

Lecture 1: August 23, 2010

---

# Introduction to Power Electronics

ECEN 4797 / 5797

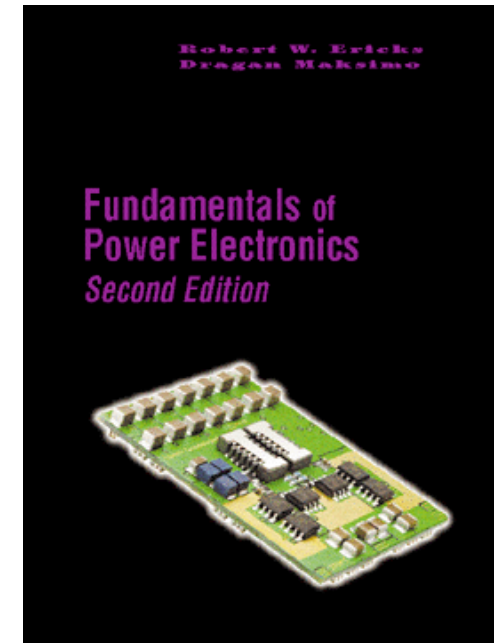
Robert W. Erickson  
University of Colorado, Boulder  
Fall 2010

# Introduction to Power Electronics

## ECEN 4797 / 5797

---

- Instructor: Prof. Bob Erickson
  - Office: ECOT 356
  - Telephone: (303) 492-7003
  - Email: [rwe@colorado.edu](mailto:rwe@colorado.edu)
  - Office hours: Th 2:00 - 3:30 pm, W 3:00 - 4:00 pm
  - Telephone office hours: M 3:00 - 4:00 pm
- Course web site:
  - <http://ece.colorado.edu/~ecen5797>
  - Includes lecture slides, handouts, homework assignments, links to online lecture files
- Textbook:
  - Erickson and Maksimovic, Fundamentals of Power Electronics, second edition, Springer, ISBN 0-7923-7270-0.
- Prerequisite:
  - A 3-4 semester sequence of undergraduate EE circuits and electronics courses (at Univ. of Colorado: ECEN 3250)



# Coursework in Power Electronics at the University of Colorado

---

---

- Power electronics courses
  - ECEN 4797/5797 (this course): Intro to power electronics (Fall)
  - ECEN 5807 Modeling and Control of Power Electronics Systems (Alt Spring semesters, including S '11)
  - ECEN 5817 Resonant and Soft-Switching Techniques in Power Electronics (Alt Spring semesters, including S '12)
  - ECEN 4517/5517 Power Electronics Laboratory (Spring)
- Professional Certificate in Power Electronics
  - ECEN 5797, 5807, and 5817
- Formats for this course
  - On-campus, for senior or graduate credit
  - Web-based lectures: recorded with ECHO 360 system, with viewing through the Flash viewer. For technical help, contact [help@cuengineeringonline.colorado.edu](mailto:help@cuengineeringonline.colorado.edu) (CAETE)

# Grading

---

- Homework
  - Due at beginning of class on date listed on Lecture Schedule web page
  - Late homework not accepted
  - Homework counts 50% of grade
  - You may speak with others about the homework, but turn in your own work
  - Password-protected solutions on web site
  - Homework and exam problems of additional depth and complexity for those earning graduate credit; separately graded
- Exams
  - Midterm exam: one-week take-home exam, 17% of grade
  - Final exam: five-day take-home exam, 33% of grade
  - See course schedule page for dates
  - See course vitals page for details

# Off-campus students

---

- Assignment due dates
  - One week grace period allowed for all assignments and exams
  - Late homework not accepted beyond the one-week grace period
- How to submit your work: mail, email, or fax
  - Fax option: ECEE Department fax 303-492-2758. On cover page, clearly direct to Prof. Erickson.
  - Email: send to Prof. Erickson at [rwe@colorado.edu](mailto:rwe@colorado.edu)
    - Scan instructions: black-and-white (no grayscale or color!), 200-300 dpi, with all pages in a single pdf file. Other file/scan formats not accepted.
  - Mail: send to: Prof. R. Erickson, ECEE Department, University of Colorado, Boulder CO 80309-0425. Must be postmarked by due date.
- Exam options
  - Send email to Prof. Erickson on your desired start date. Prof. Erickson replies with exam as email attachment. You fax or email completed exam directly to Prof. Erickson by due date. No Educational Officer (EO) required.
  - Second option: your company EO receives the exam from CAETE, then administers the exam to you.

# Key dates

---

- Drop deadlines
  - September 8: last day to drop the course and receive full tuition refund, with no “W” grade appearing on transcript
  - October 6: last day to drop the course without petitioning the Dean’s office
- Tentative exam dates
  - Midterm exam: 1 week take-home exam. For on-campus students: handed out Oct. 22, due in class on Oct. 29. One week grace period allowed for CAETE students.
  - Final exam: Five day take-home exam. For on-campus students: handed out Dec. 10, due in Prof. Erickson’s office on Dec. 15. One week grace period allowed for CAETE students.
- Grades assigned in December appear on your permanent university transcript
- Campus holidays
  - Labor day: Sept. 6
  - Fall break / Thanksgiving holiday: Nov. 22-26

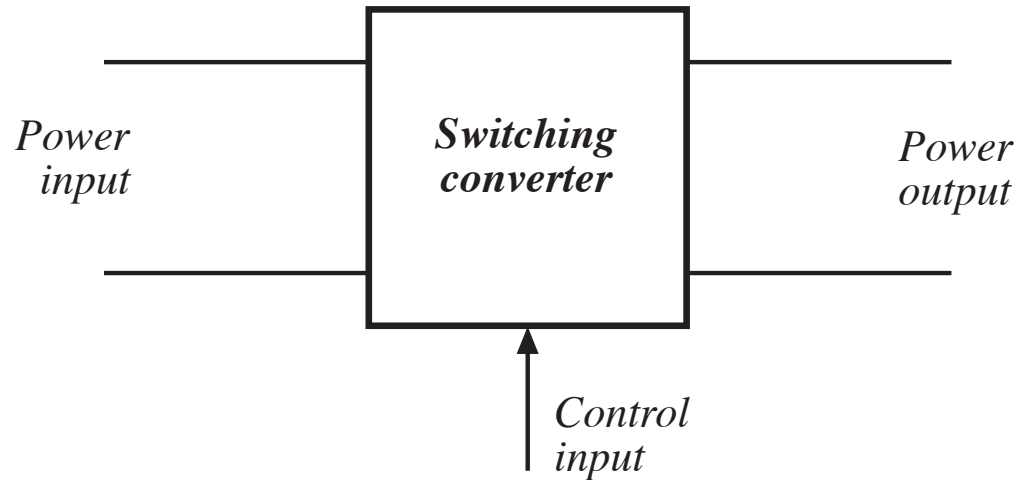
# Chapter 1: Introduction

---

- 1.1. Introduction to power processing
  - 1.2. Some applications of power electronics
  - 1.3. Elements of power electronics
- Summary of the course

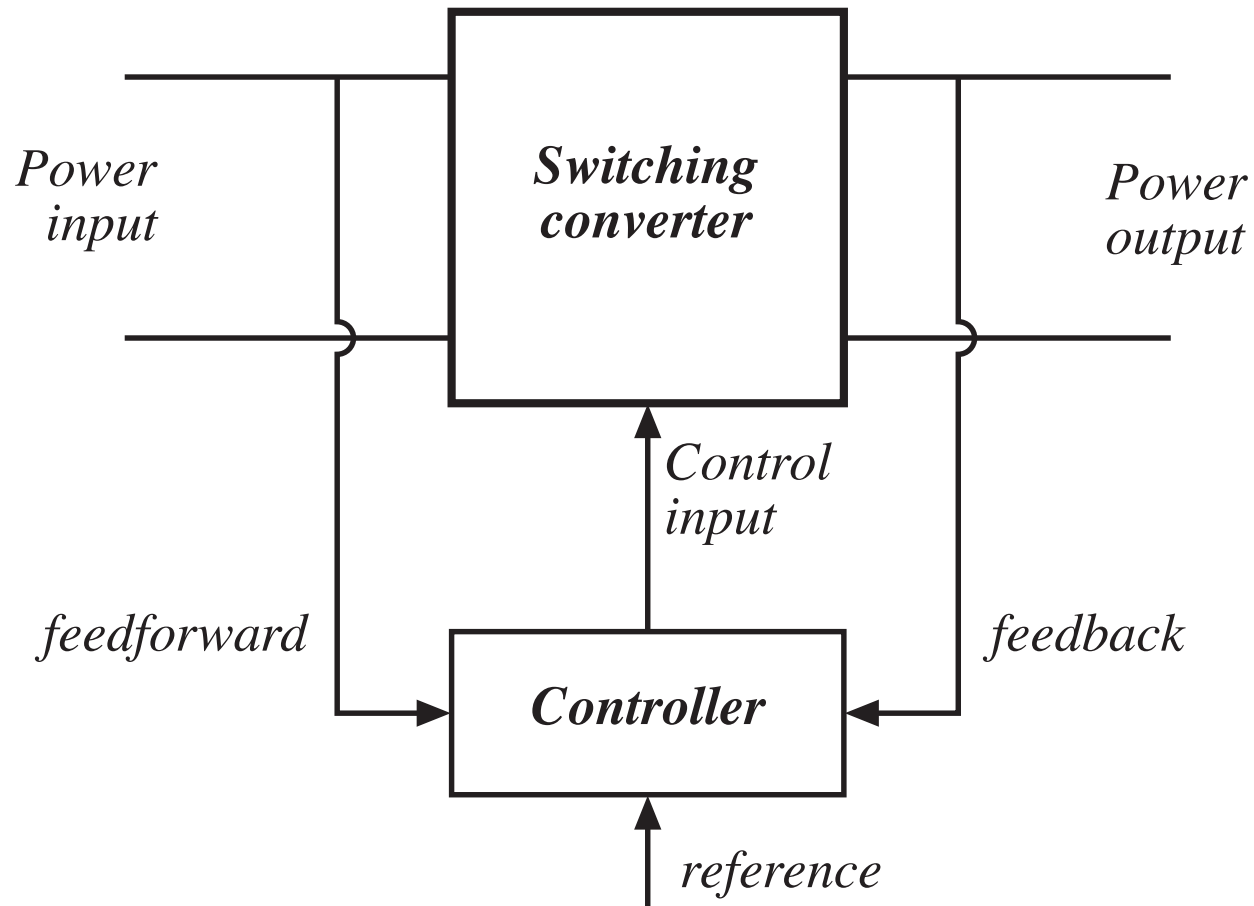
# 1.1 Introduction to Power Processing

---



- Dc-dc conversion:* Change and control voltage magnitude
- Ac-dc rectification:* Possibly control dc voltage, ac current
- Dc-ac inversion:* Produce sinusoid of controllable magnitude and frequency
- Ac-ac cycloconversion:* Change and control voltage magnitude and frequency

