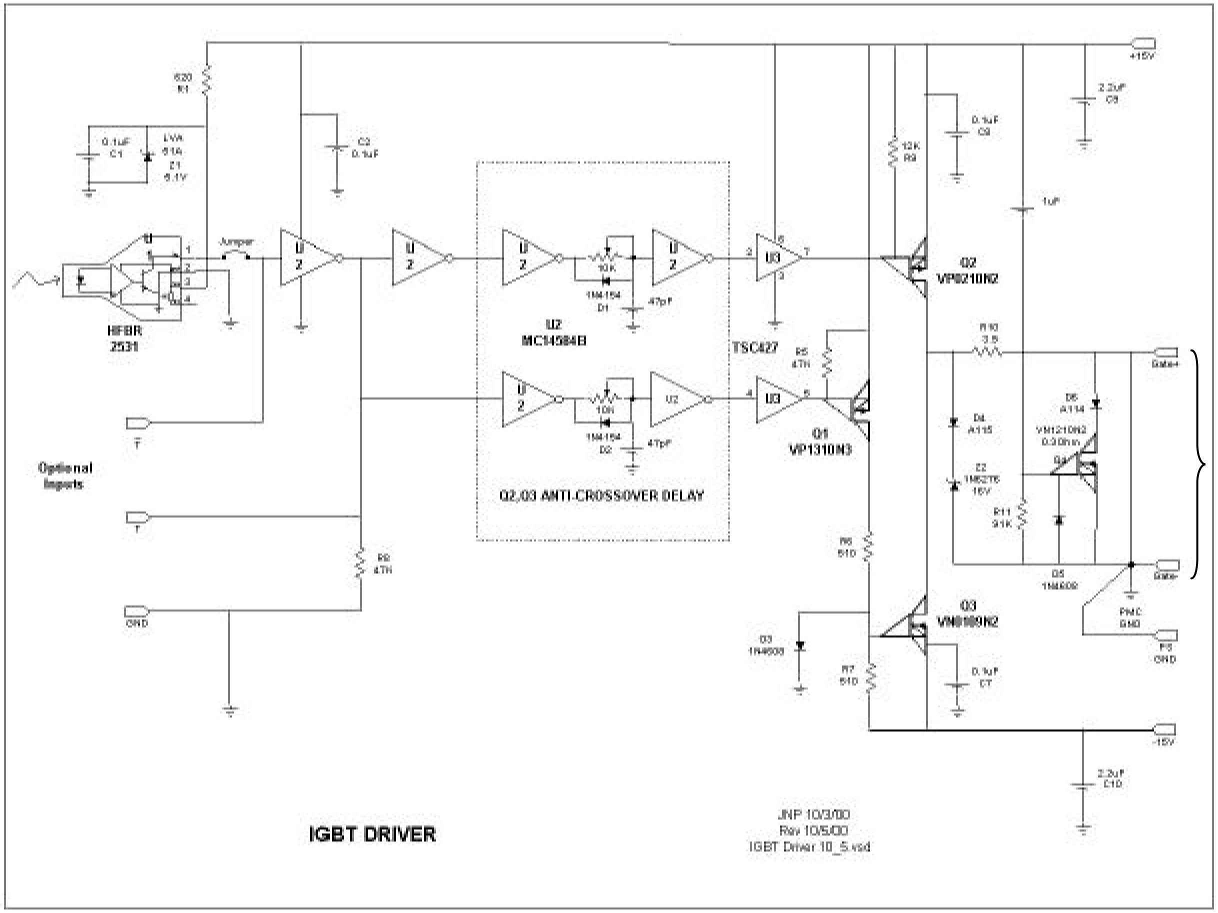
Control Signals for S1, S2, S3 and S4

High Frequency Oscillator

Hybrid Inverter: IGBT Drivers

