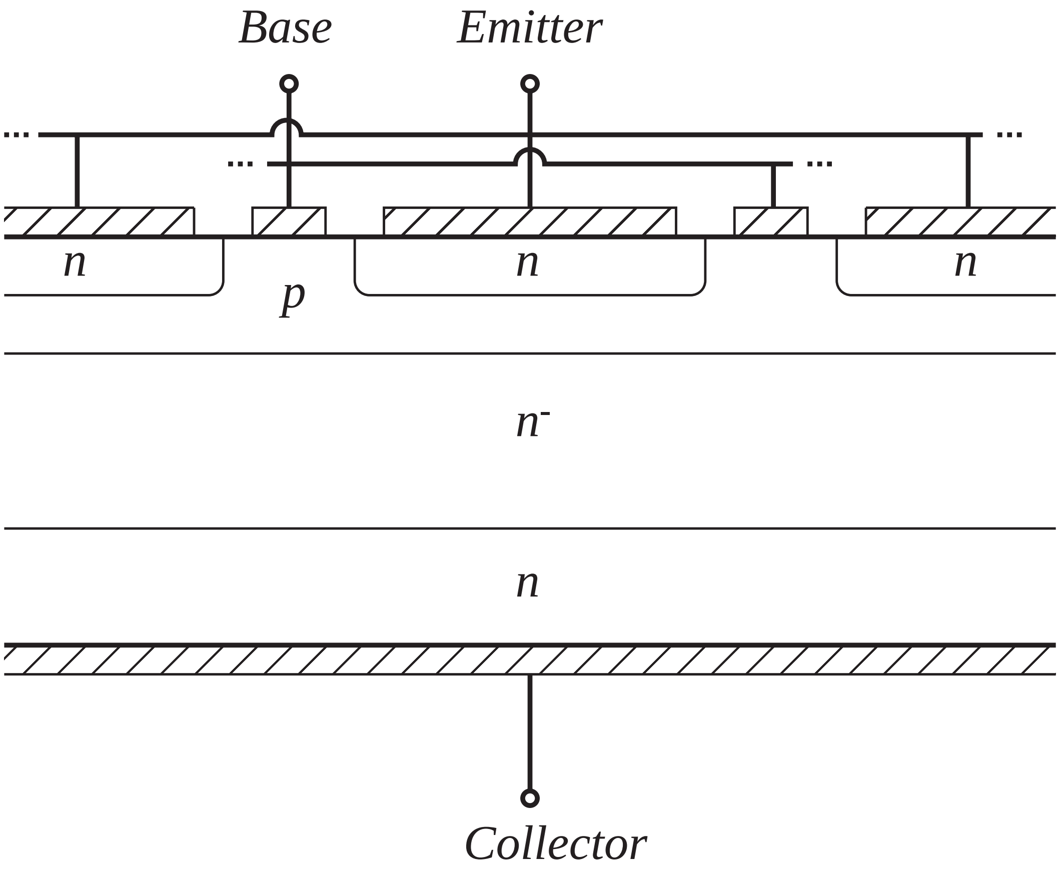
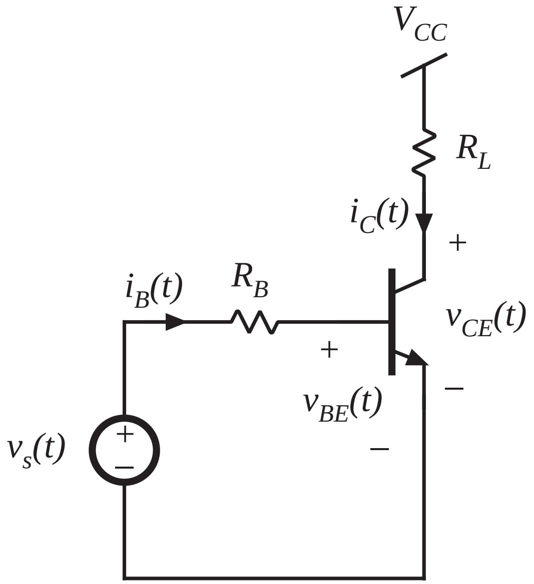
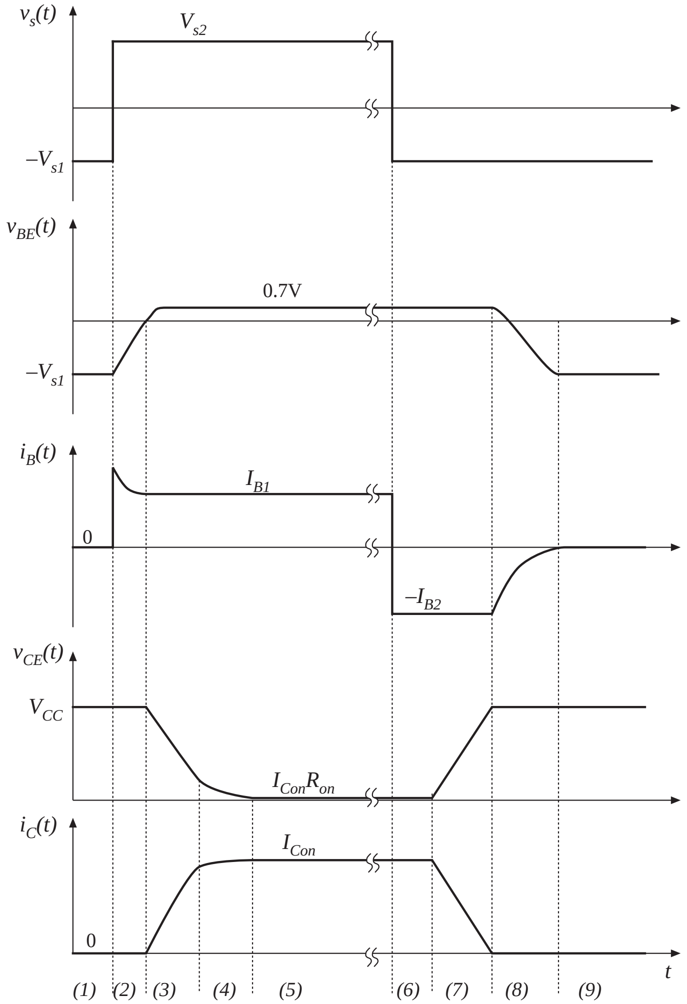
4.2.3. Bipolar Junction Transistor (BJT)