# Control is invariably required

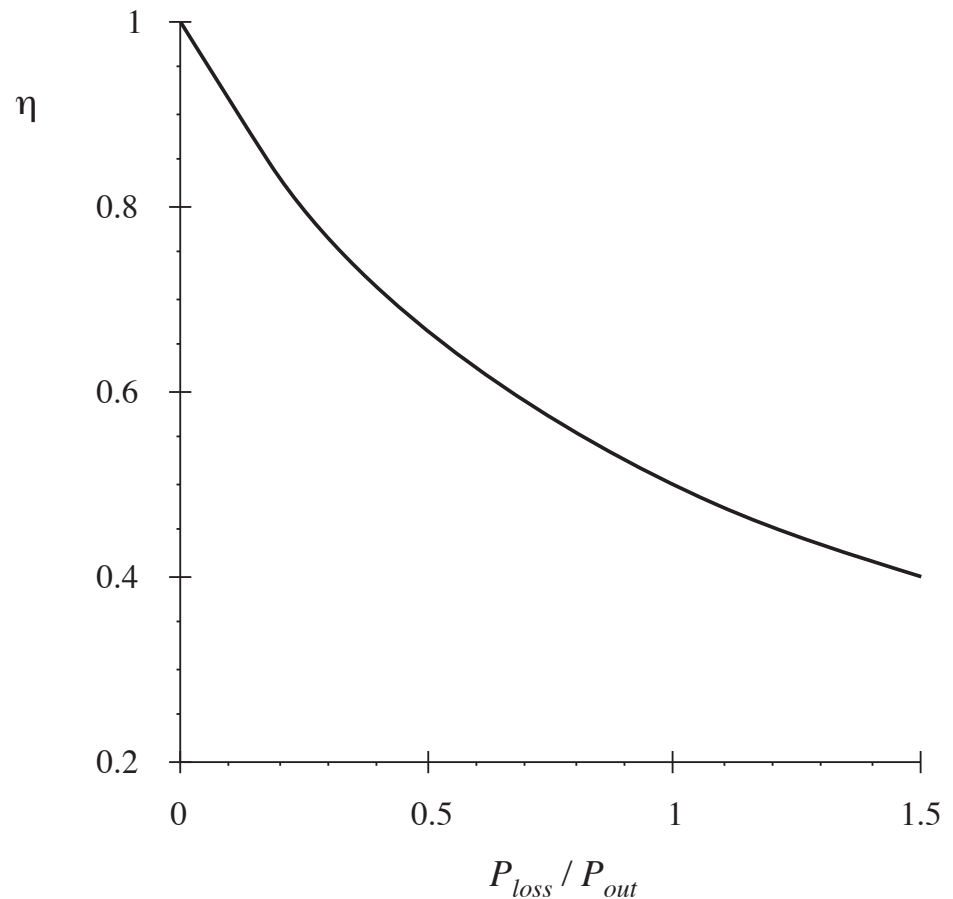


# High efficiency is essential

$$\eta = \frac{P_{out}}{P_{in}}$$

$$P_{loss} = P_{in} - P_{out} = P_{out} \left( \frac{1}{\eta} - 1 \right)$$

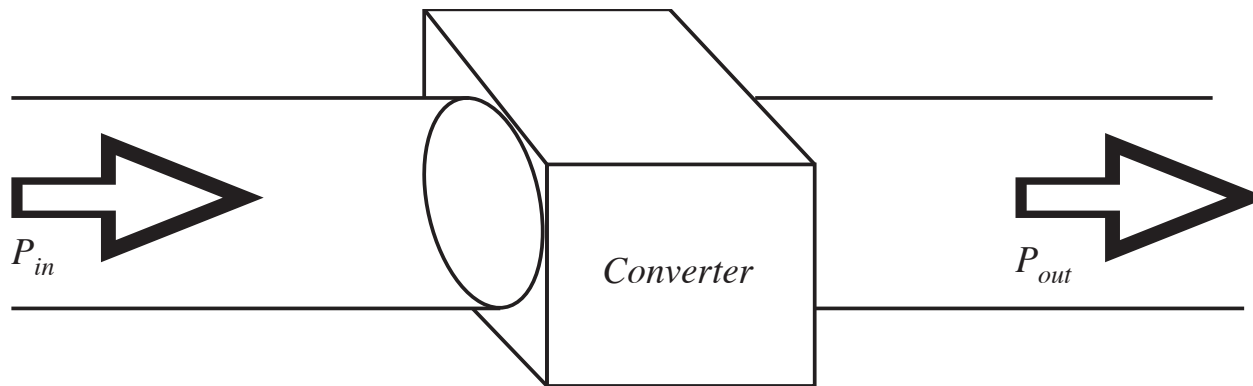
High efficiency leads to low  
power loss within converter  
Small size and reliable operation  
is then feasible  
Efficiency is a good measure of  
converter performance



# A high-efficiency converter

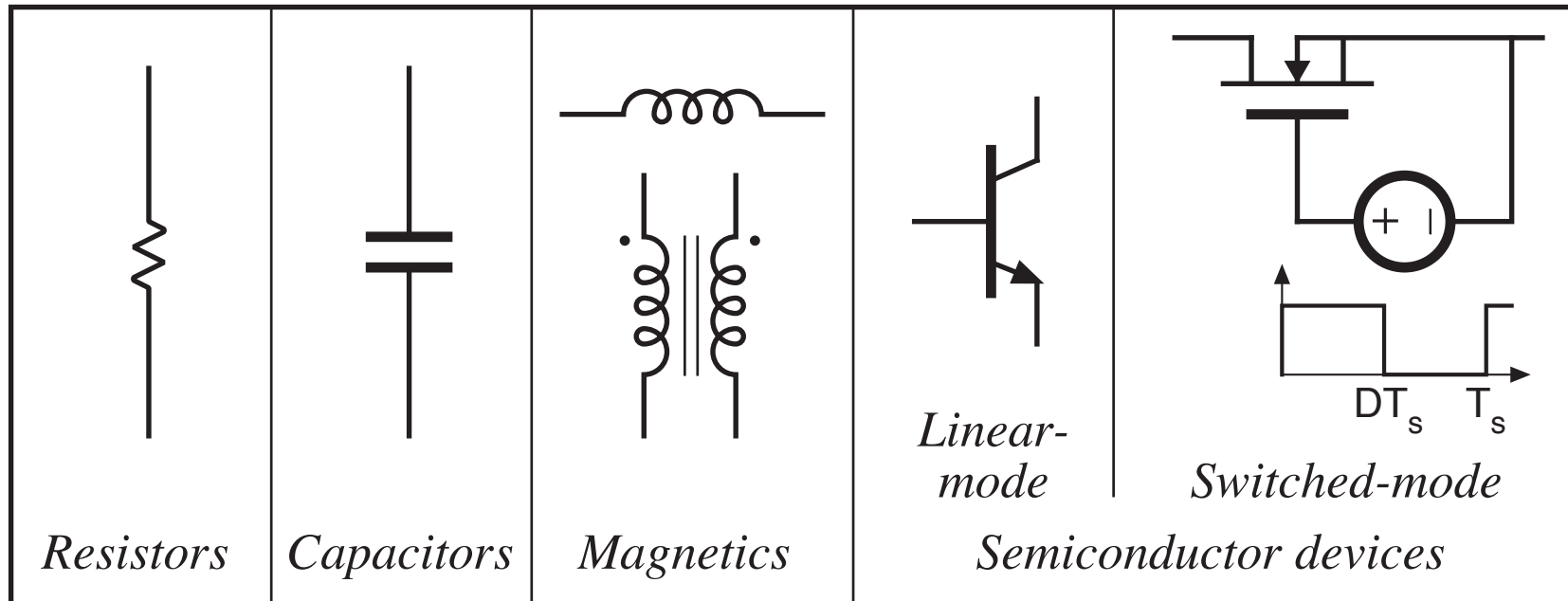
---

---

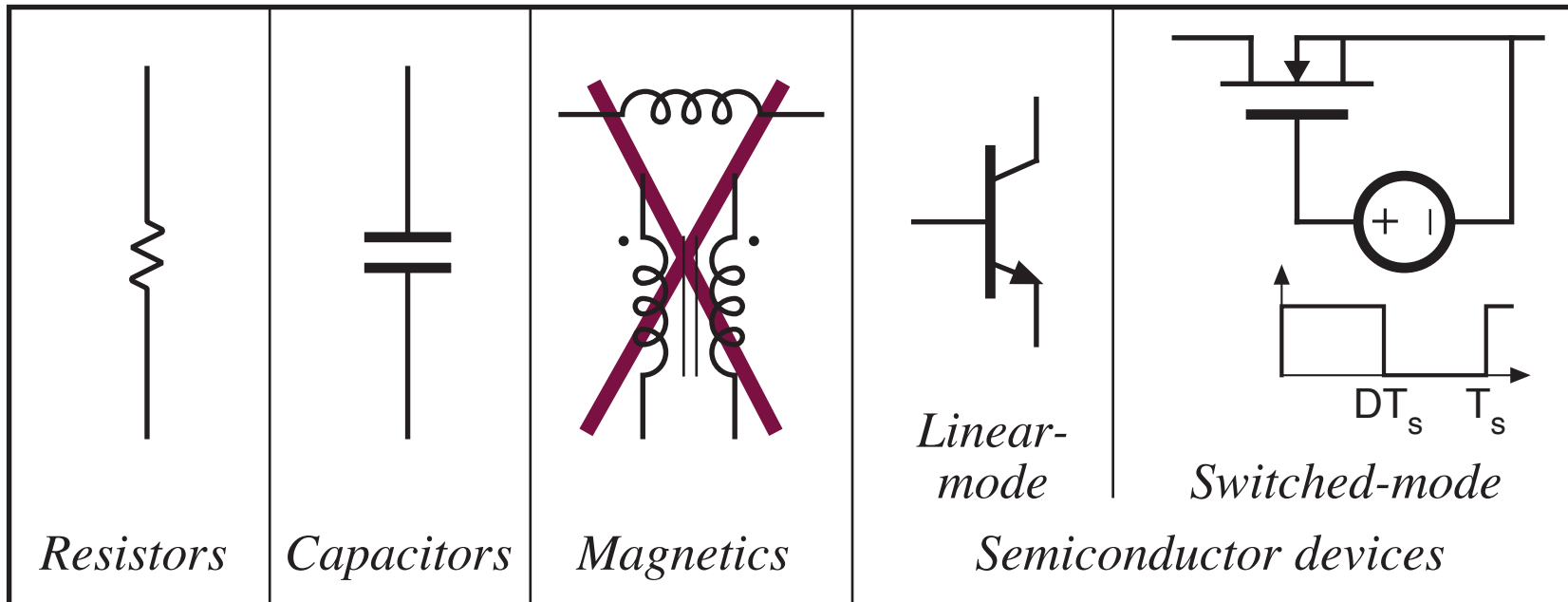


A goal of current converter technology is to construct converters of small size and weight, which process substantial power at high efficiency

