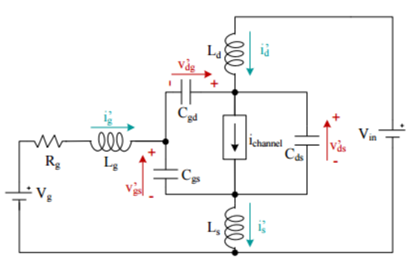
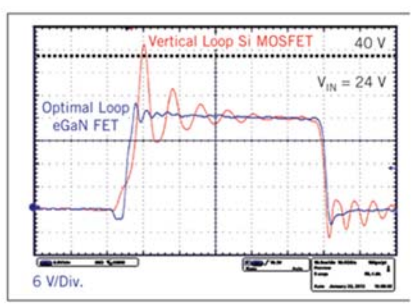
Announcements

Experimental Switching Waveforms





D Reusch, "eGaN® FET-Silicon Power Shoot-Out Vol. 13, Part 2: Optimal PCB Layout"
M Rodriguez et al, "Analysis of the switching process of power MOSFETs using a new analytical losses model"

The Double Pulse Test

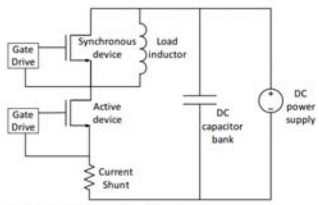


Fig. 7. Double pulse test circuit schematic.

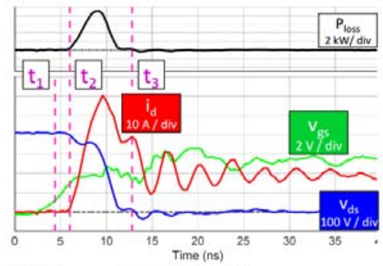


Fig. 11. Turn-on waveform at 400 V, 10 A, 25 °C.

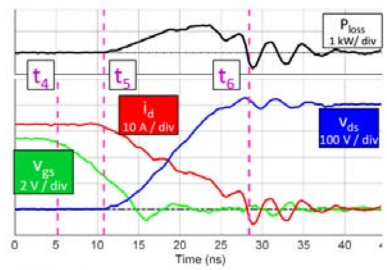


Fig. 12. Turn-off waveform at 400 V, 10 A, 25 °C.

The Double Pulse Test

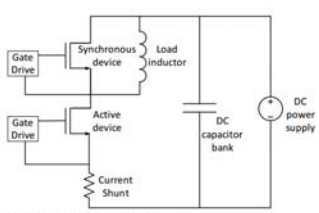


Fig. 7. Double pulse test circuit schematic.

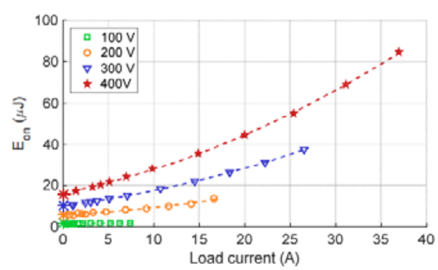
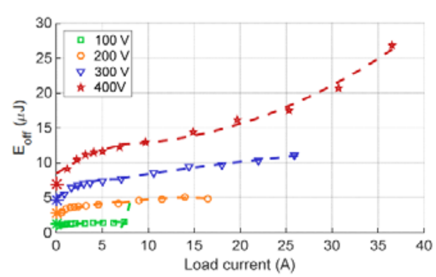
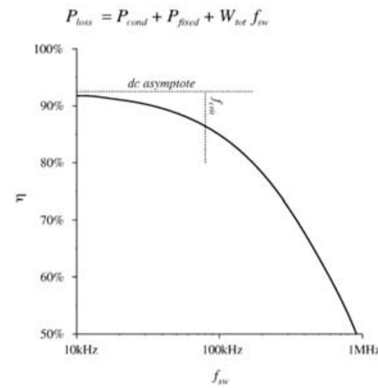


Fig. 16. Turn-on energy E_{on} at 25 °C.