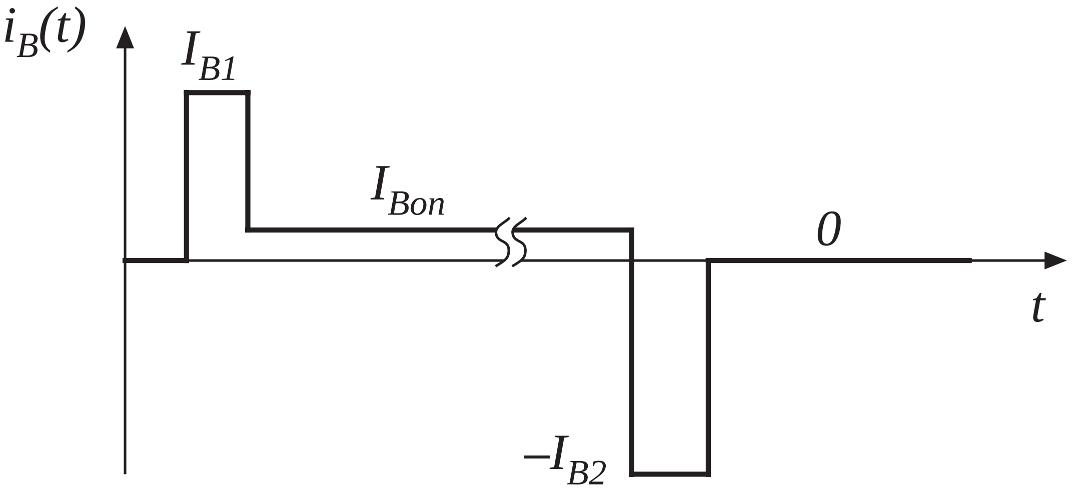
- Interdigitated base and emitter contacts
- Vertical current flow
- npn device is shown
- minority carrier device
- on-state: base-emitter and collector-base junctions are both forward-biased
- on-state: substantial minority charge in p and n^- regions, conductivity modulation