# Devices available to the circuit designer

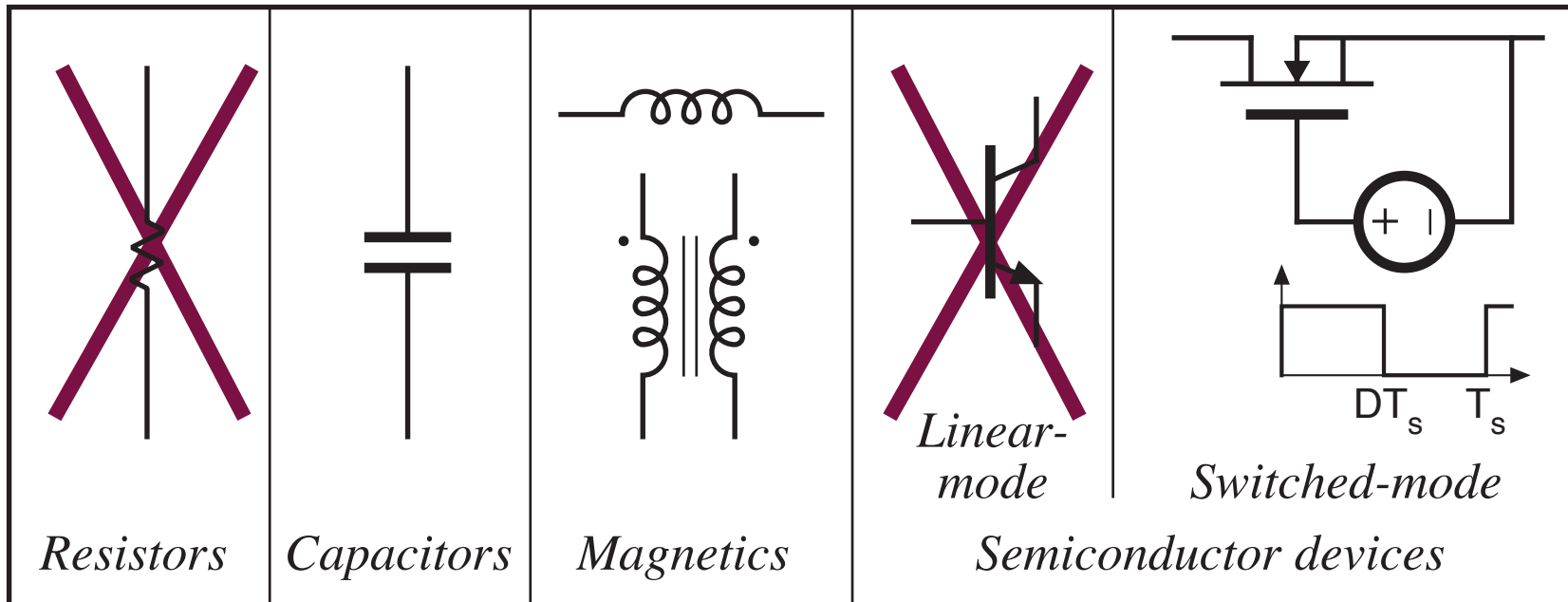


# Devices available to the circuit designer



Signal processing: avoid magnetics

# Devices available to the circuit designer



Power processing: avoid lossy elements

# Power loss in an ideal switch

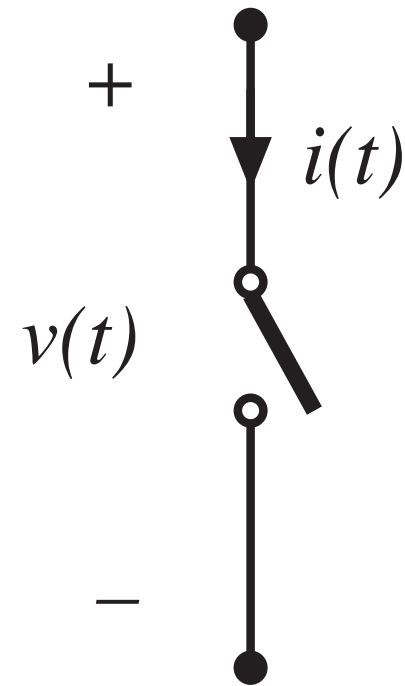
---

Switch closed:  $v(t) = 0$

Switch open:  $i(t) = 0$

In either event:  $p(t) = v(t) i(t) = 0$

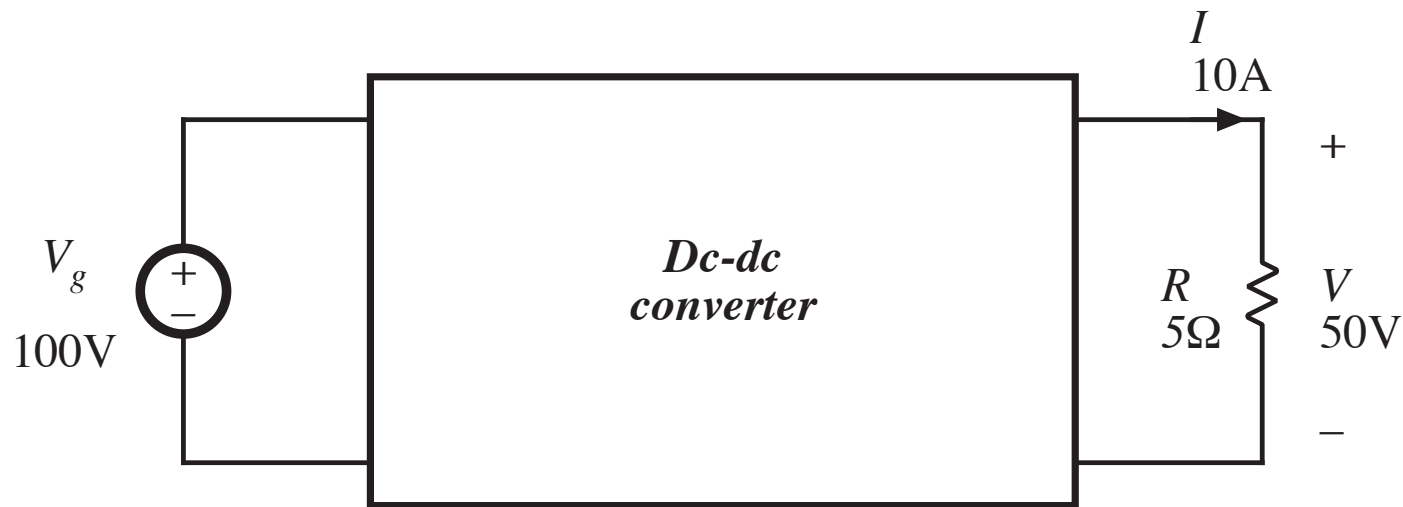
Ideal switch consumes zero power



# A simple dc-dc converter example

---

---



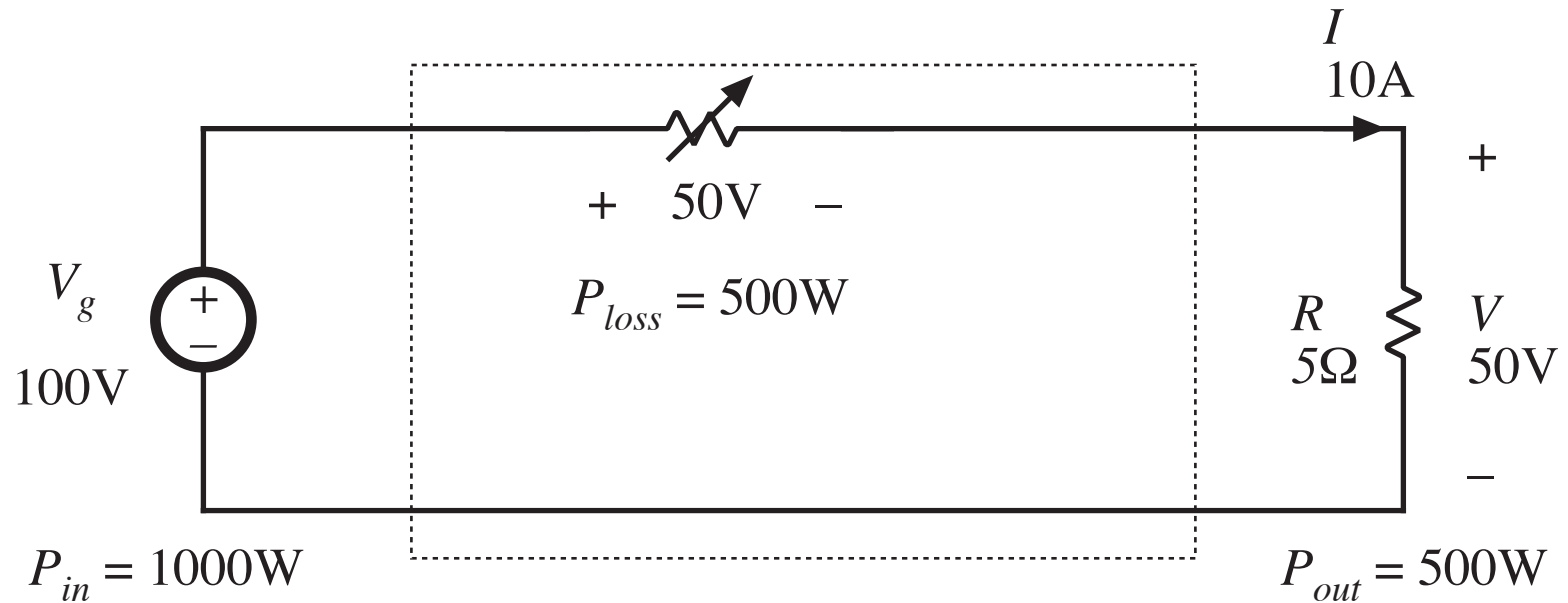
Input source: 100V

Output load: 50V, 10A, 500W

How can this converter be realized?