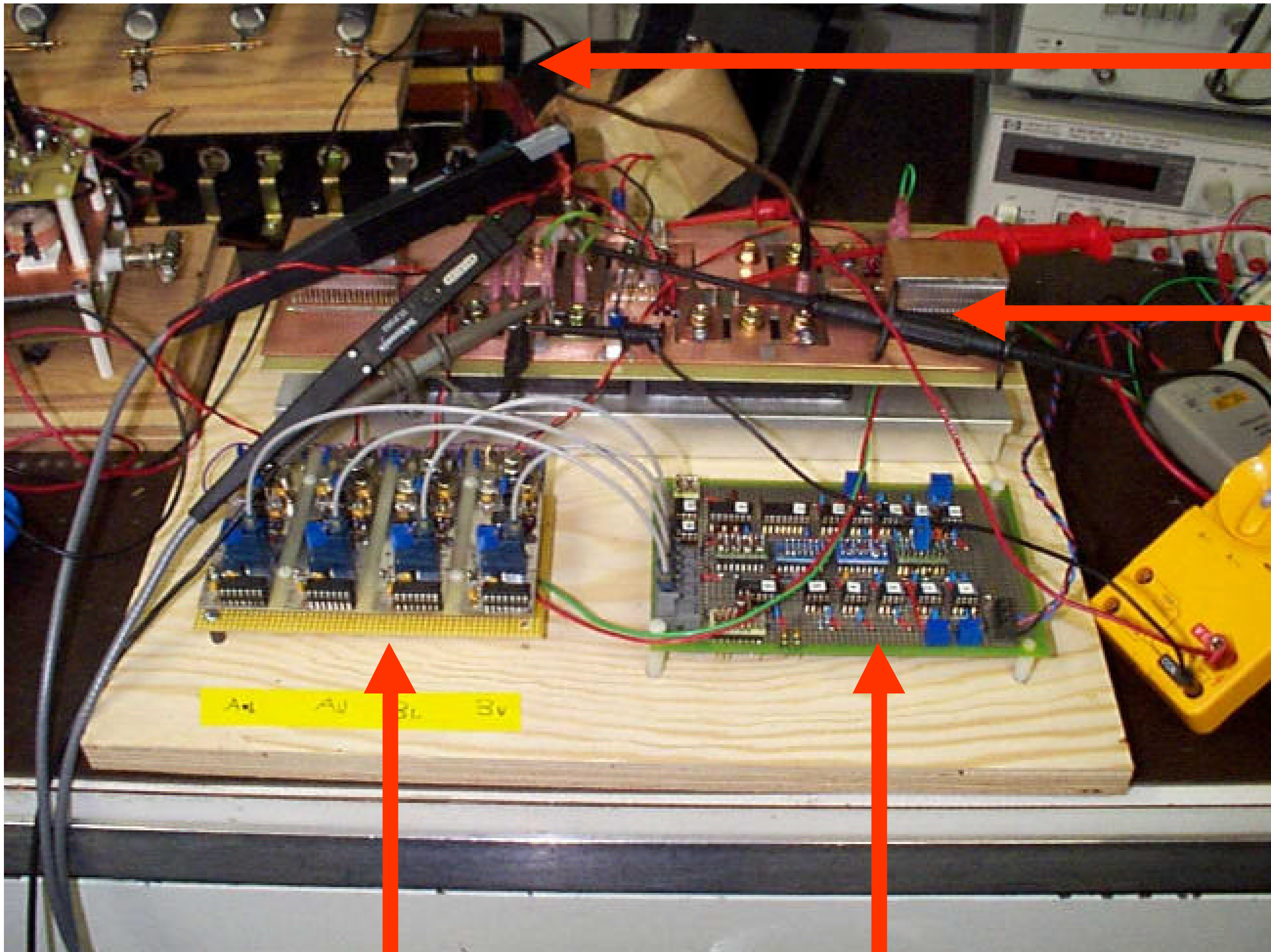
IGBT Driver Circuit

Control Input



To IGBT Gate Emitter

Hybrid Si/SiC Inverter: Hardware



Hybrid Si/SiC Inverter Waveforms

