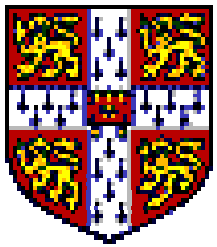

UNIVERSITY OF CAMBRIDGE

Thermal issues in high current power semiconductor devices

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I. Introduction to High Power IGBTs II. Issues in IGBT operation III. IGBTs in series ? Future devices

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OUTLINE

I. Introduction to High Power IGBTs

II. Issues in IGBT operation

III. IGBTs in series

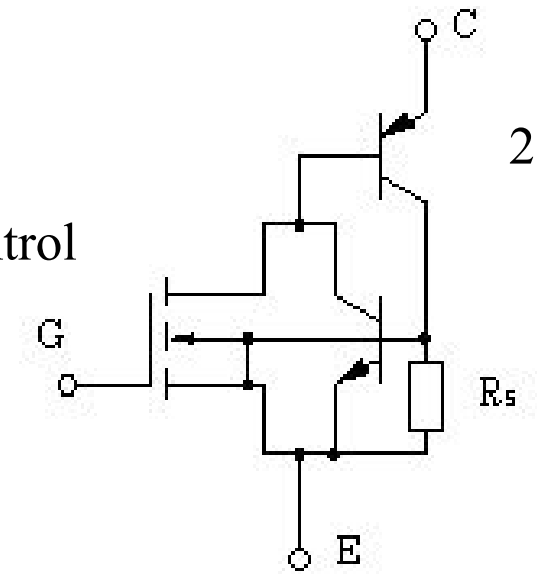
- Future devices

I Introduction to High Power IGBTs

The IGBT schematic

Main Features

1. MOS gate control

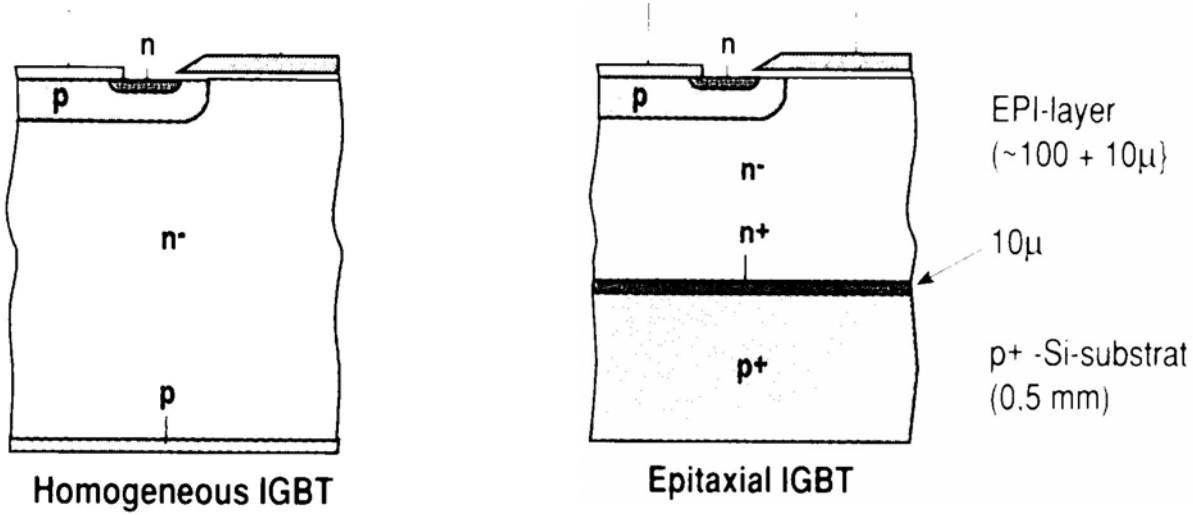


2. Bipolar assisted on-state

3. Latch-up free

Ratings up to 2000A and 4.5kV

IGBT STRUCTURES

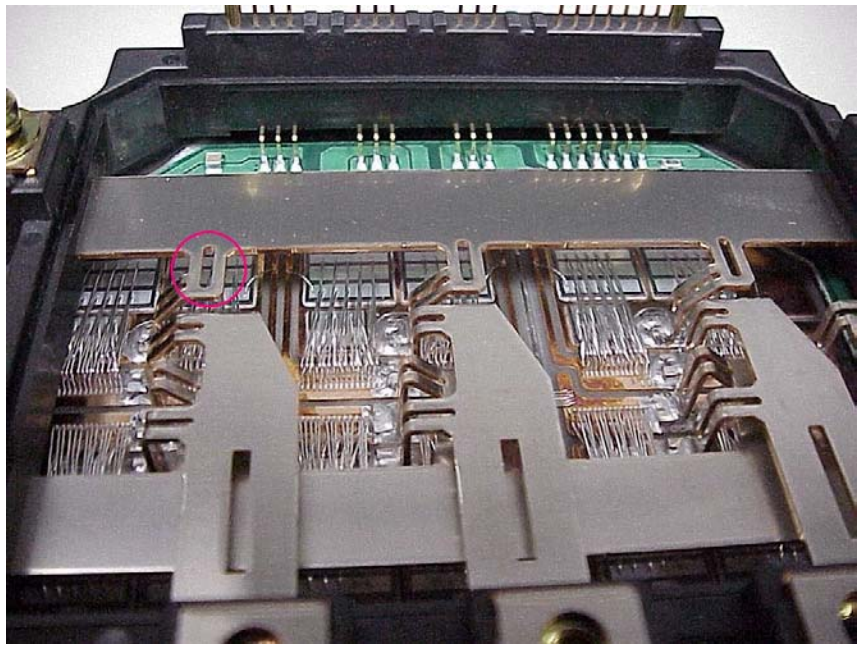


- Parasitic Thyristor is shorted out
- Wide-base pnp transistor
- Conventional MOS gate input