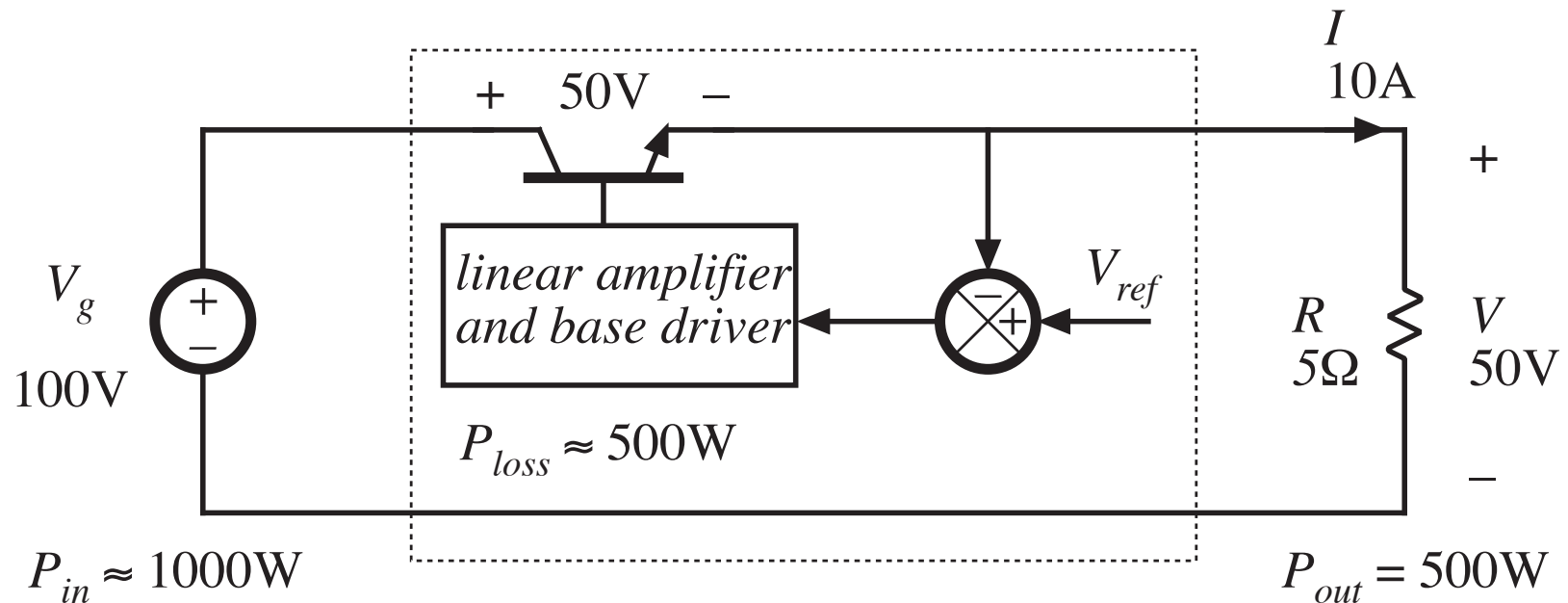
# Dissipative realization

## Resistive voltage divider

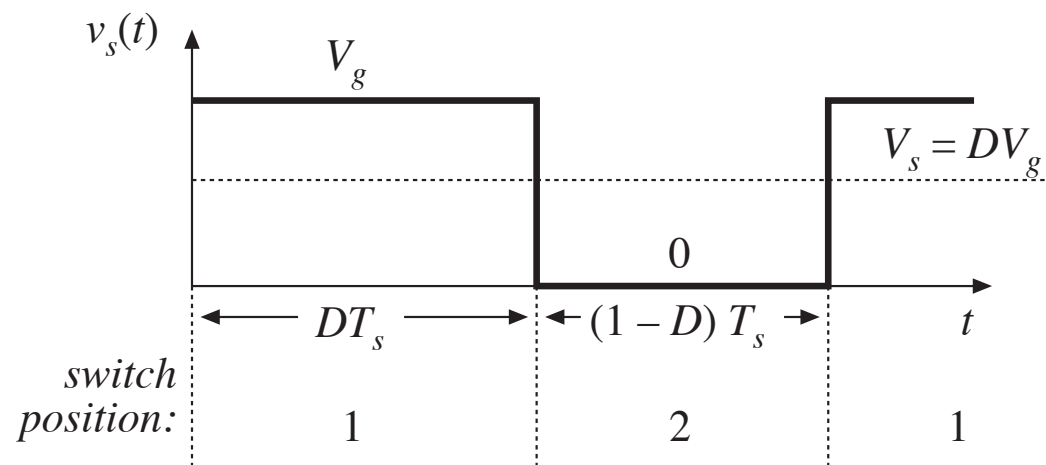
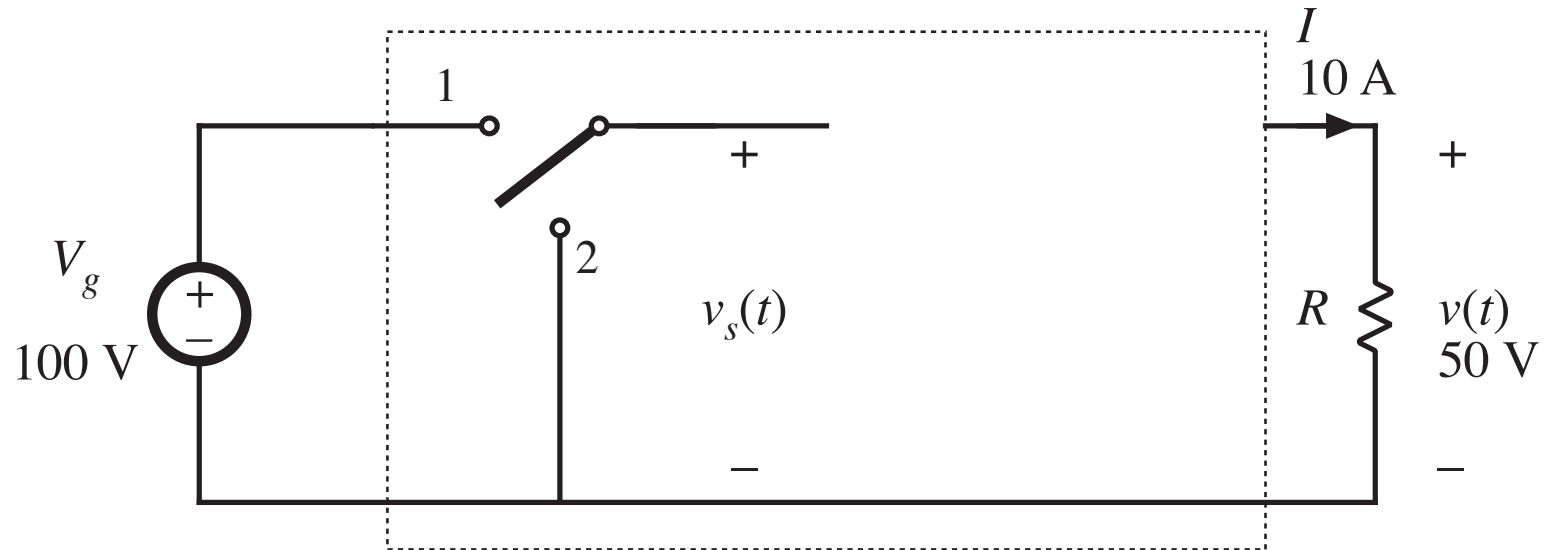


# Dissipative realization

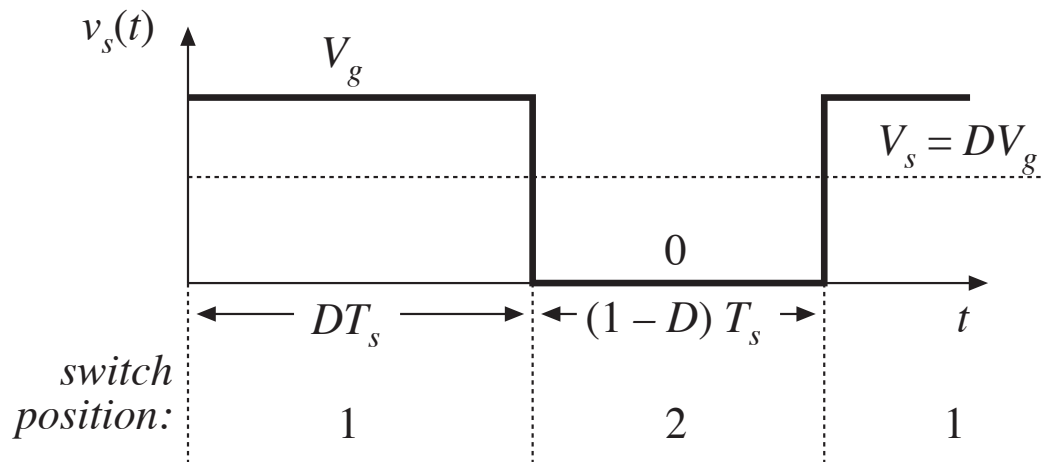
Series pass regulator: transistor operates in active region