BJT switching times

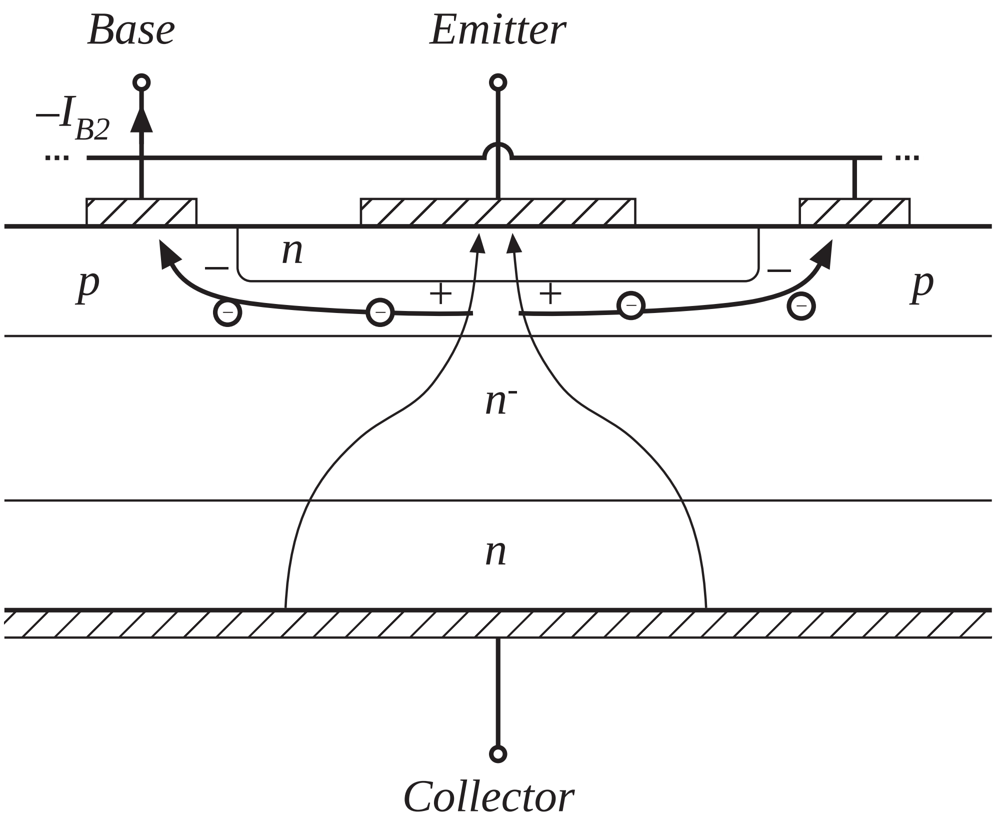




Ideal base current waveform

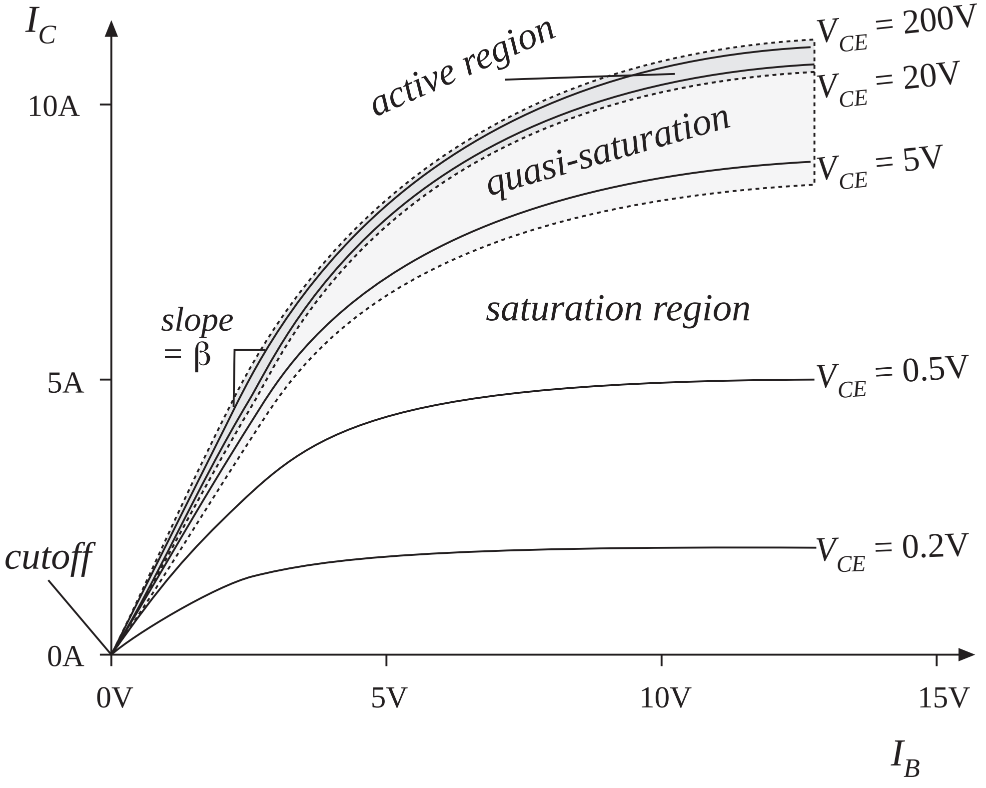


Current crowding due to excessive I_{B2}



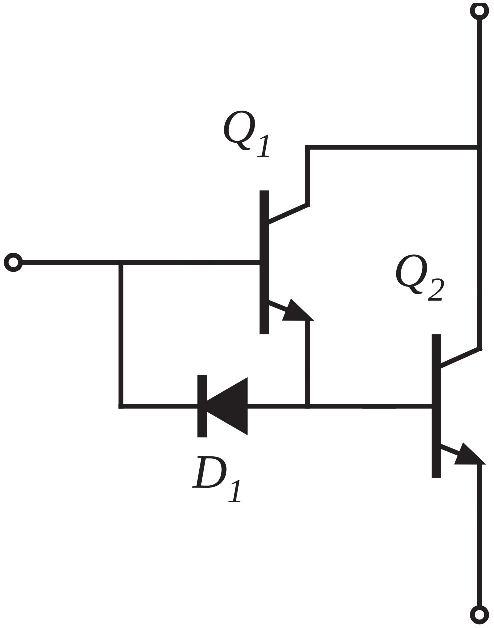
can lead to formation of hot spots and device failure

BJT characteristics



- Off state: $I_B = 0$
- On state: $I_B > I_C / \beta$
- Current gain β decreases rapidly at high current. Device should not be operated at instantaneous currents exceeding the rated value