There are many variations including some Trench and Terraced Gates

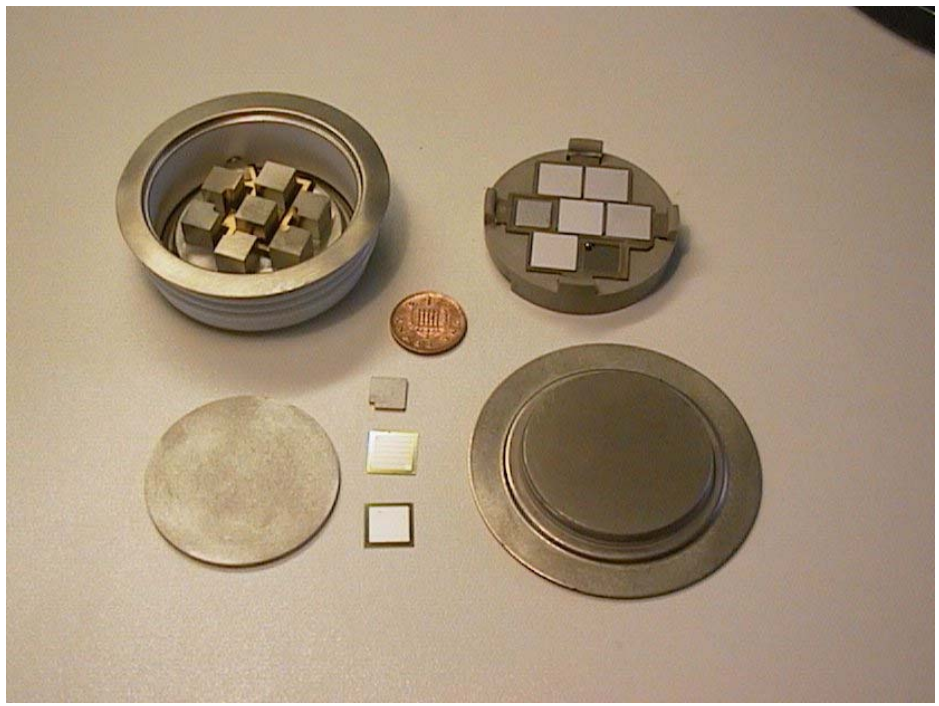
MODULE IGBTs

- Permit simple inverter arrangement - Laminated busbars.
- Can be easily air cooled.
- Reliability is high.
- Are short circuit current rated.



CAPSULE IGBTs

- Double sided cooling.
- Are easily water cooled.
- Reliable capsule package.
- Fail short circuit.