# Use of a SPDT switch



# The switch changes the dc voltage level



$D$  = switch duty cycle  
 $0 \leq D \leq 1$

$T_s$  = switching period

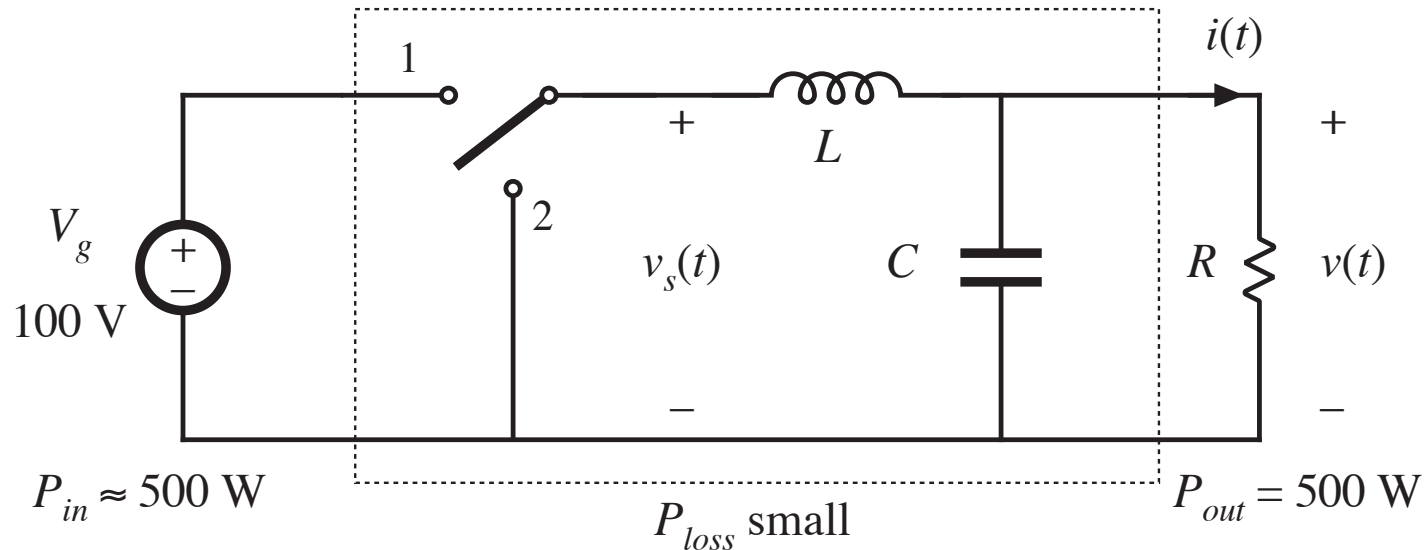
$f_s$  = switching frequency  
 $= 1 / T_s$

DC component of  $v_s(t)$  = average value:

$$V_s = \frac{1}{T_s} \int_0^{T_s} v_s(t) dt = DV_g$$

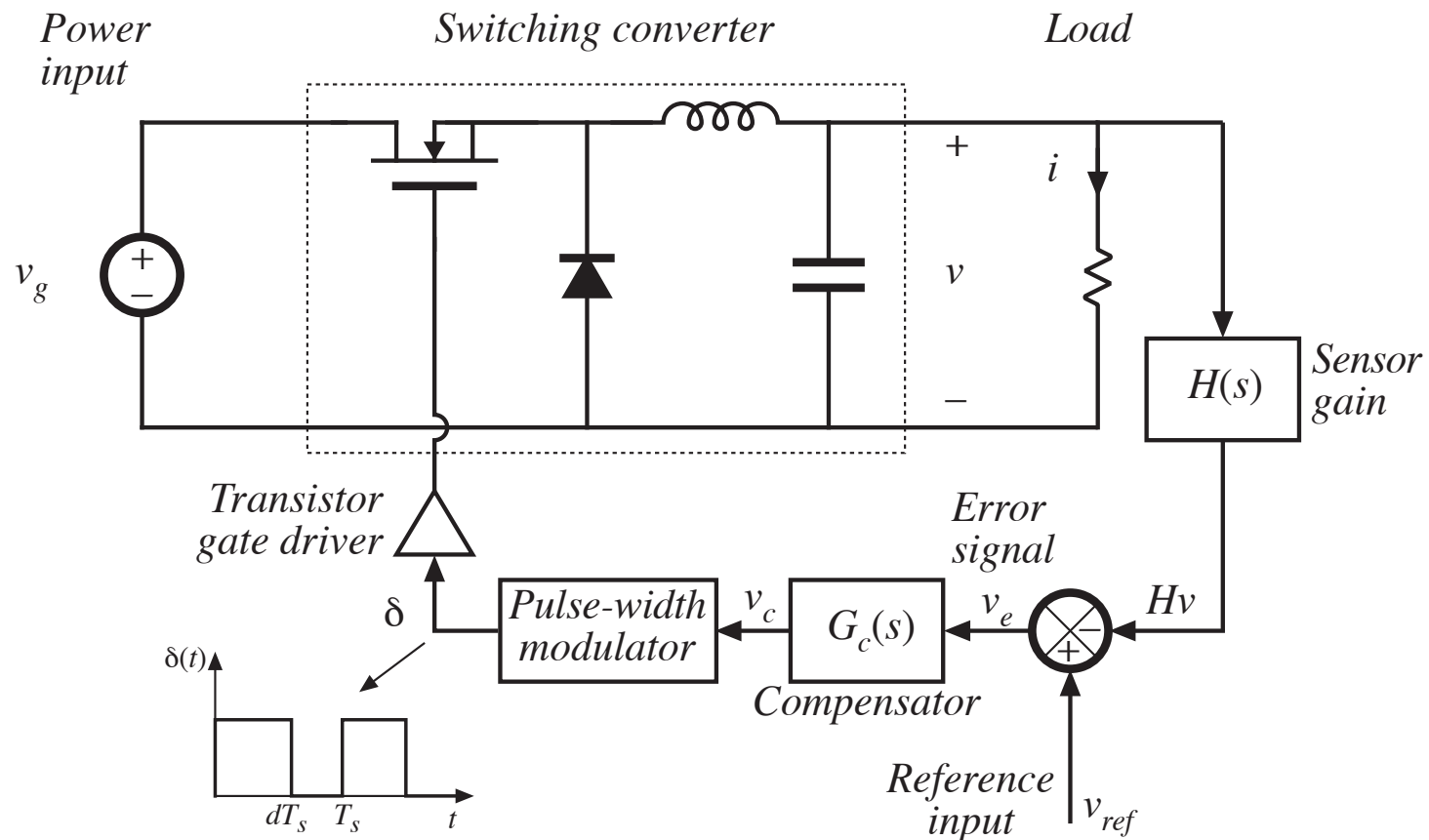
# Addition of low pass filter

Addition of (ideally lossless)  $L$ - $C$  low-pass filter, for removal of switching harmonics:

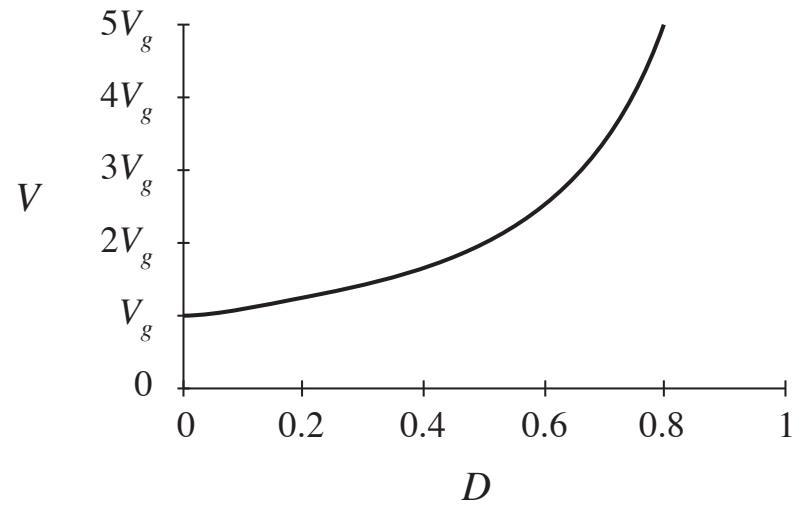
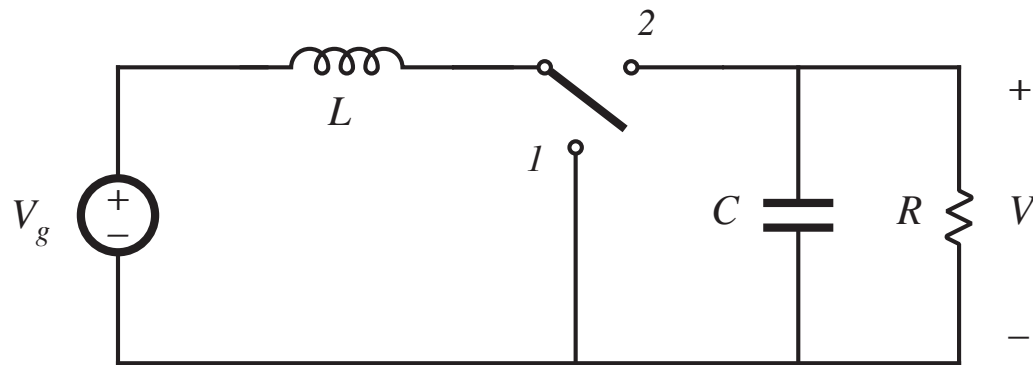


- Choose filter cutoff frequency  $f_0$  much smaller than switching frequency  $f_s$
- This circuit is known as the “buck converter”