Converter Efficiency Vs. f_s



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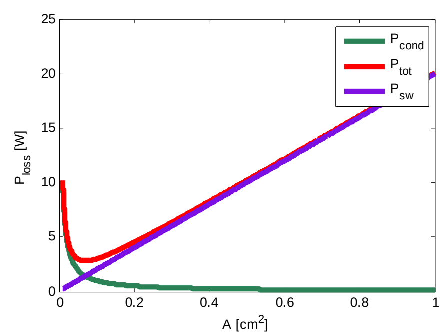
Die Size Selection



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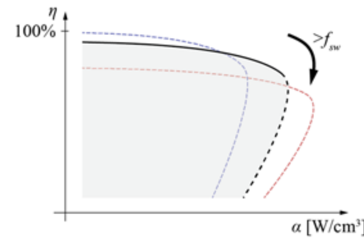
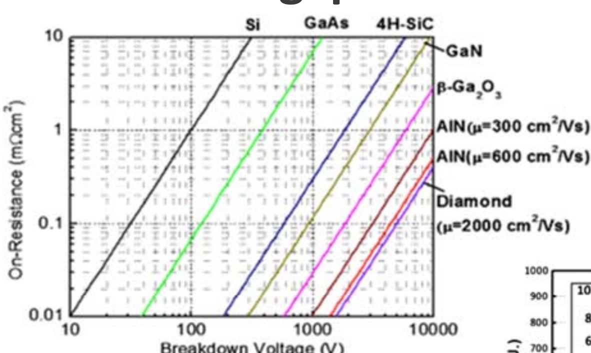
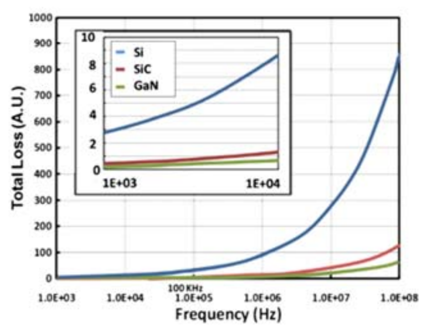
Converter Optimization



Wide Bandgap Materials



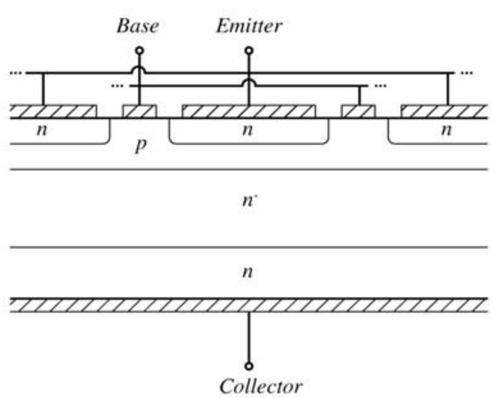


Srabanti Chowdhury *et al* "Current status and scope of gallium nitride-based vertical transistors for high-power electronics application" 2013 *Semicond. Sci. Technol.* 28, 074014

Power MOSFET: Conclusions

- A majority-carrier device: fast switching speed
- Typical switching frequencies: tens and hundreds of kHz
- On-resistance increases rapidly with rated blocking voltage
- Easy to drive
- The device of choice for blocking voltages less than 500V
- 1000V devices are available, but are useful only at low power levels (100W)
- Part number is selected on the basis of on-resistance rather than current rating

Bipolar Junction Transistor

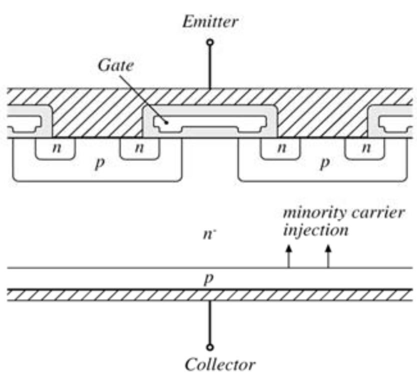


- Interdigitated base and emitter contacts
- Vertical current flow
- npn device is shown
- minority carrier device
- on-state: base-emitter and collector-base junctions are both forward-biased
- on-state: substantial minority charge in p and n^- regions, conductivity modulation

BJT: Conclusions

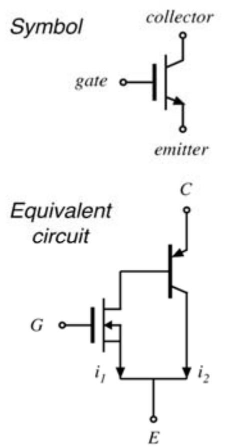
- BJT has been replaced by MOSFET in low-voltage (<500V) applications
- BJT is being replaced by IGBT in applications at voltages above 500V
- A minority-carrier device: compared with MOSFET, the BJT exhibits slower switching, but lower on-resistance at high voltages

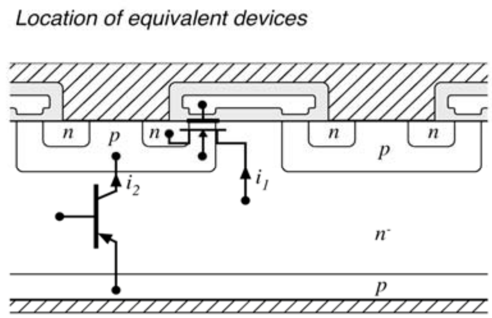
Insulated Gate Bipolar Junction Transistor