II Issues in IGBT operation

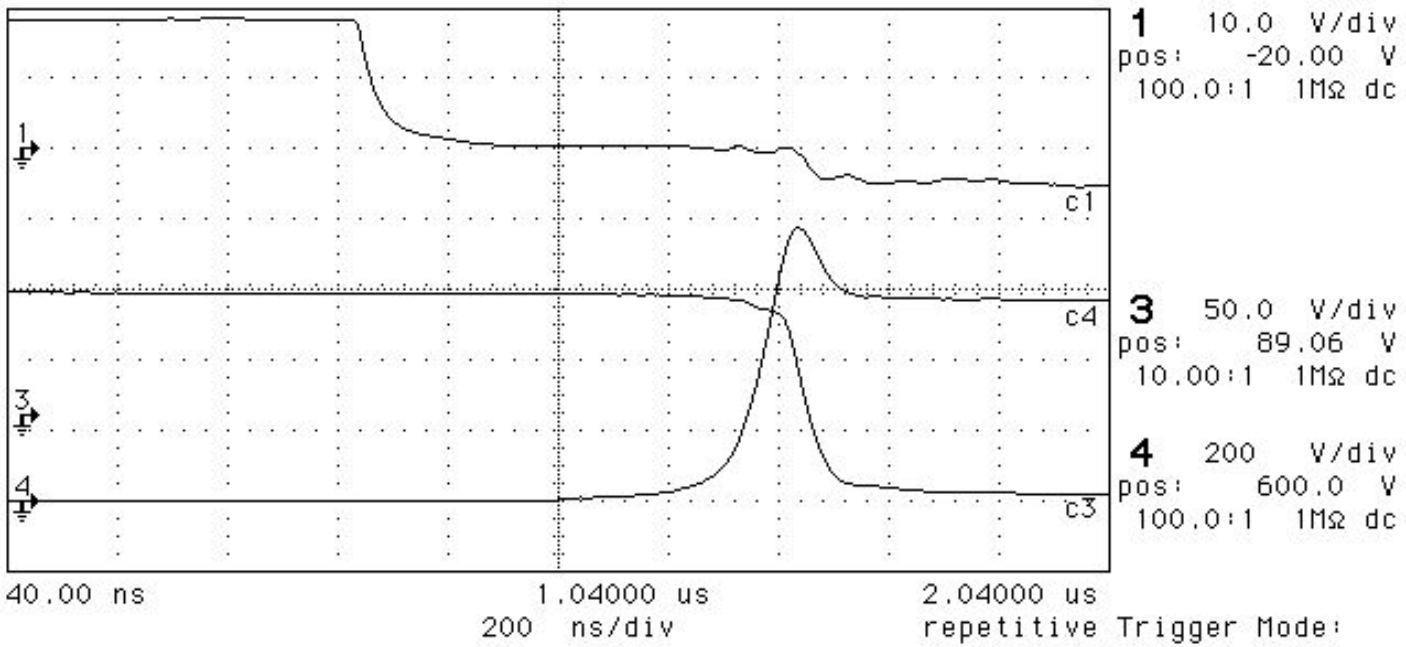
SUMMARY OF ISSUES

For devices made of paralleled chips we must consider

1. Steady State current sharing
2. Transient current sharing
3. Stability in operation - gate resistors

Chip manufacturing and selection cannot produce closely matched chips and the package often introduces asymmetry in the cooling

TYPICAL IGBT SWITCHING WAVEFORMS



C1 Gate voltage (10V/div)

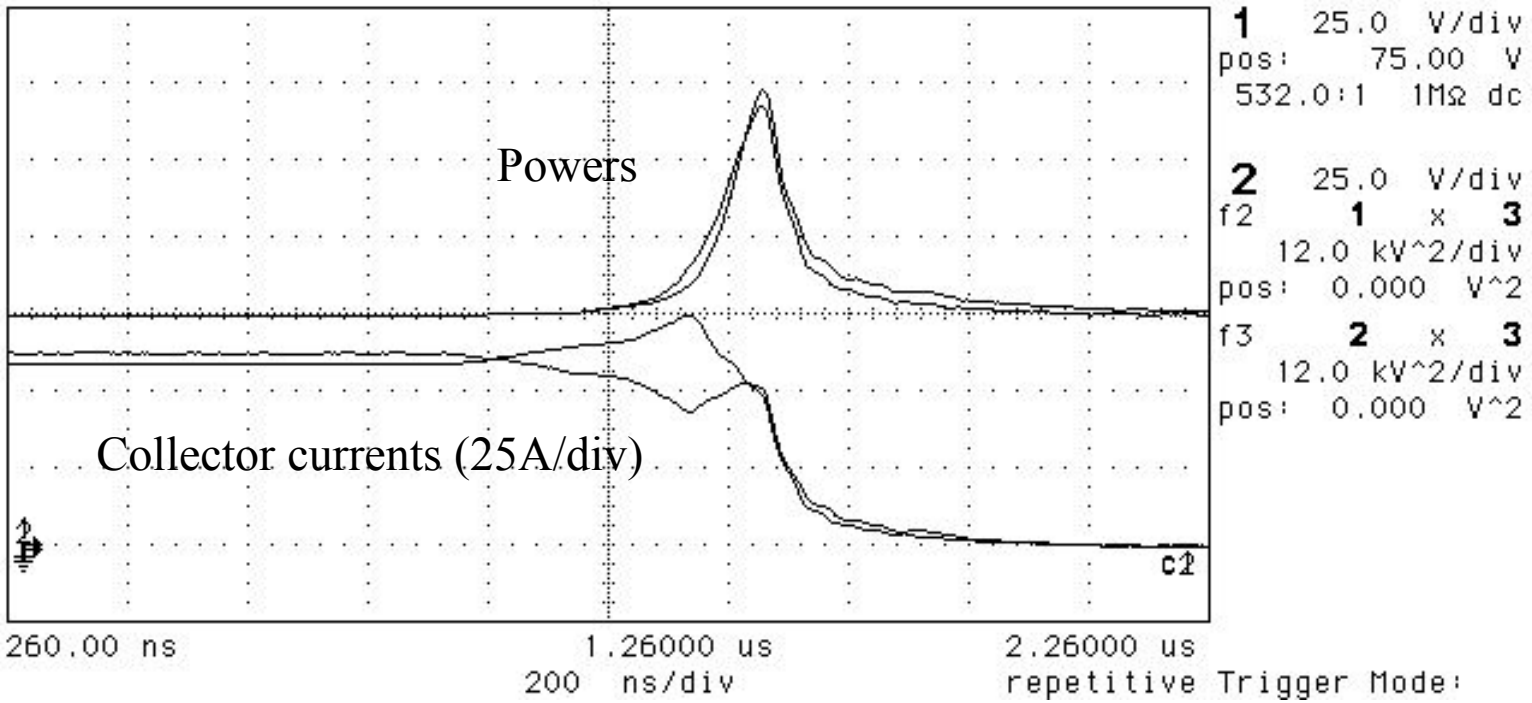
C3 Collector current (50A/div)

C4 Collector-emitter voltage (200V/div)

