ECE 481: Power Electronics

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University of Tennessee Knoxville
Fall 2013

ECE 481: Power Electronics

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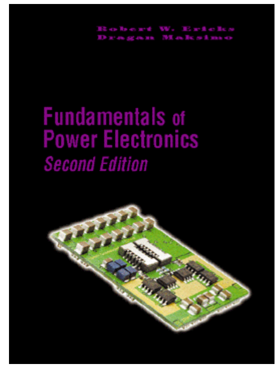
Course Materials

- Textbook:
  - Erickson and Maksimovic, *Fundamentals of Power Electronics*, second edition, Kluwer Academic Publishers, ISBN 0-7923-7270-0
  - Available through campus bookstore, online vendors, or UT libraries
- Course Website
  - http://web.eecs.utk.edu/courses/fall2013/ece481/
  - Includes lectures slides, handouts, supplemental notes, homework assignments, course announcements



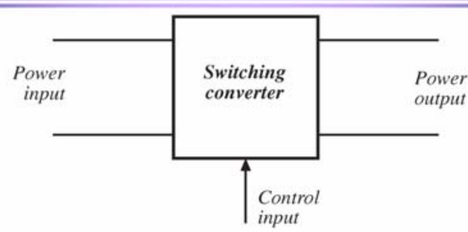
Grading

- Homework
  - Due at beginning of class on date listed on Lecture Schedule web page
  - Homework counts for 40% of grade
  - Collaboration is encouraged on all homework assignments
- Exams
  - 2 Midterms: 25% of grade
  - 1 Final: 35% of grade
  - 1 week, take-home exams
  - Absolutely *no collaboration* allowed on exams

Power Electronics Courses at UTK

Junior	Senior	Graduate	
ECE 325 Electric Energy System Components	ECE 481 Power Electronics	ECE 523 Power Electronics and Drives	ECE 623 Advanced Power Electronics and Drives
	ECE 482 Power Electronic Circuits	ECE 525 Alternative Energy Sources	ECE 625 Utility Applications of Power Electronics
			ECE 626 Solid State Power Semiconductors

1.1 Introduction to Power Processing



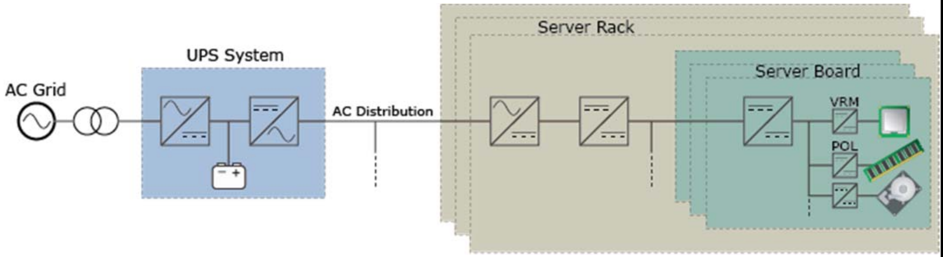
Dc-dc conversion: Change and control voltage magnitude

Ac-dc rectification: Possibly control dc voltage, ac current

Dc-ac inversion: Produce sinusoid of controllable magnitude and frequency

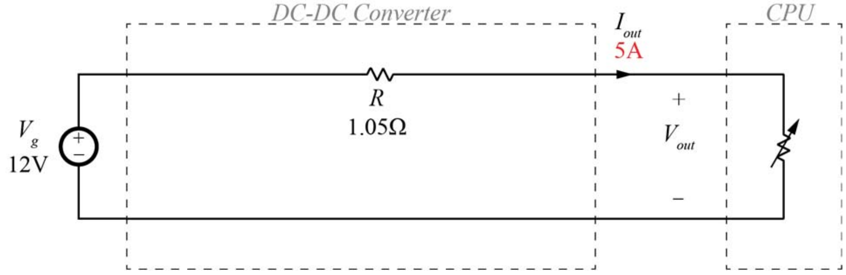
Ac-ac cycloconversion: Change and control voltage magnitude and frequency