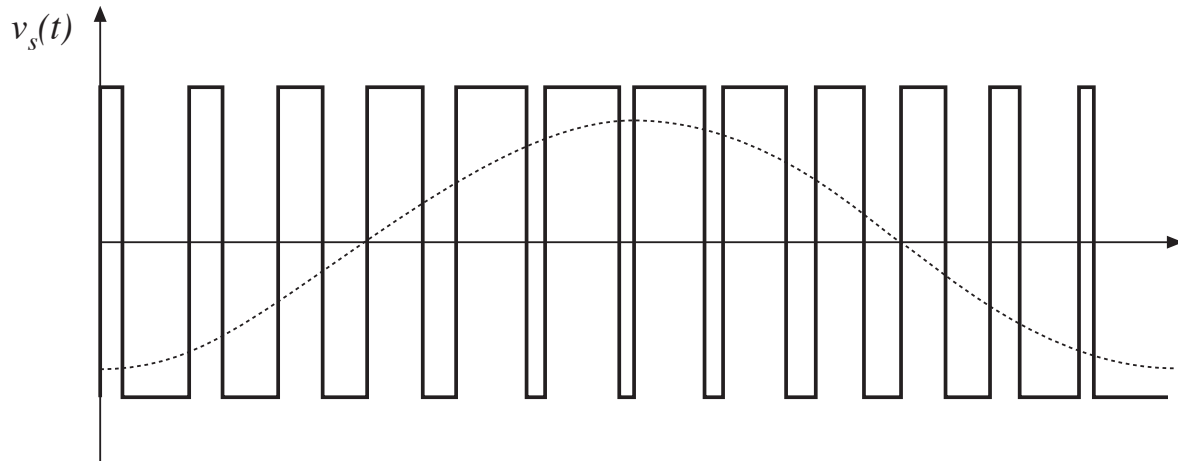
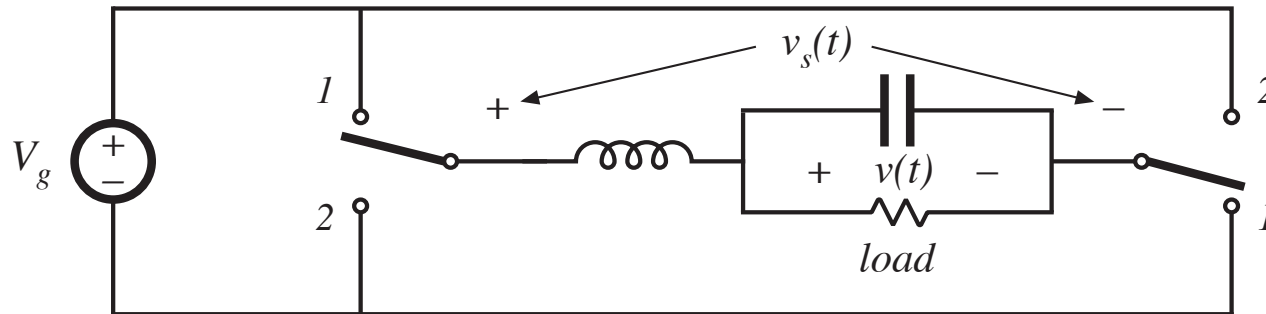
# Addition of control system for regulation of output voltage



# The boost converter



# A single-phase inverter



“H-bridge”

Modulate switch duty cycles to obtain sinusoidal low-frequency component

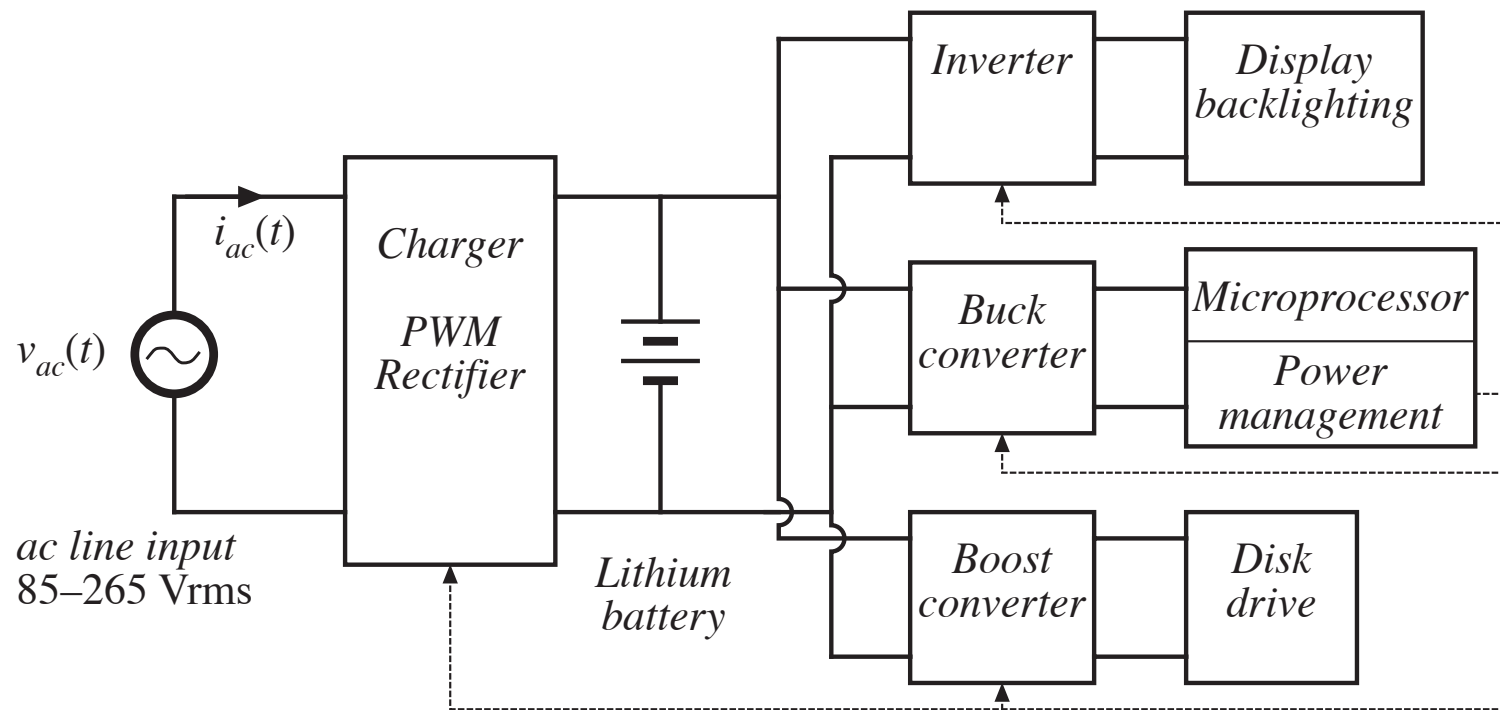
## 1.2 Several applications of power electronics

---

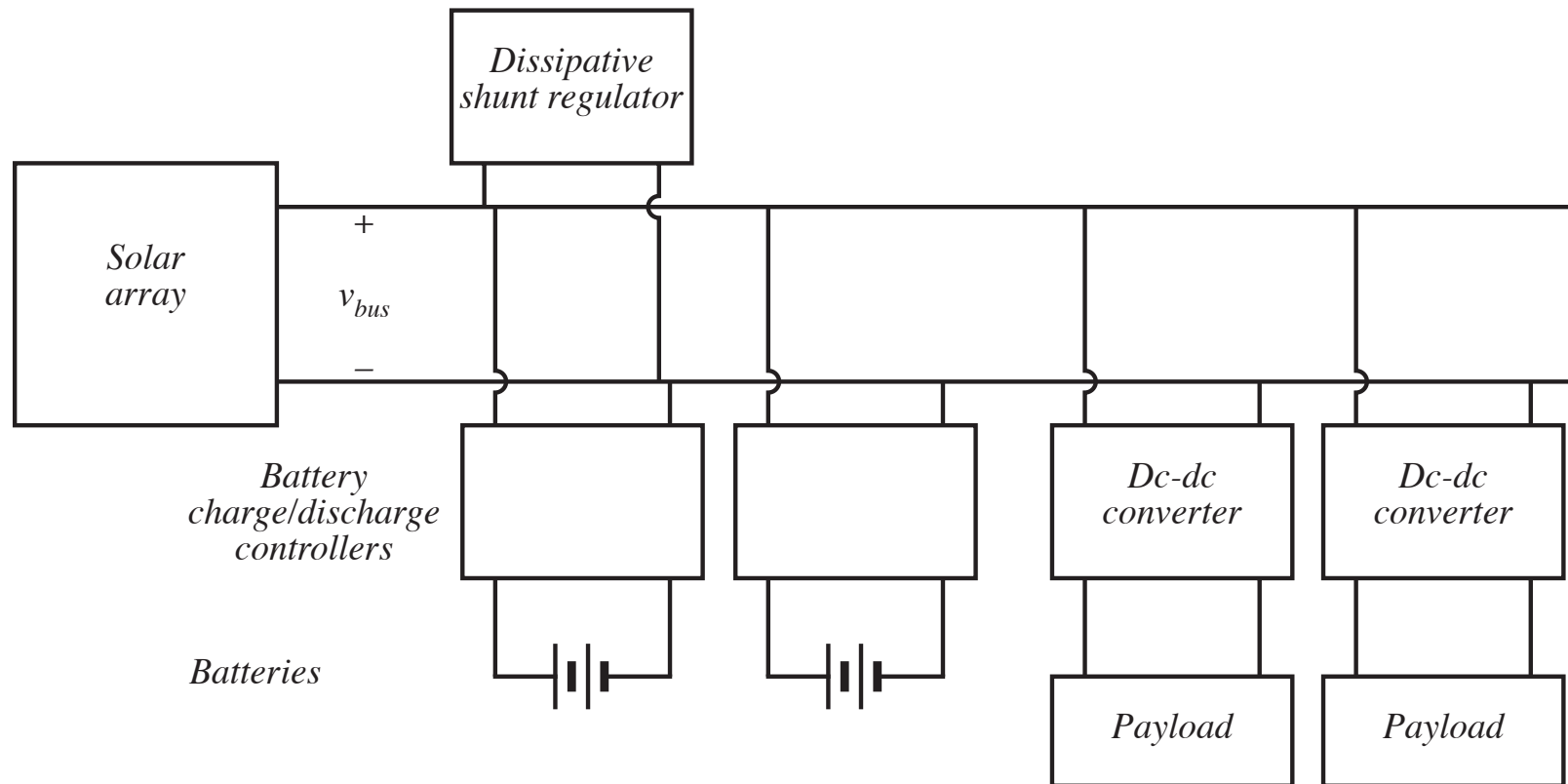
Power levels encountered in high-efficiency converters

