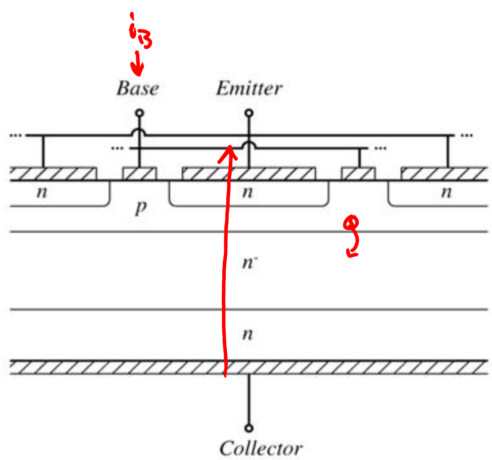
Announcements

- Next week: ECCE Conference Mon.-Thurs.
  - Recorded lectures to be posted on the website
  - Generally available via e-mail for questions
  - Homework as normal
  - http://2015.ecceconferences.org/wp-content/uploads/2015/09/ECCE2015program_webSep131.pdf

THE UNIVERSITY OF TENNESSEE KNOXVILLE

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

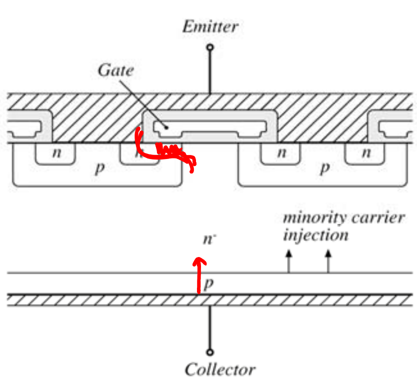
Fundamentals of Power Electronics 56 *Chapter 4: Switch realization*

THE UNIVERSITY OF TENNESSEE KNOXVILLE

BJT: Conclusions

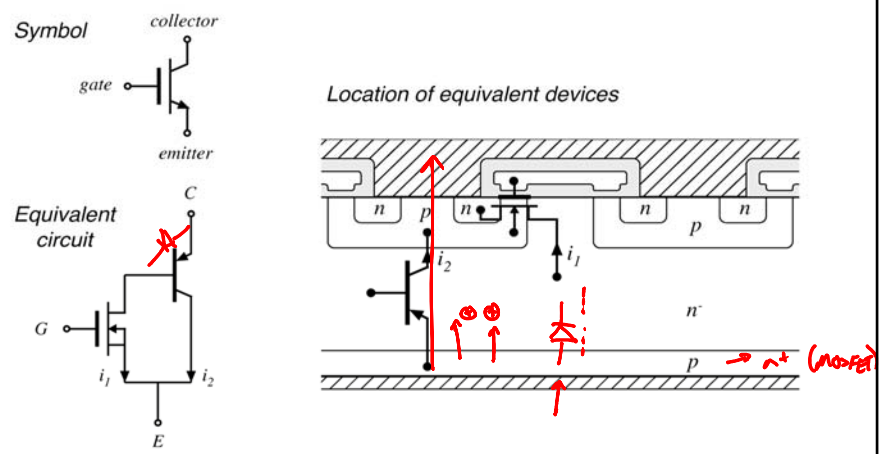
- BJT has been replaced by MOSFET in low-voltage (<500V) applications
- BJT is being replaced by IGBT in applications at voltages above 500V
- A minority-carrier device: compared with MOSFET, the BJT exhibits slower switching, but lower on-resistance at high voltages

Insulated Gate Bipolar Junction Transistor

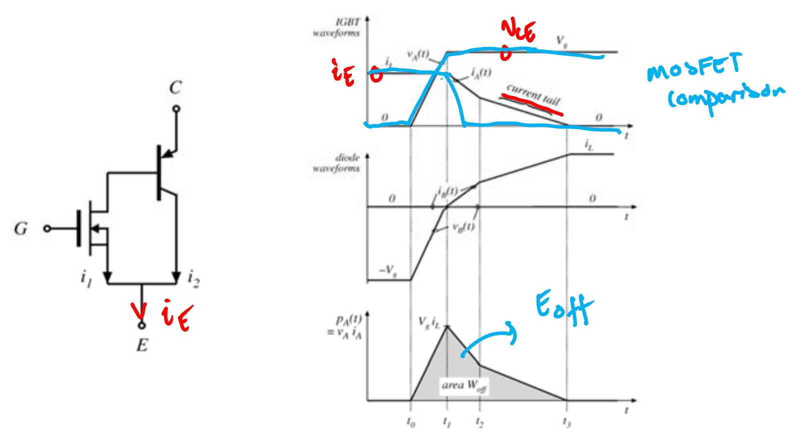


- A four-layer device
- Similar in construction to MOSFET, except extra *p* region
- On-state: minority carriers are injected into n^- region, leading to conductivity modulation
- compared with MOSFET: slower switching times, lower on-resistance, useful at higher voltages (up to 1700V)