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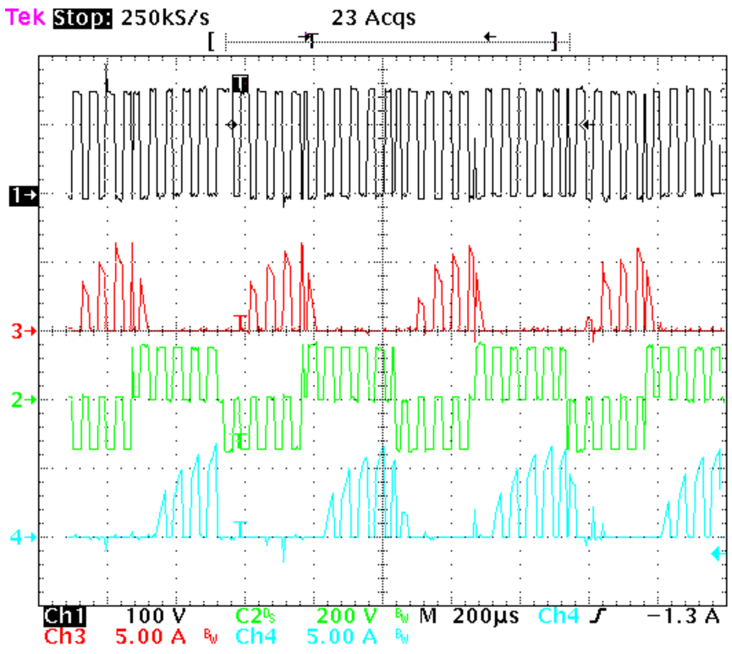
V_{bus}=150Vdc, Fs=20kHz, F_{load}=2kHz, R_{load}=12.5W, L=1mH