- less than 1 W in battery-operated portable equipment
- tens, hundreds, or thousands of watts in power supplies for computers or office equipment
- kW to MW in variable-speed motor drives
- 1000 MW in rectifiers and inverters for utility dc transmission lines

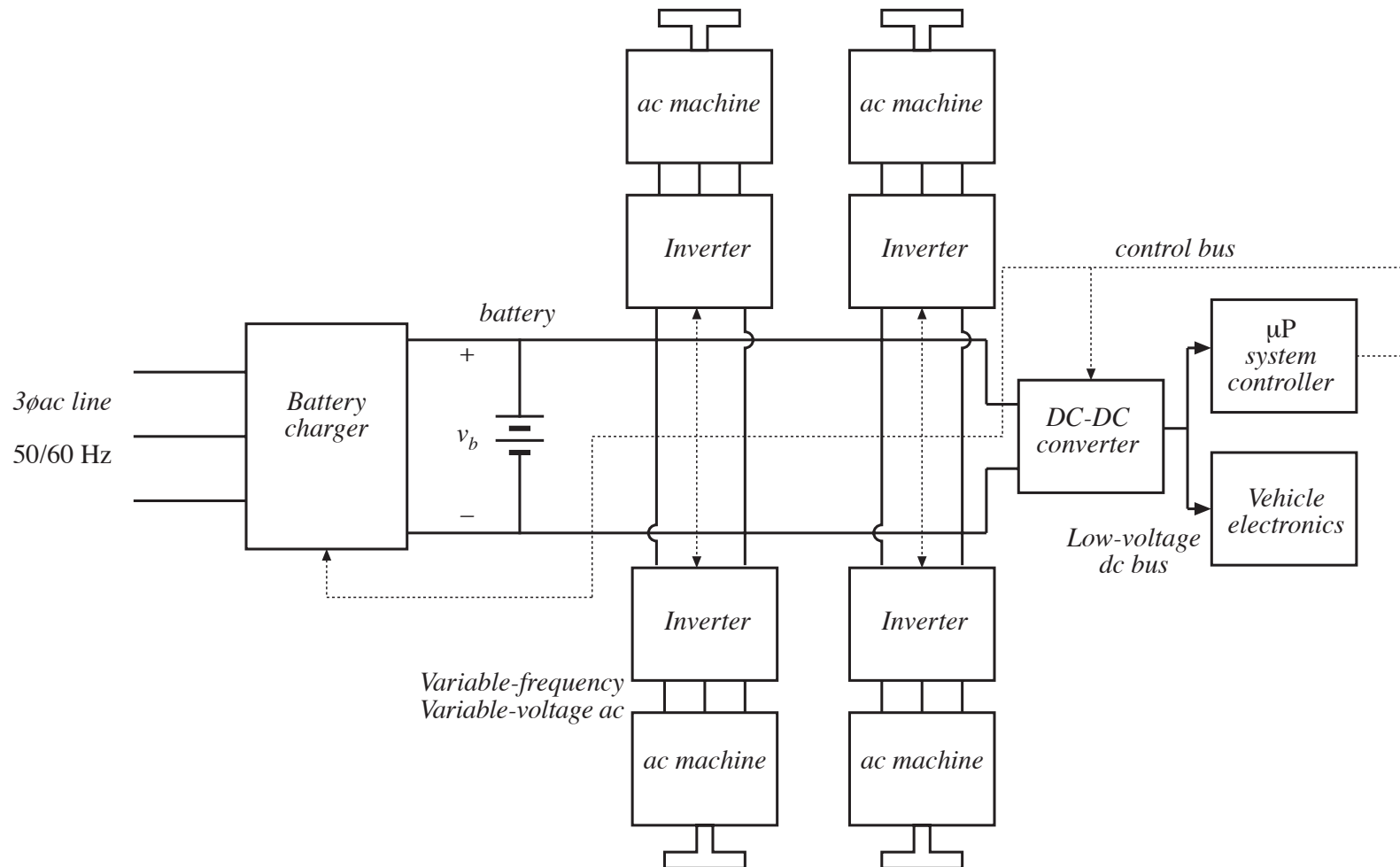
# A laptop computer power supply system



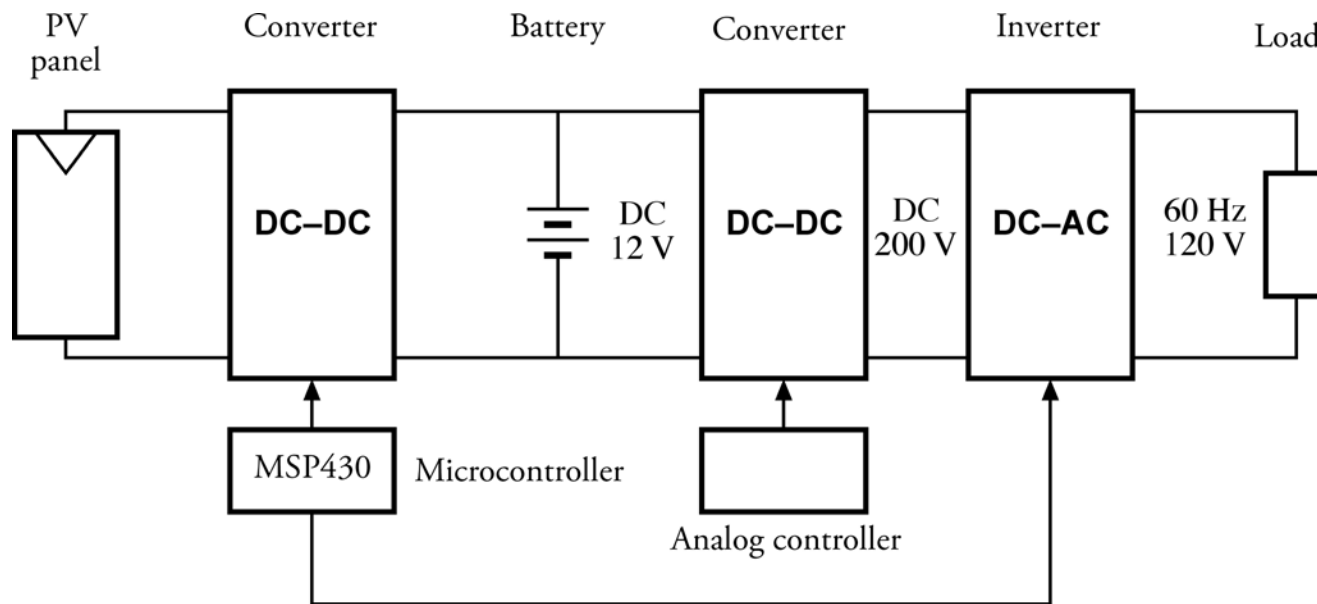
# Power system of an earth-orbiting spacecraft



# An electric vehicle power and drive system



# A standalone photovoltaic power system



The system constructed in ECEN 4517/5517 Power Electronics and Photovoltaic Systems Laboratory

## 1.3 Elements of power electronics

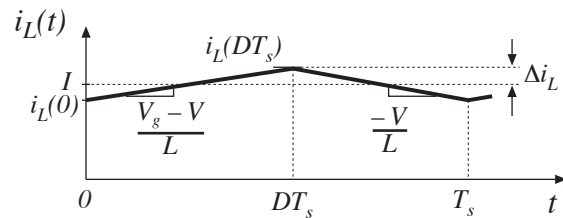
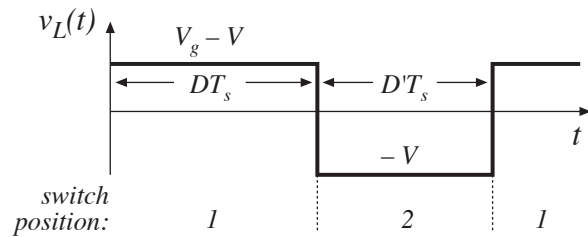
---

Power electronics incorporates concepts from the fields of

- analog circuits
- electronic devices
- control systems
- power systems
- magnetics
- electric machines
- numerical simulation