Note the significant gate ‘plateau’ period

TRANSIENT CURRENT SHARING

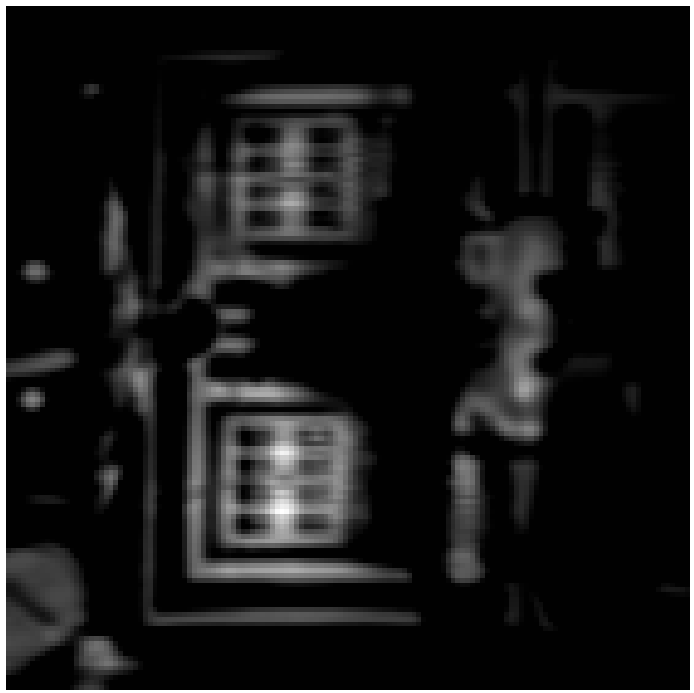
Hard switched



- The divergence of the chip currents coincides with the gently rising collector-emitter voltage.
- No obvious problems.

THERMAL IMAGE

Hard switched @ 4kHz

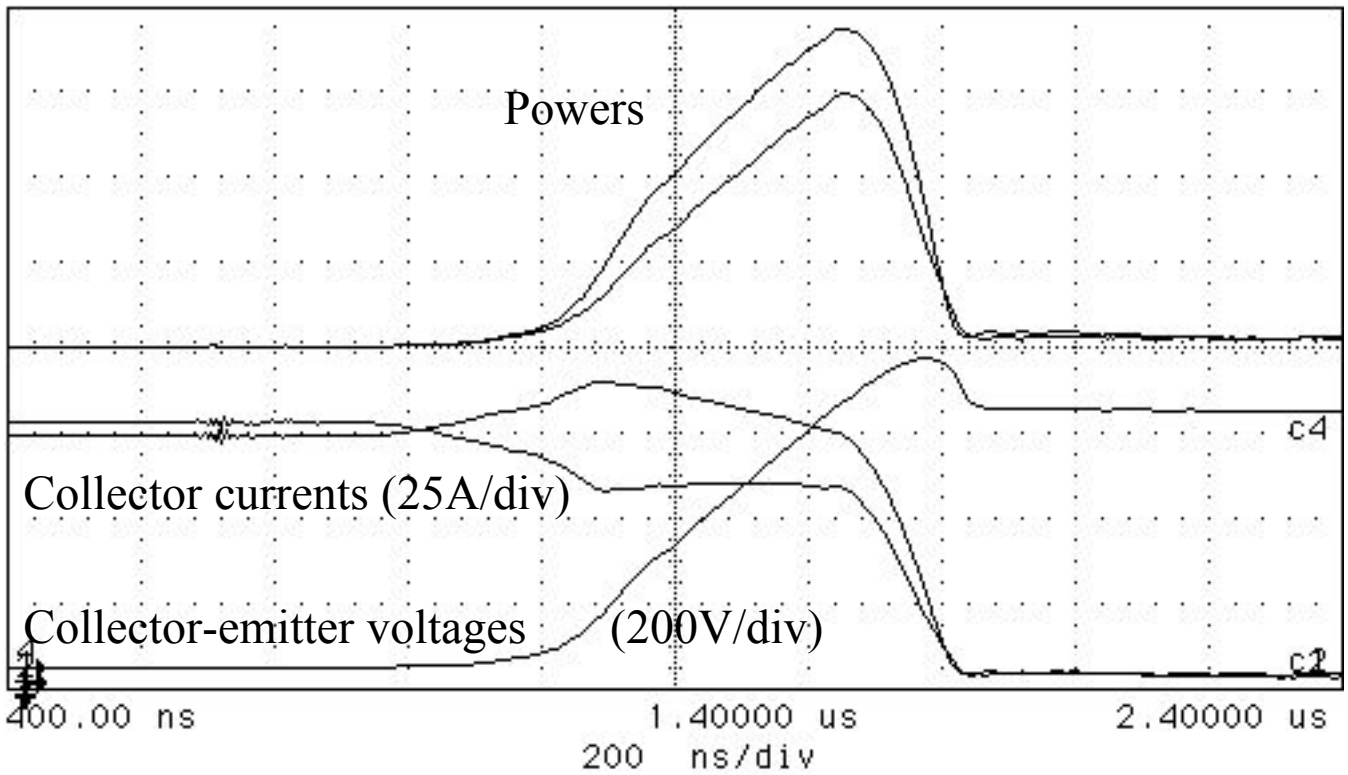


- Maximum temperature difference of about 3 ^{O}C

Positive feedback mechanism!