200ms/div

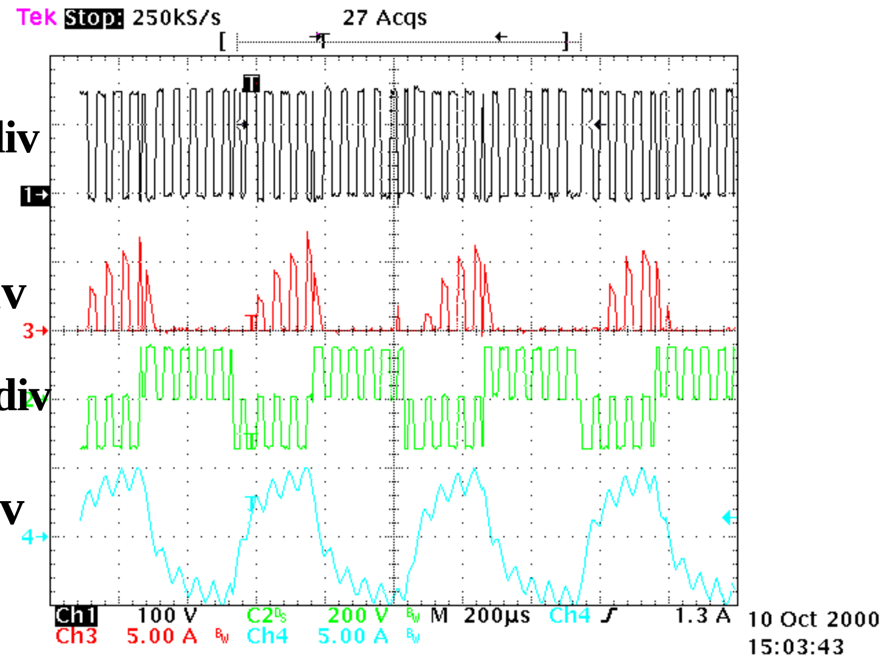


100V/div

5A/div

200V/div

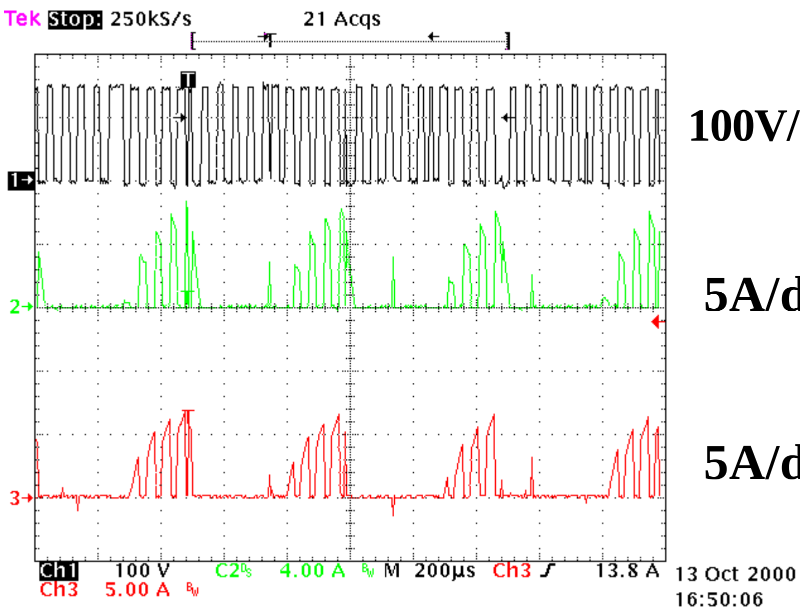
5A/div



Left	Right
Module (IGBT/Diode) Voltage	**Module (IGBT/Diode) Voltage**
SiC Diode Current	**SiC Diode Current**
Load Voltage	**Load Voltage**
IGBT Current	**Load Current**