Example Server Power Distribution

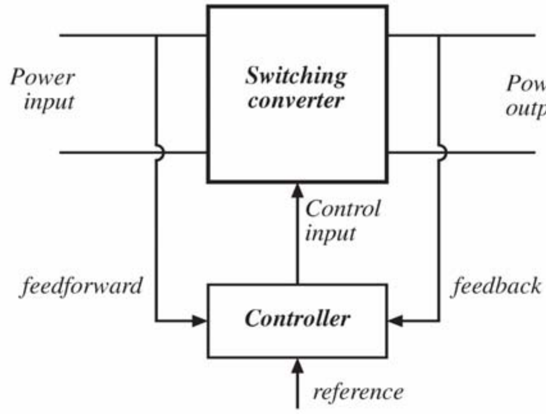


Example VRM Design

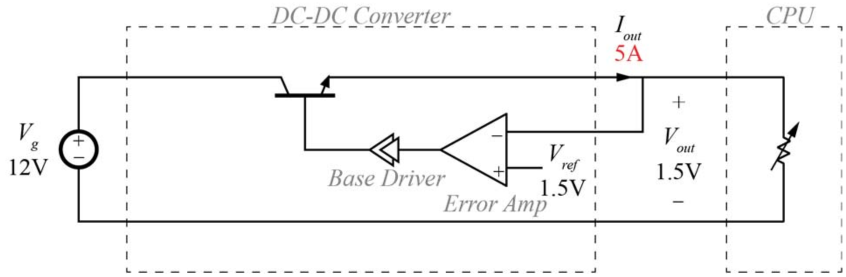
Variations in Load



Control is invariably required



Linear Regulator



High efficiency is essential

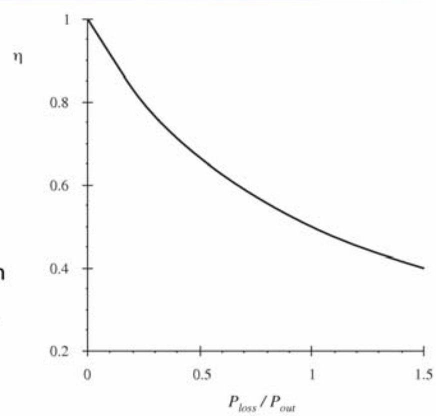
$$\eta = \frac{P_{out}}{P_{in}}$$

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

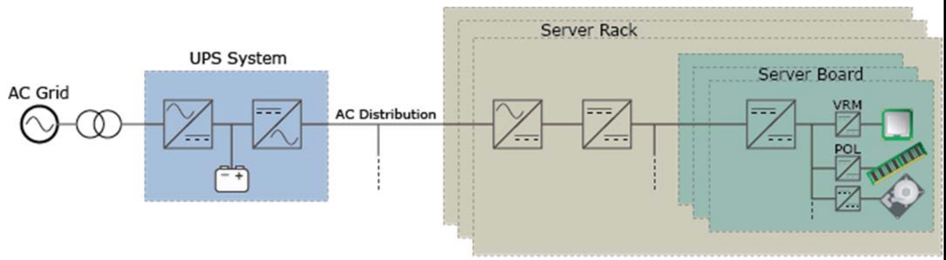
High efficiency leads to low power loss within converter

Small size and reliable operation is then feasible

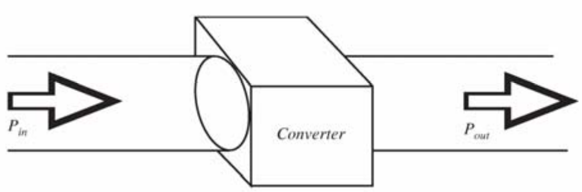
Efficiency is a good measure of converter performance