TRANSIENT CURRENT SHARING

Active dv/dt Snubber



The form of the divergence varies with the circuit conditions

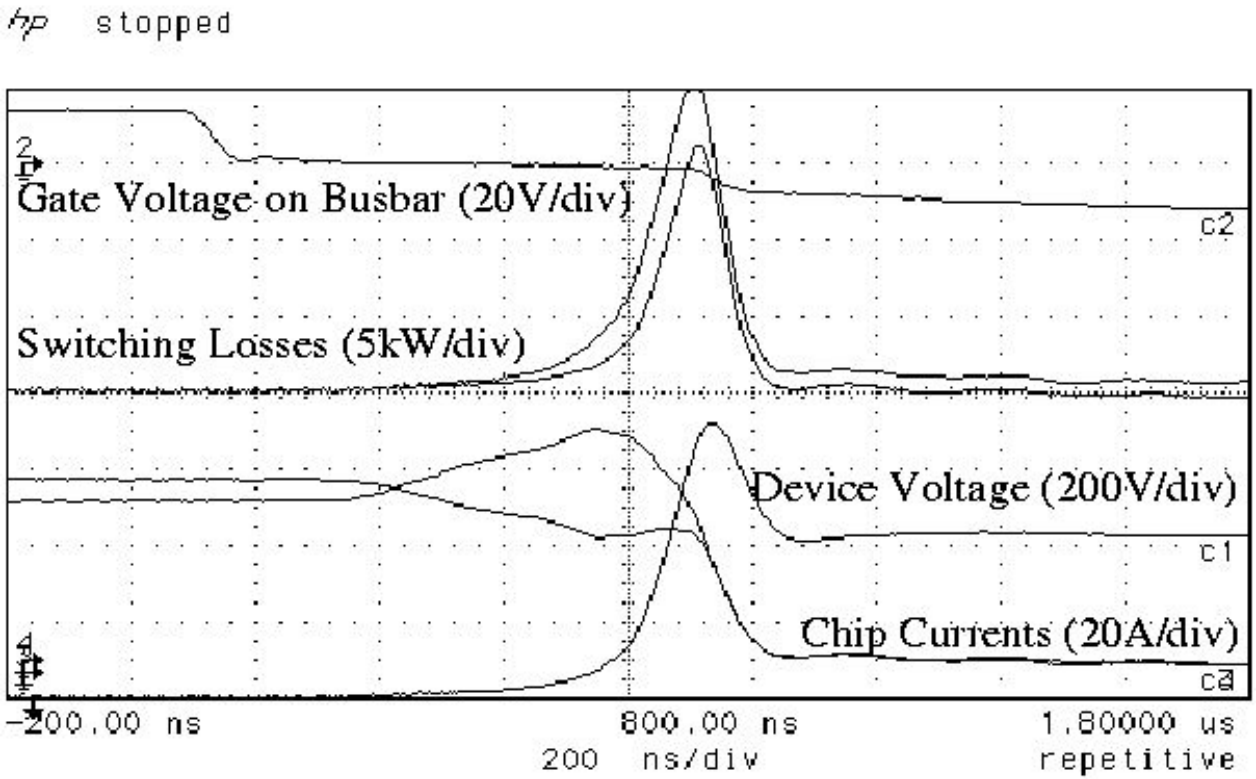
THERMAL IMAGE

Active dv/dt Snubber @ 4kHz

- Maximum temperature difference of about $10^{O}C$

TRANSIENT CURRENT SHARING

Matched Pair, Hot (100°C and 50°C)

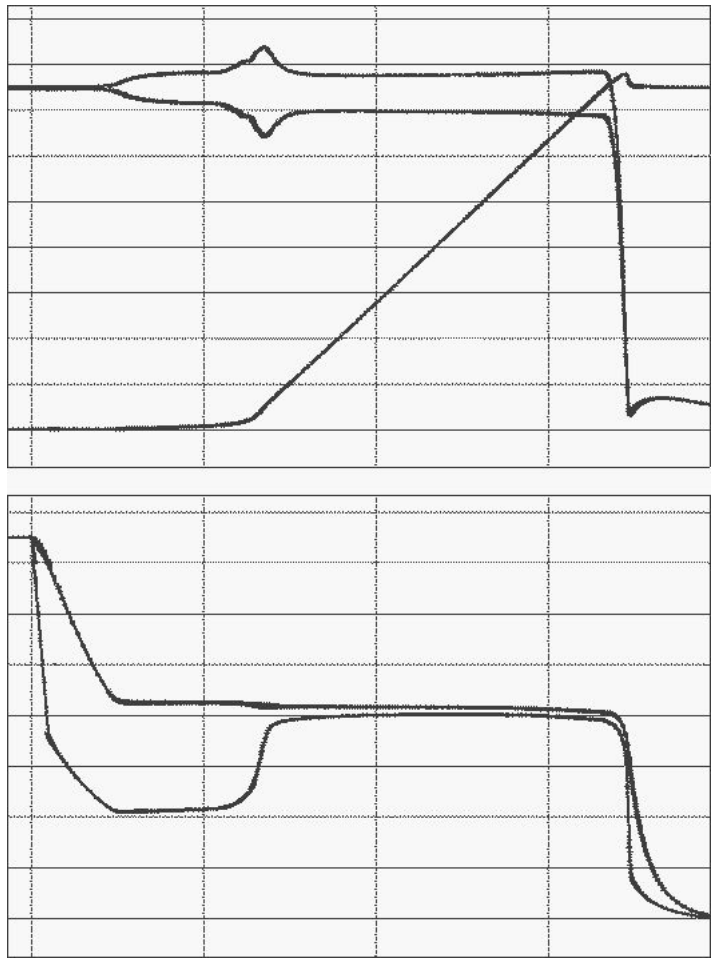


- Ideal behaviour is lost when the chips are at different temperatures.

And a positive feedback mechanism appears in the transient losses!

TRANSIENT CURRENT SHARING - Silvaco

1% Gate oxide difference



2.7% P-base doping difference

Ideally matched devices cannot be made!