V_{bus}=150Vdc, Fs=20kHz, F_{load}=2kHz, R_{load}=12.5Ω, L=1mH

200μs/div

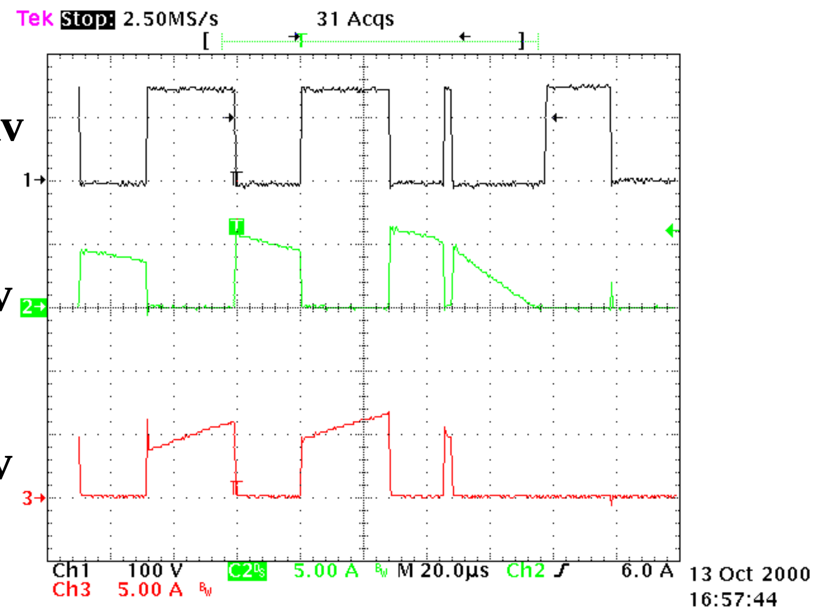


100V/div

5A/div

5A/div

20μs/div



Module (IGBT/Diode) Voltage
SiC Diode Current
IGBT Current

Module (IGBT/Diode) Voltage
SiC Diode Current
IGBT Current

Hybrid Si/SiC Inverter vs. All Si Inverter

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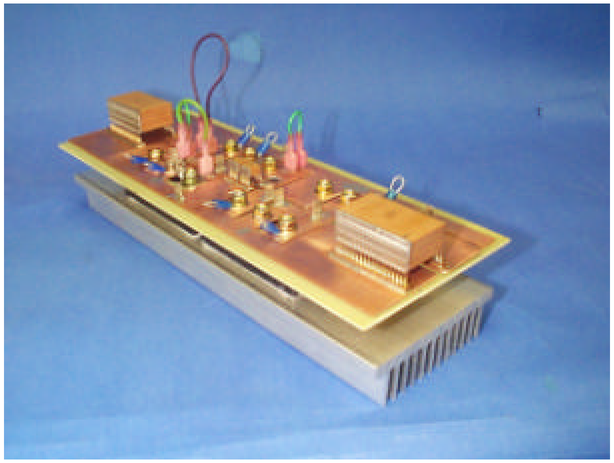
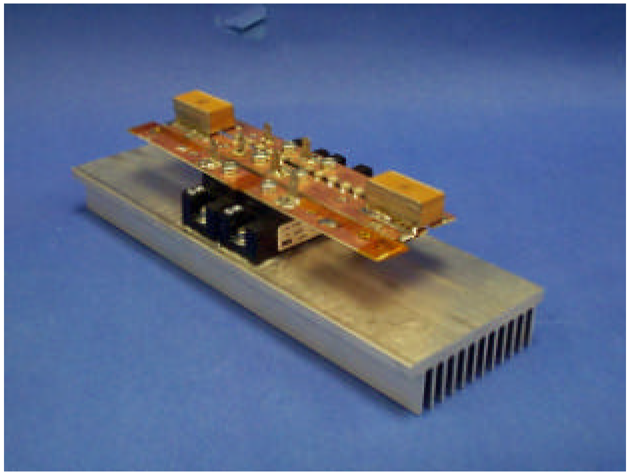
Si/SiC Inverter



All Si Inverter



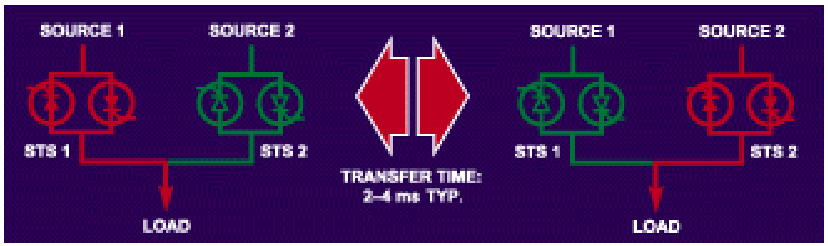
DC Bus Voltage	100V	150V	200V	250V
Load Input Power	114W	250W	440W	690W
Hybrid Si/SiC Efficiency	**90.6%**	**96.3%**	**97.5%**	**97.8%**
All Si Inverter Efficiency	**92%**	**92.7%**	**95.5%**	**97.1%**