Darlington-connected BJT

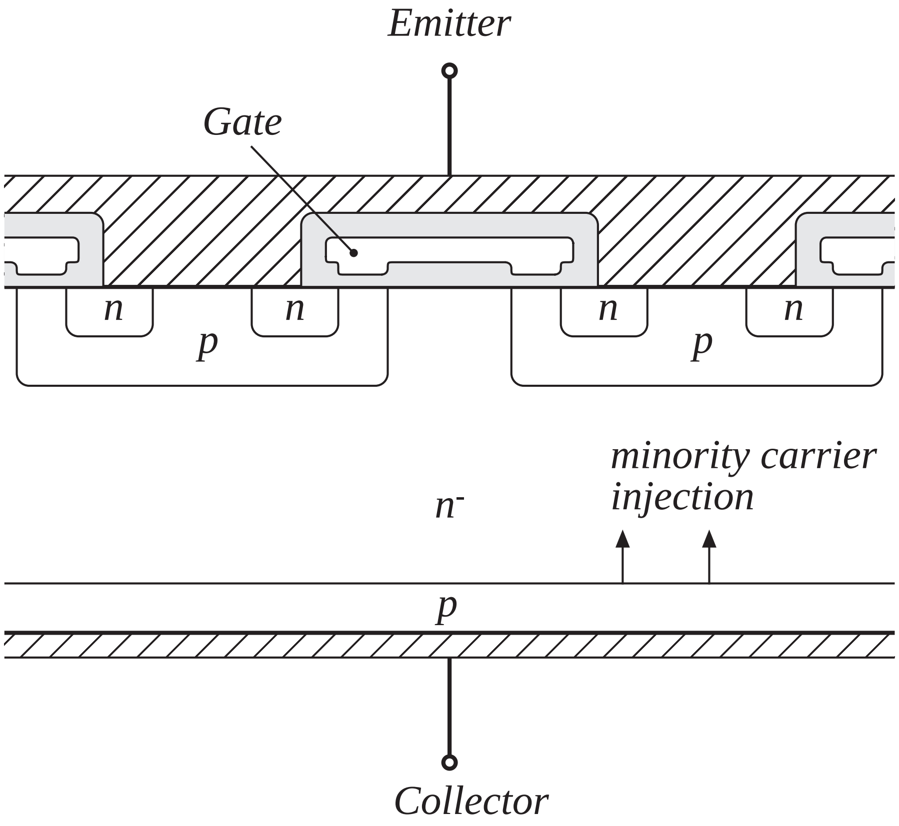


- Increased current gain, for high-voltage applications
- In a monolithic Darlington device, transistors Q_1 and Q_2 are integrated on the same silicon wafer
- Diode D_1 speeds up the turn-off process, by allowing the base driver to actively remove the stored charge of both Q_1 and Q_2 during the turn-off transition

Conclusions: BJT

- 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

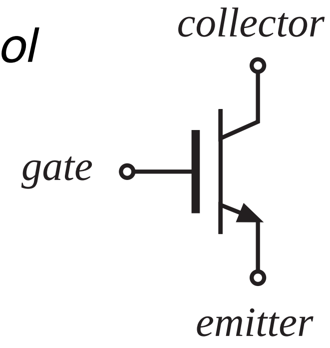
4.2.4. The Insulated Gate Bipolar Transistor (IGBT)



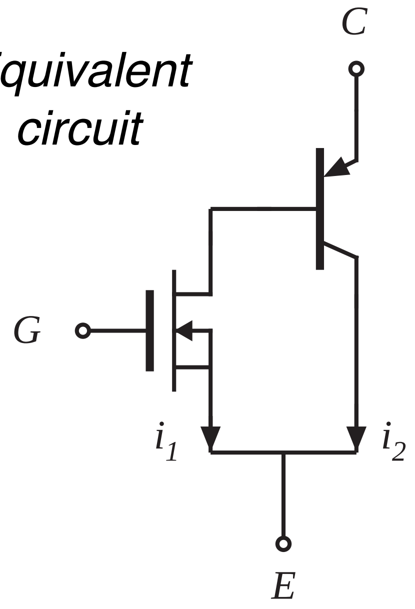
- A four-layer device
- Similar in construction to MOSFET, except extra *p* region
- On-state: minority carriers are injected into n^- region, leading to conductivity modulation
- compared with MOSFET: slower switching times, lower on-resistance, useful at higher voltages (up to 1700V)