III IGBTs in series and the 2-Step method

THE SERIES CONFIGURATION

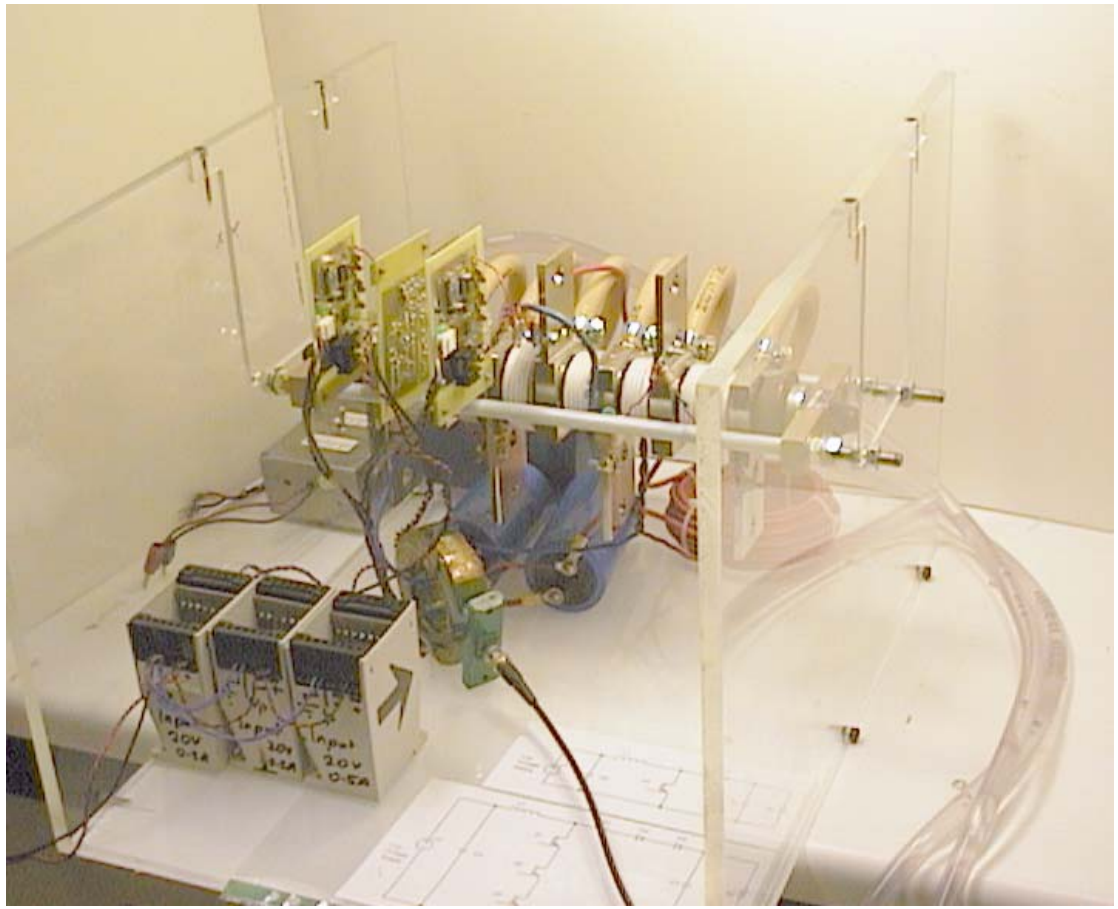
Necessity for seriesing:

1. To achieve high voltage ratings
2. To utilise low voltage devices - cheaper?
3. Redundancy

- Many new applications are appearing due to deregulation and distributed generation with new energy sources.

For example: ABB's 'HVDC Lite'

HIGH VOLTAGE SERIES IGBT RIG



Three capsule IGBTs and three Diodes in series with water cooling

Specification of the Westcode Capsule IGBT

- 400A, 1700V ‘development’ devices
- 47mm diameter, hermetic, cold weld
- Each capsule has 5 IGBT chips, 2 anti-parallel diodes
- On state volts of 5V
- Internal diode rating 400A, Vf= 2V, tr=550ns
- Thermal resistance IGBT 55K/kW, diode 84K/kW