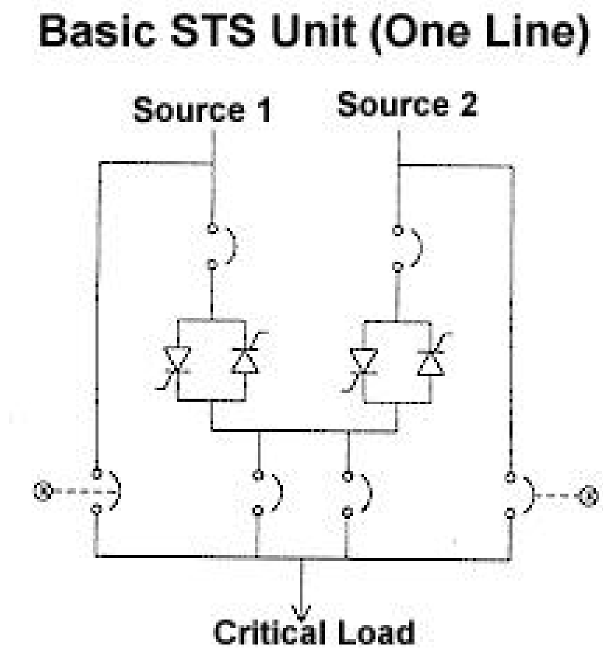
Power Systems Applications

- For Power Systems Applications, High Voltage, High Current Diodes as well as High Current/High Voltage SCRs are needed for a number of applications:

  - Static Transfer Switches
  - Dynamic Voltage Restorers
  - Static Var Compensators
  - HVDC
  - FACTS

Static Transfer Switches

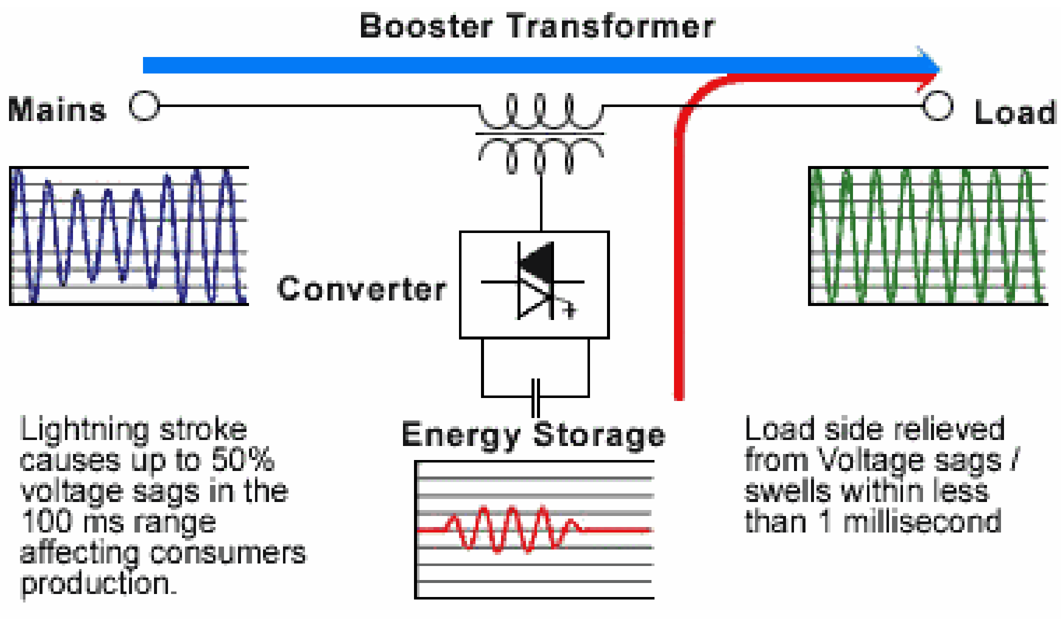




Static Transfer Switch Operation for Two Source System

Problem: Need High Voltage/High Current SCRs (up to 25kV, Up to 5000A)
Silicon Solution: Strings of 5kV SCRs in Series and in parallel to sustain Voltage
Silicon Carbide Opportunity: With High Voltage SCRs (4kV-10kV), the size of Transfer Switches can be reduced. Further the SiC High Temperature and High Current density can reduce the size of the cooling system