The IGBT

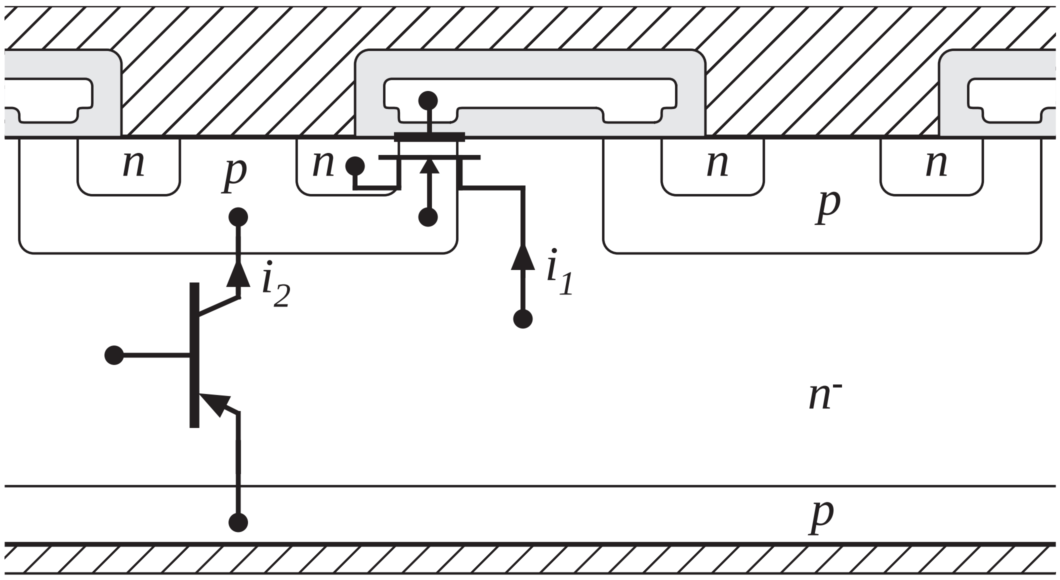
Symbol



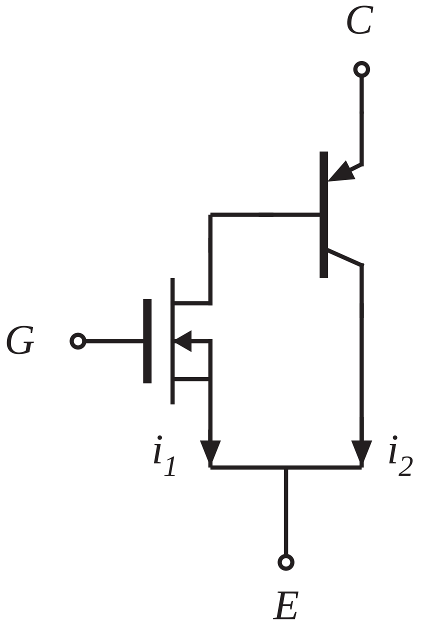
Equivalent circuit

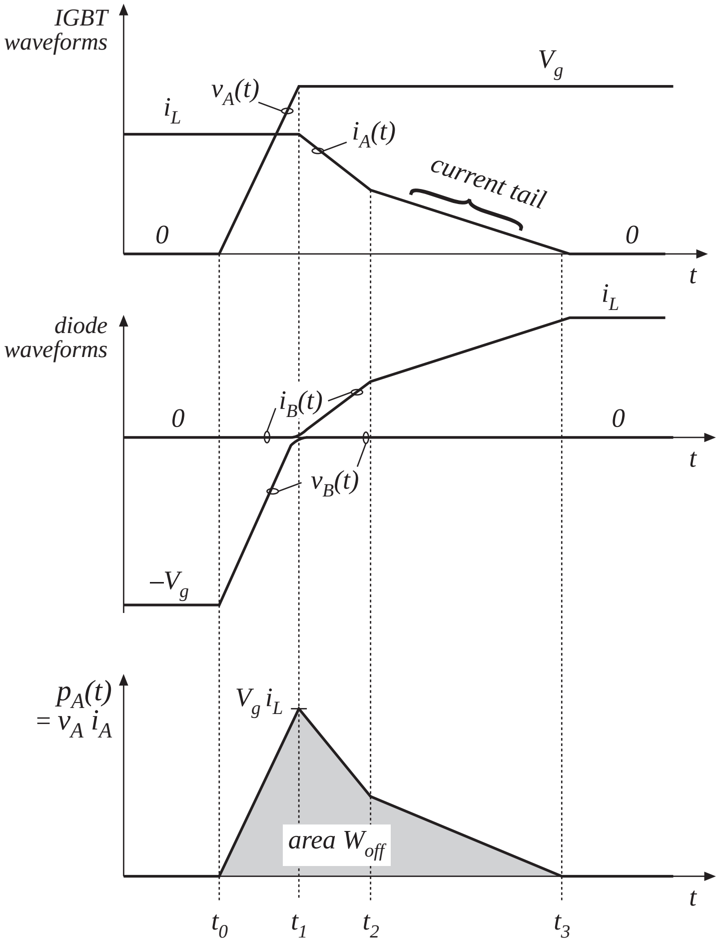


Location of equivalent devices

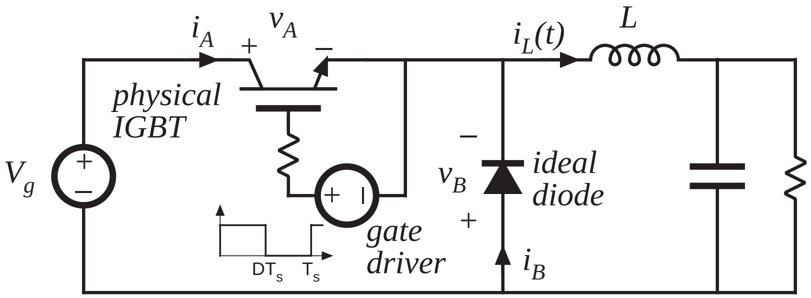


Current tailing in IGBTs

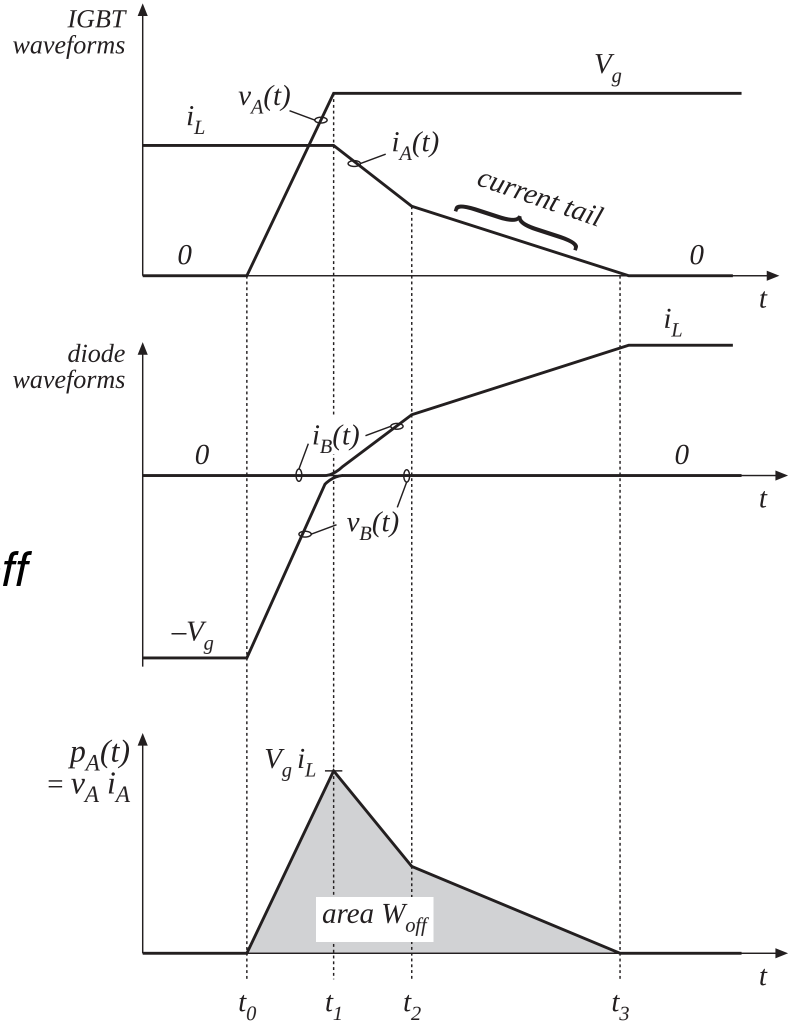




Switching loss due to current-tailing in IGBT



Example: buck converter with IGBT



transistor turn-off transition

$$P_{sw} = \frac{1}{T_s} \int_{\substack{\text{switching}\\ \text{transitions}}} p_A(t)\, dt = (W_{on} + W_{off})\ f_s$$

Characteristics of several commercial devices

Part number	*Rated max voltage*	*Rated avg current*	V_F *(typical)*	t_f *(typical)*
Single-chip devices				
HGTG32N60E2	600V	32A	2.4V	0.62μs
HGTG30N120D2	1200V	30A	3.2A	0.58μs
Multiple-chip power modules				
CM400HA-12E	600V	400A	2.7V	0.3μs
CM300HA-24E	1200V	300A	2.7V	0.3μs

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