ISSUES IN SERIES CONNECTION

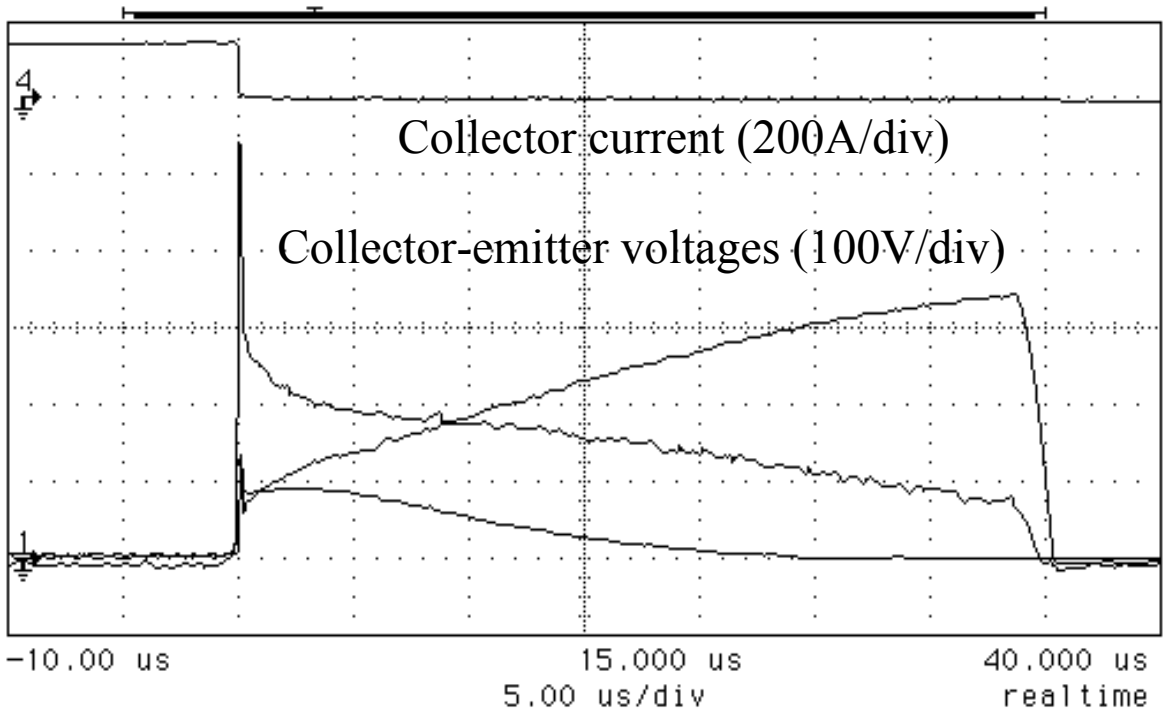
The voltage sharing problem can be divided up:

- transient behaviour
- steady state behaviour
- losses.

Driven by:

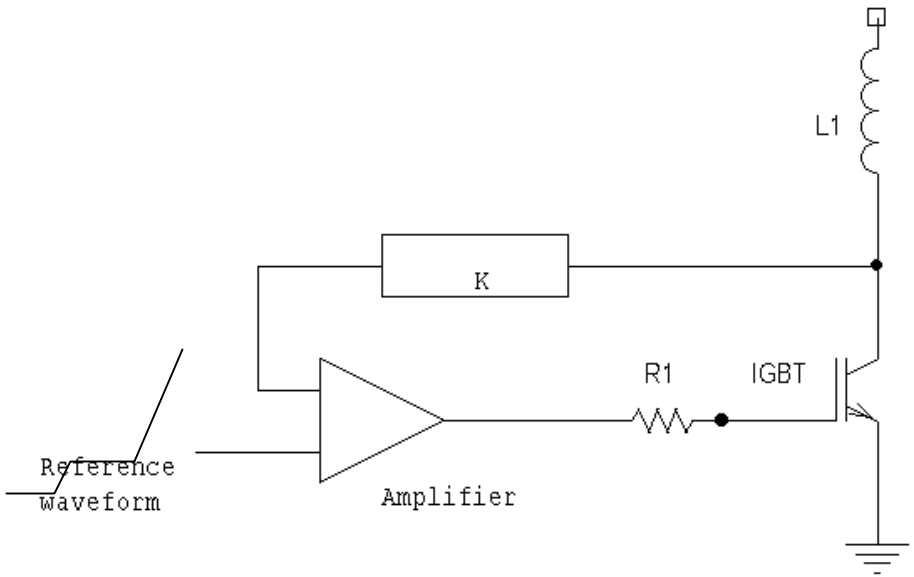
- differences between similar devices
- long term maintianability
- total cost over whole life.

HARD SWITCHED - 3 devices in series



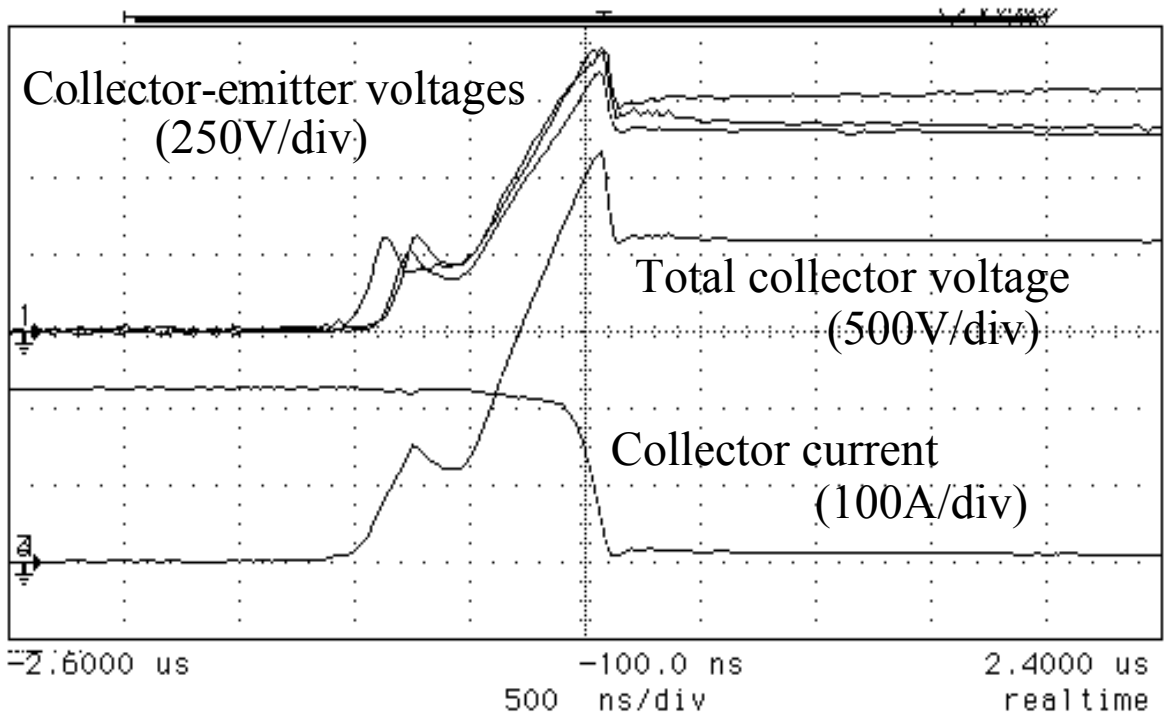
- The poor transient sharing is followed by poor sharing in the off state.