The IGBT

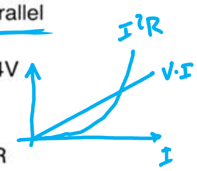


IGBT: Current Tailing



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



THE UNIVERSITY OF TENNESSEE KNOXVILLE

Chapter 5: Discontinuous Conduction Mode

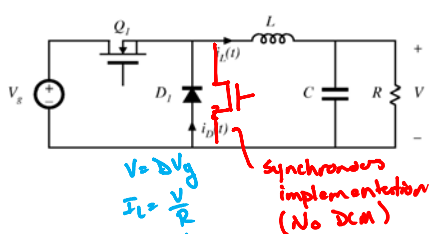
THE UNIVERSITY OF TENNESSEE KNOXVILLE

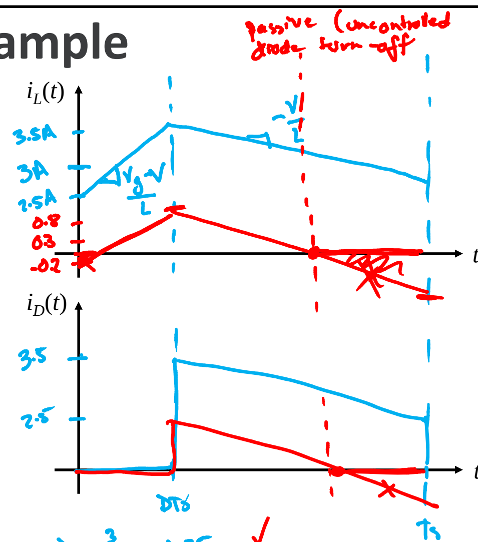
DCM Introduction

- 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:
  - V/V_g = 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





$V = DV_g$

$I_L = \frac{V}{R}$

$2\Delta i_L = \frac{V_g - V}{L} DT_s$

ex: $V_g = 12$ $V = 3$ $L = 100\,\mu H$ $T_s = 50\,\mu s$

first, $R = 1\,\Omega$

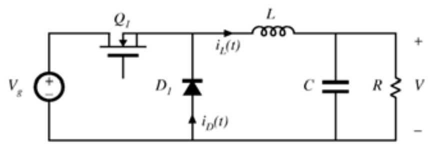
Now $R \to 10\,\Omega$

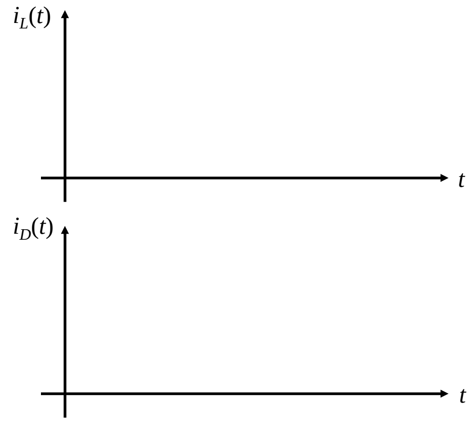
$D = \frac{3}{12} = 0.25$ ✓

$I_L = \frac{3V}{1\Omega} = 3A \to 0.3A$ *

$\Delta i_L = 0.56A$ ✓ ($\Delta i_L > I_L$?)

Buck Converter: Low Load





DCM/CCM Modes of Operation

Continuous Conduction Mode: (CCM)
- what we've seen so far
- one switch is always on in each 'pair' that implements an SPDT switch

Discontinuous Conduction Mode (DCM):
- some element's ripple causes passive turn-off of a switch
- e.g. $\Delta i_L > I_L$ calculated for CCM

Critical Conduction Mode (CRM) or Boundary Cond. Mode (BCM)
- e.g. $\Delta i_L = I_L$

K_{crit} and R_{crit}

$(V = DV_g)$

Buck converter:

$$I_L = \frac{V}{R} = \frac{DV_g}{R} \qquad \Delta i_L = \frac{V_g - V}{2L} D T_s = \frac{V_g D'}{2L} D T_s$$

In CCM when $I_L > \Delta i_L$

Go into DCM when $I_L < \Delta i_L$

for CCM:

$$\frac{DV_g}{R} > \frac{V_g D'}{2L} D T_s$$

$$K = \frac{2L}{RT_s} > D' = K_{crit}(D)$$

$K > K_{crit}(D)$ for CCM

DCM Mode Boundary: Summary

$$K > K_{crit}(D) \quad or \quad R < R_{crit}(D) \quad for\ CCM$$
$$K < K_{crit}(D) \quad or \quad R > R_{crit}(D) \quad for\ DCM$$

Table 5.1. CCM-DCM mode boundaries for the buck, boost, and buck-boost converters

Converter	$K_{crit}(D)$	$\max_{0 \le D \le 1}(K_{crit})$	$R_{crit}(D)$	$\min_{0 \le D \le 1}(R_{crit})$
Buck	$(1 - D)$	1	$\frac{2L}{(1-D)T_s}$	$2\frac{L}{T_s}$
Boost	$D(1-D)^2$	$\frac{4}{27}$	$\frac{2L}{D(1-D)^2 T_s}$	$\frac{27}{2}\frac{L}{T_s}$
Buck-boost	$(1-D)^2$	1	$\frac{2L}{(1-D)^2 T_s}$	$2\frac{L}{T_s}$