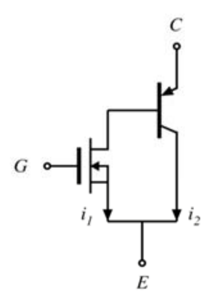
- A four-layer device
- Similar in construction to MOSFET, except extra *p* region
- On-state: minority carriers are injected into n^- region, leading to conductivity modulation
- compared with MOSFET: slower switching times, lower on-resistance, useful at higher voltages (up to 1700V)

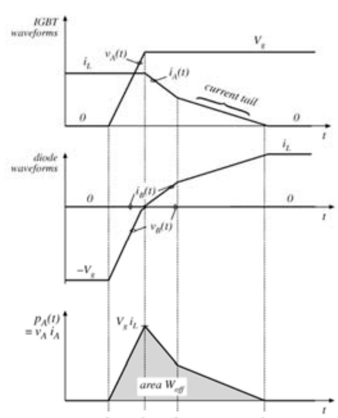
The IGBT





IGBT: Current Tailing





Conclusions: IGBT

- Becoming the device of choice in 500 to 1700V+ applications, at power levels of 1-1000kW
- Positive temperature coefficient at high current —easy to parallel and construct modules
- Forward voltage drop: diode in series with on-resistance. 2-4V typical
- Easy to drive —similar to MOSFET
- Slower than MOSFET, but faster than Darlington, GTO, SCR
- Typical switching frequencies: 3-30kHz
- IGBT technology is rapidly advancing:
  - 3300 V devices: HVIGBTs
  - 150 kHz switching frequencies in 600 V devices

Chapter 5: Discontinuous Conduction Mode

5.1. Origin of the discontinuous conduction mode, and mode boundary

5.2. Analysis of the conversion ratio $M(D,K)$

5.3. Boost converter example

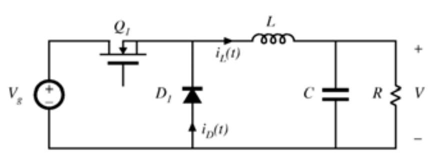
5.4. Summary of results and key points

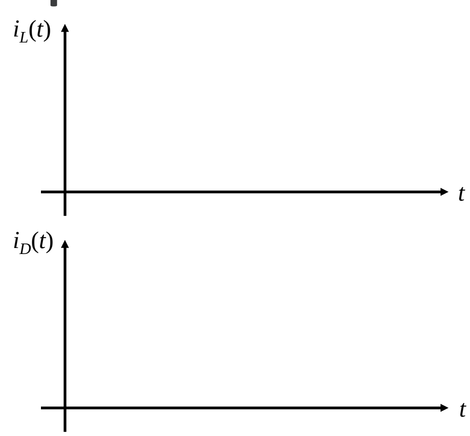
DCM Introduction

- Occurs because switching ripple in inductor current or capacitor voltage causes polarity of applied switch current or voltage to reverse, such that the current- or voltage-unidirectional assumptions made in realizing the switch are violated.
- Commonly occurs in dc-dc converters and rectifiers, having single-quadrant switches. May also occur in converters having two-quadrant switches.
- Typical example: dc-dc converter operating at light load (small load current). Sometimes, dc-dc converters and rectifiers are purposely designed to operate in DCM at all loads.
- Properties of converters change radically when DCM is entered:
  - M becomes load-dependent
  - Output impedance is increased
  - Dynamics are altered
  - Control of output voltage may be lost when load is removed

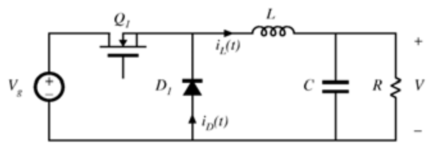
Fundamentals of Power Electronics 2 *Chapter 5: Discontinuous conduction mode*

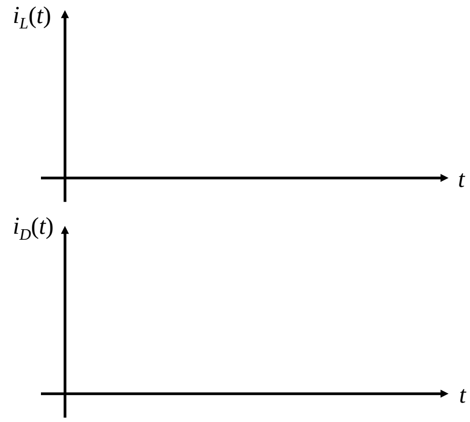
Buck Converter Example





Buck Converter: Low Load





DCM/CCM Modes of Operation