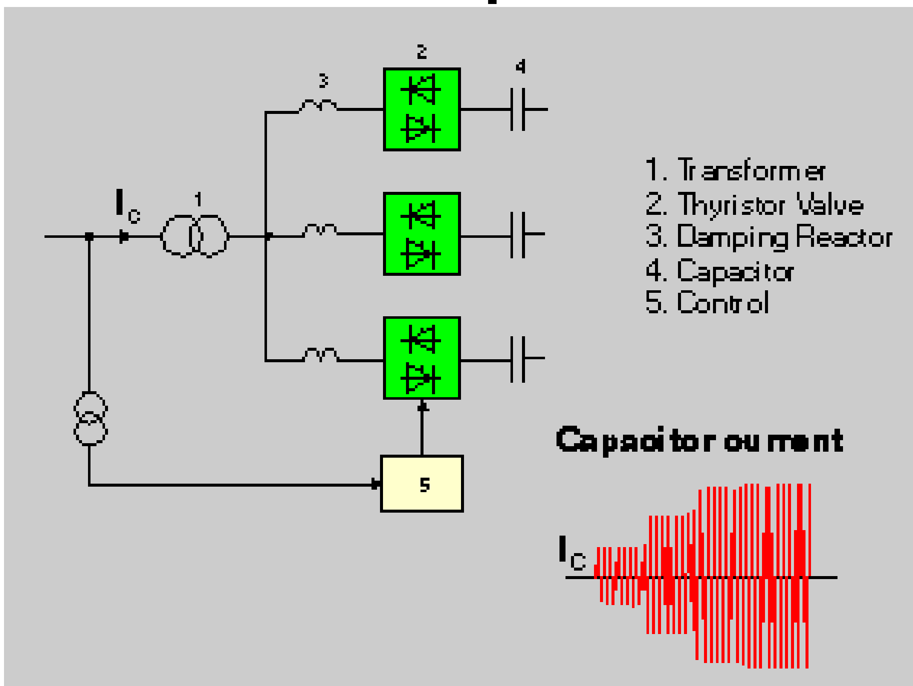
Dynamic Voltage Restorers



Source: ABB Power Electronic Systems

Problem: Need High Voltage/High Current GTOs, SCRs or IGBTs for Inverter and Chopper
Silicon Solution: Strings of 5kV SCRs in Series and in parallel to sustain Voltage and Current
Silicon Carbide Opportunity:SiC can reduce the size of the converters by providing high voltage devices and in this case also reducing Inverter and Chopper Losses, hence increasing their efficiency

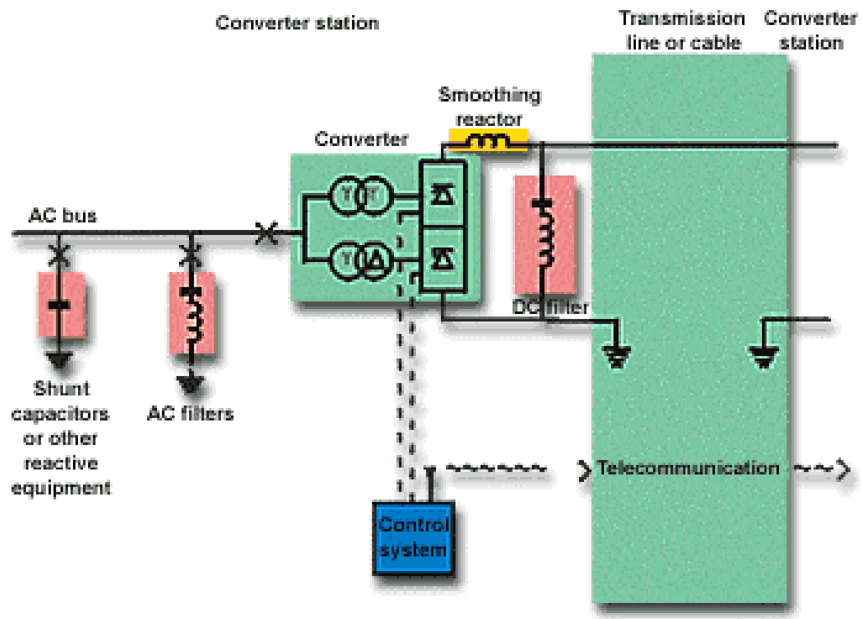
Static Var Compensators



Source: ABB Power Transmission

Problem: Need High Voltage/High Current SCRs, GTOs, IGCTs,… for the Series AC Switch
Silicon Solution: Strings of 5kV SCRs in Series and in parallel to sustain Voltage (Up to 25kV or more, Large currents (Thousands of Amps.)
Silicon Carbide Opportunity: Very High Voltage SCRs (>=10kV), the size of the Valves can be reduced dramatically, hence reducing the overall size and Cost of these Systems