# Part I. Converters in equilibrium

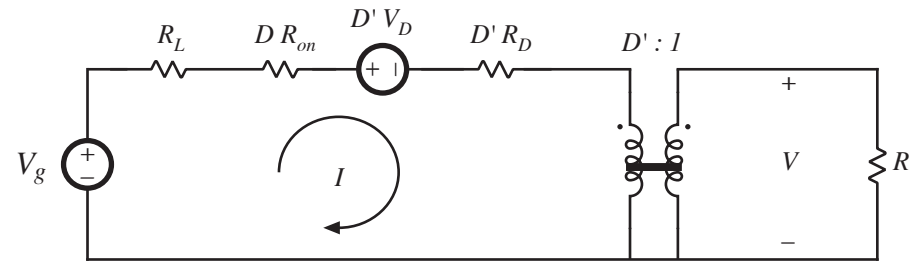
## Inductor waveforms



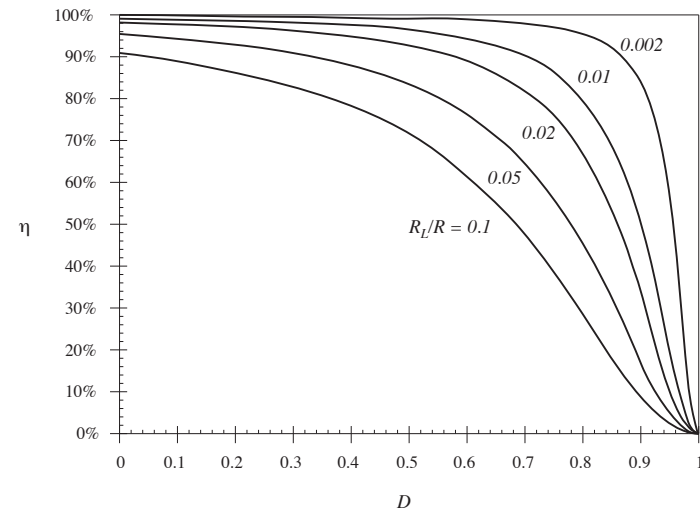
Discontinuous conduction mode

Transformer isolation

## Averaged equivalent circuit

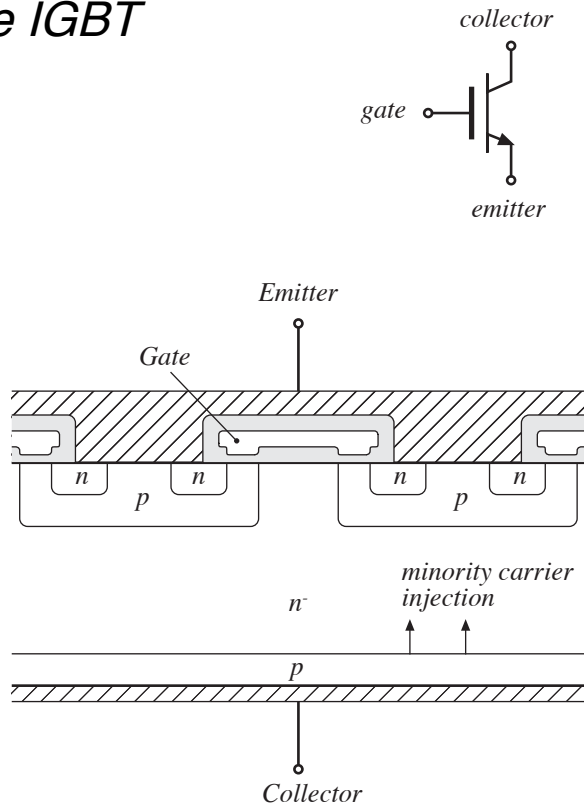


## Predicted efficiency

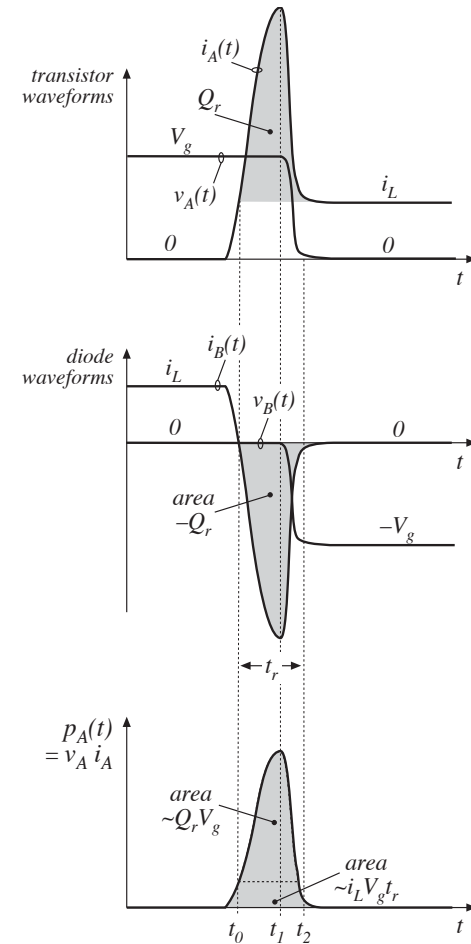


# Switch realization: semiconductor devices

## The IGBT



## Switching loss



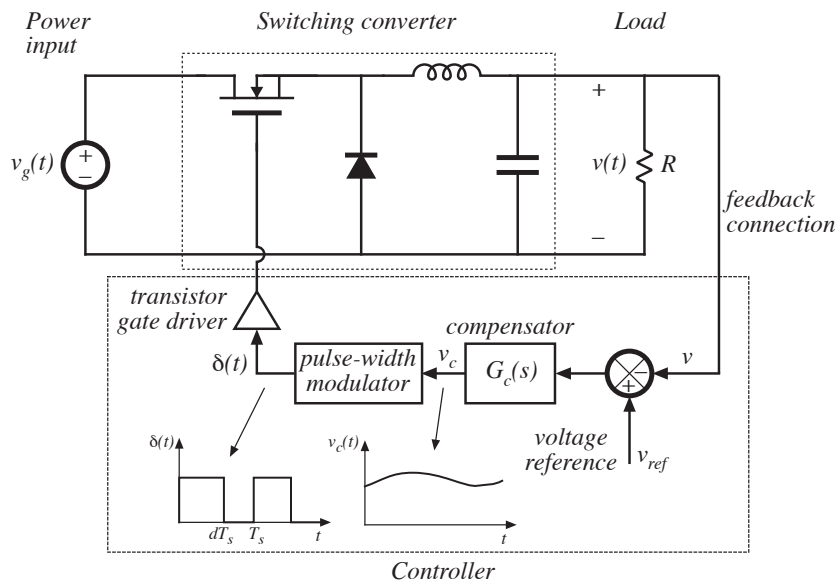
# Part I. Converters in equilibrium

---

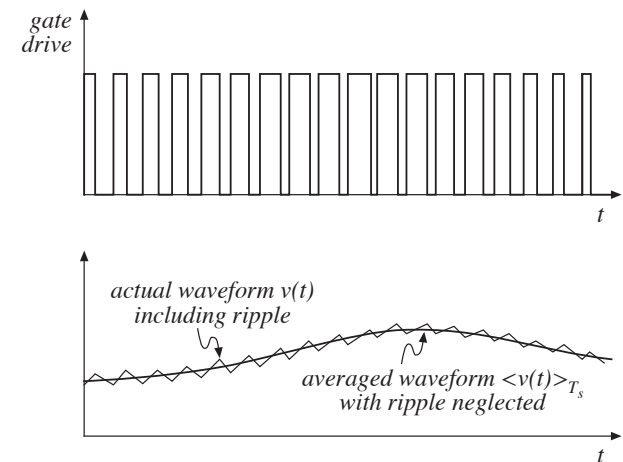
2. Principles of steady state converter analysis
3. Steady-state equivalent circuit modeling, losses, and efficiency
4. Switch realization
5. The discontinuous conduction mode
6. Converter circuits

# Part II. Converter dynamics and control

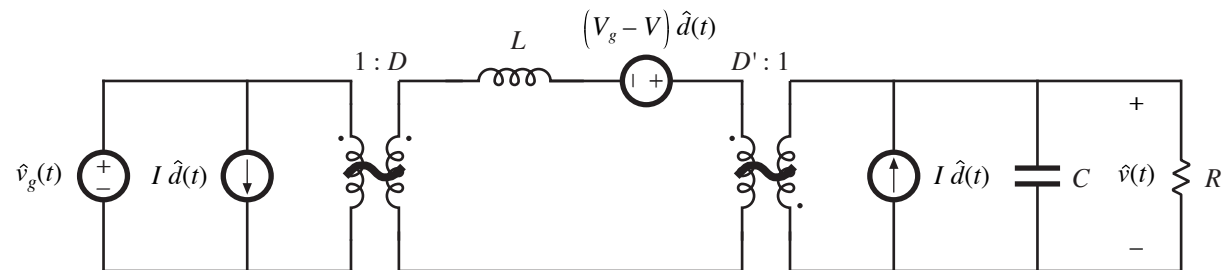
## Closed-loop converter system



## Averaging the waveforms



## Small-signal averaged equivalent circuit



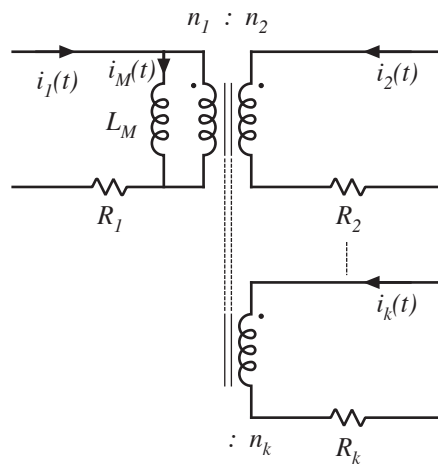
# Part II. Converter dynamics and control

---

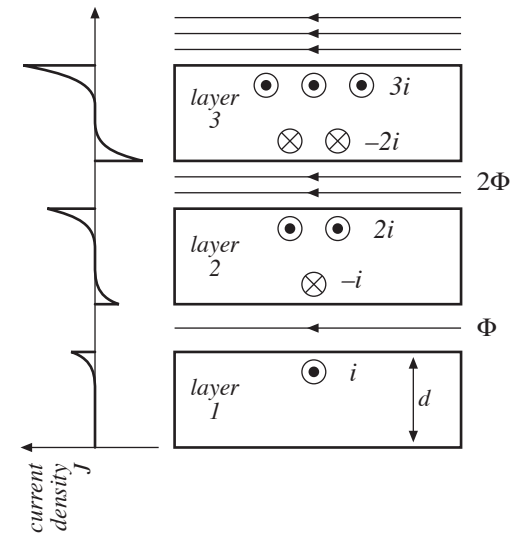
7. Ac modeling
8. Converter transfer functions
9. Controller design
10. Input filter design
11. Ac and dc equivalent circuit modeling of the discontinuous conduction mode
12. Current-programmed control

# Part III. Magnetics

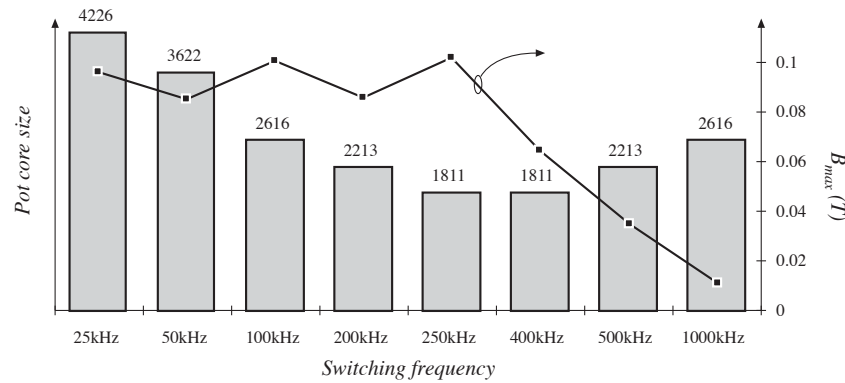
*transformer design*



*the proximity effect*



*transformer size vs. switching frequency*



# Part III. Magnetics

---

- 13. Basic magnetics theory
- 14. Inductor design
- 15. Transformer design