ACTIVE VOLTAGE CONTROL PRINCIPLES



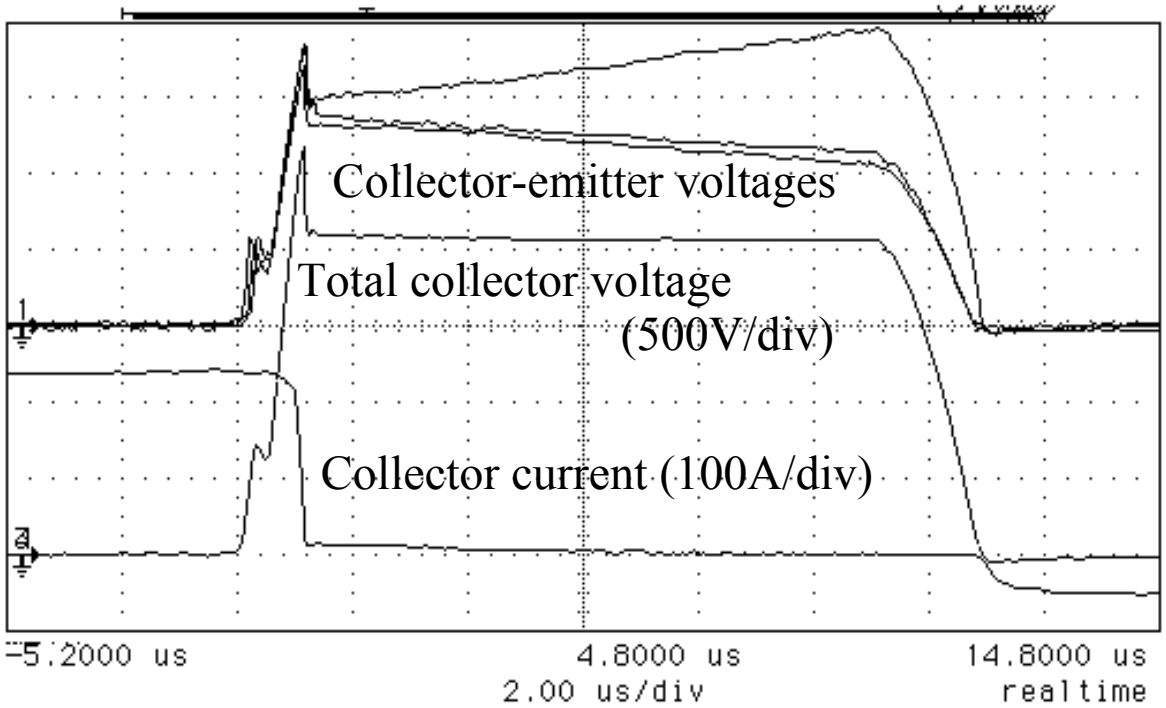
- Utilises the IGBT's gate control capability
- Closed Loop Voltage Control
- Collector voltage follows reference waveform

ACTIVE VOLTAGE CONTROL - 3 devices in series



- Small preconditioning step followed by turn-off ramp.
- Poor transient sharing in step 1 followed by excellent sharing in the ramp.

ACTIVE VOLTAGE CONTROL - 3 devices in series



- Sharing in the off state is much improved also.

Off-state characteristics are temperature dependent

IV Future Devices

TECHNOLOGY DRIVERS

- High Ratings: 6.5 kV, 1000A IGBTs
  - Very high switching losses per unit volume
- High Temperatures: SiC , 300 ^{O}C
  - Materials issues within the package
- Integrated Systems: Power chips and logic/microprocessors in one plastic package
  - Large Power ‘Bricks’

CONCLUSIONS

- The thermal arrangement must be symmetrical to ensure balanced operation.
- Plastic and Capsule devices are reliable under typical conditions, but asymmetries cause problems when switching at a high frequency.
- Feedback control offers exciting opportunities.
- New Si and SiC devices demand better packages.
- New package topologies are needed to remove some of the stability problems and make power bricks more practical.

V SELECTED PUBLICATIONS

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- "Some causes of current redistribution in IGBTs during turn off", J.C. Joyce and *P.R. Palmer*, IEEE/IEEJ International Symposium on Power Semiconductor Devices and ICs, pp. 273-, Toronto, May 1999
- "The use of capsule IGBTs in the series connection", *P.R.Palmer*, H.S.Rajamani, N.Dutton, PEVD'00, IEE Conference Publication No. 475, pp. 250-255, London, Sept. 2000
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