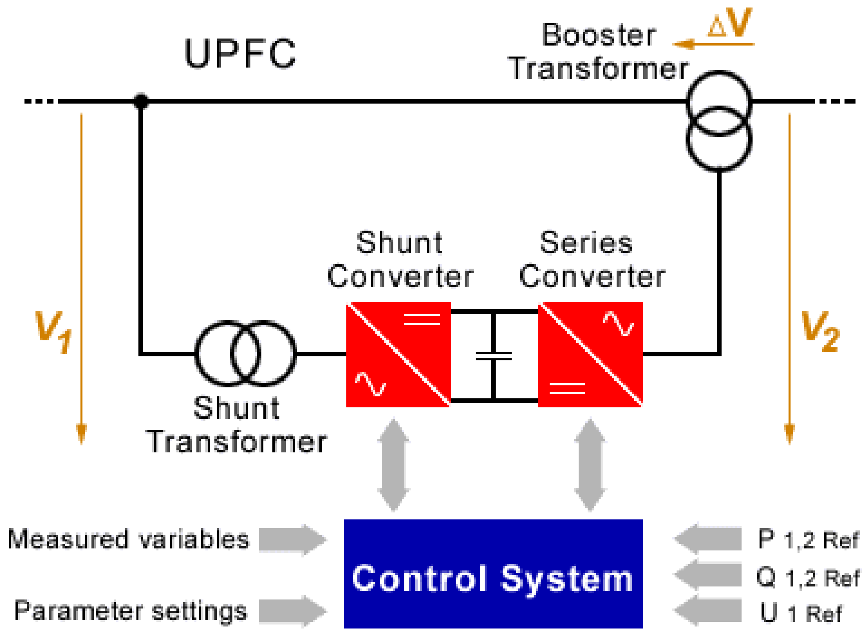
High Voltage DC Transmission (HVDC)



Source: ABB Power Transmission

Problem: Need High Voltage/High Current SCRs for Very High Voltage Rectification
Silicon Solution: Strings of 5kV SCRs in Series and in parallel to sustain Voltage and Currents
Silicon Carbide Opportunity: Very High Voltage SCRs (>=10kV) will reduce the size of the HVDC Converters, reducing in turn the cost by eliminating Snubbers, balancing Resistors and Capacitors,...

Flexible AC Transmission System (FACTS)



Source: ABB Power Electronic Systems

Problem: Need High Voltage/High Current GTOs and SCRs
Silicon Solution: Strings of 5kV SCRs in Series and in parallel to sustain Voltage and Current
Silicon Carbide Opportunity: With High Voltage SCRs (>=10kV), the size of the Shunt and Series Converter can be reduced. Cost will be also reduced and Cooling will be optimized.

Remaining Tasks

- Further Tests on the Hybrid Si/SiC Inverter to confirm our Initial Results
- Increase Switching frequency (50-75kHz), Bus Voltage (400V)
- Build an All SiC PWM Inverter with:
    - Packaged SiC GTOs and Diodes
- Test it at High Temperature, High Voltage (at least 600V) and High Current (~25 to 50A Peak)

Summary

- Hybrid Modules with Si IGBTs or MOSFETs and SiC Diodes can play a major role in increasing the overall switching frequency of All Si Inverters while providing significant improvements in Efficiency
- SiC GTOs and SiC Diodes (Schottkys and PiNs) are a key to getting SiC within the application community. These device types have a mature technology. Many manufacturers are starting or planing to offer these devices in the near term.