Example Server Power Distribution

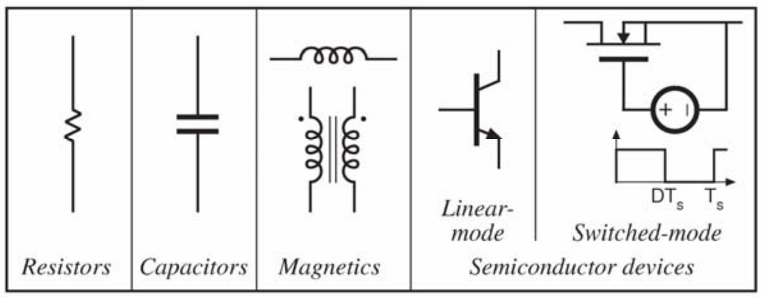


A high-efficiency converter

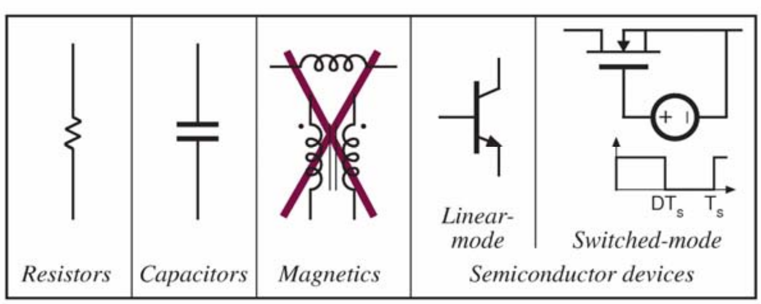


A goal of current converter technology is to construct converters of small size and weight, which process substantial power at high efficiency

Devices available to the circuit designer

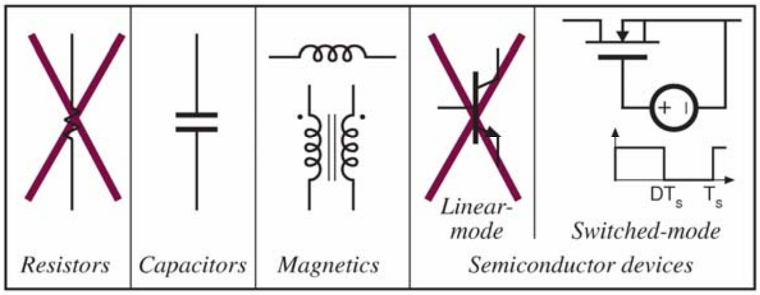


Devices available to the circuit designer



Signal processing: avoid magnetics

Devices available to the circuit designer



Power processing: avoid lossy elements

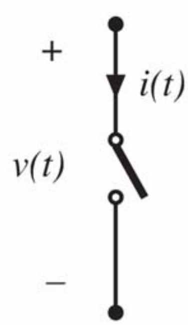
Power loss in an ideal switch

Switch closed: $v(t) = 0$

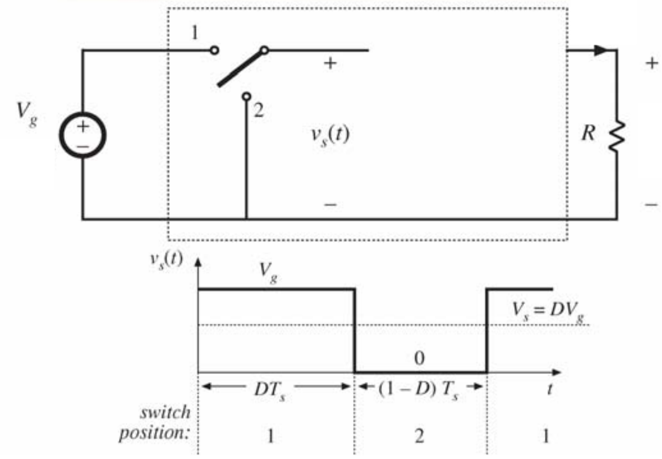
Switch open: $i(t) = 0$

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

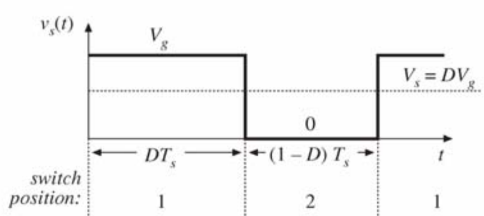
Ideal switch consumes zero power



Use of a SPDT switch



The switch changes the dc voltage level



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

T_s = switching period

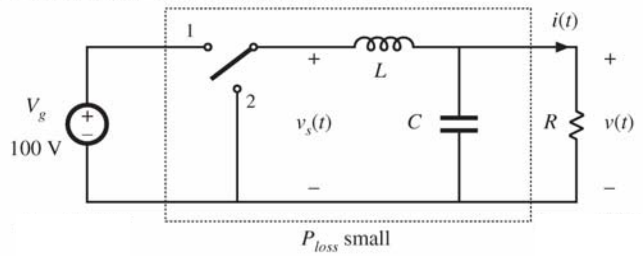
f_s = switching frequency
$= 1 / T_s$

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

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

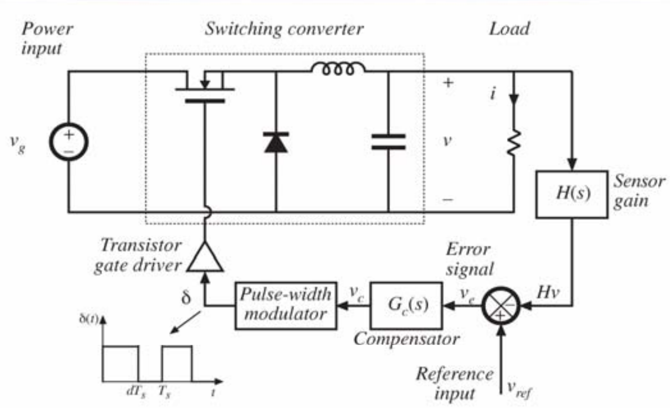
Addition of low pass filter

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

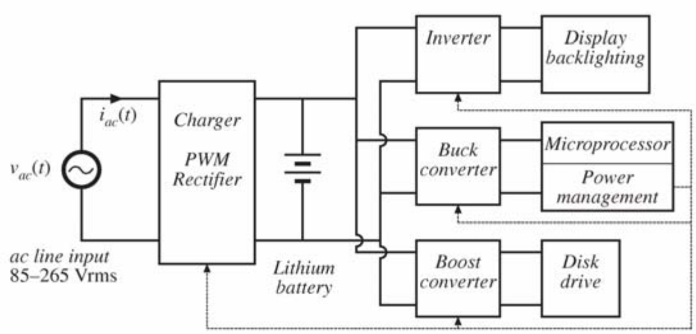


1.2 Several applications of power electronics

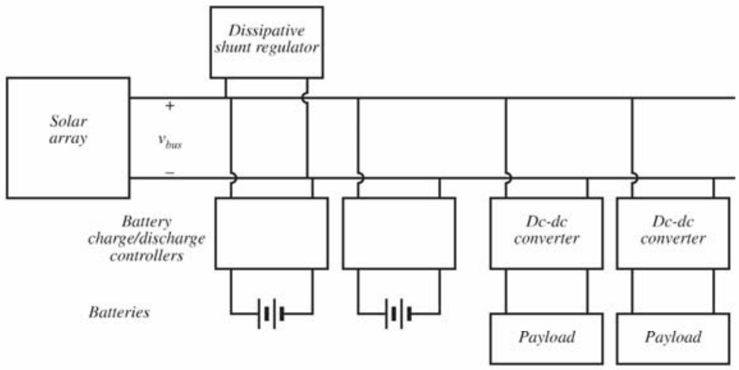
Power levels encountered in high-efficiency converters

- 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

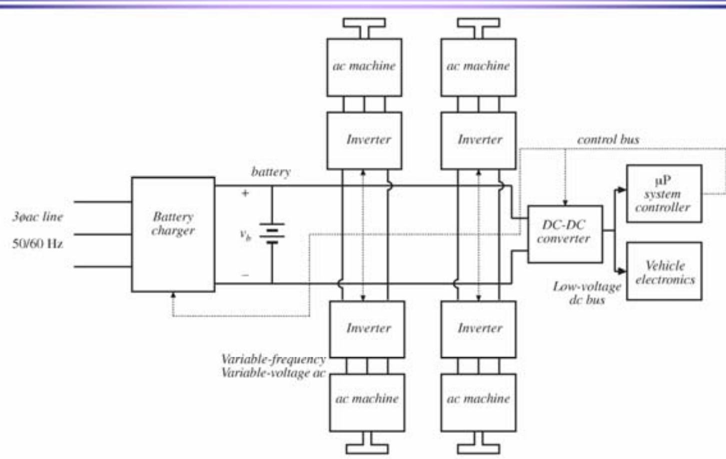
A laptop computer power supply system



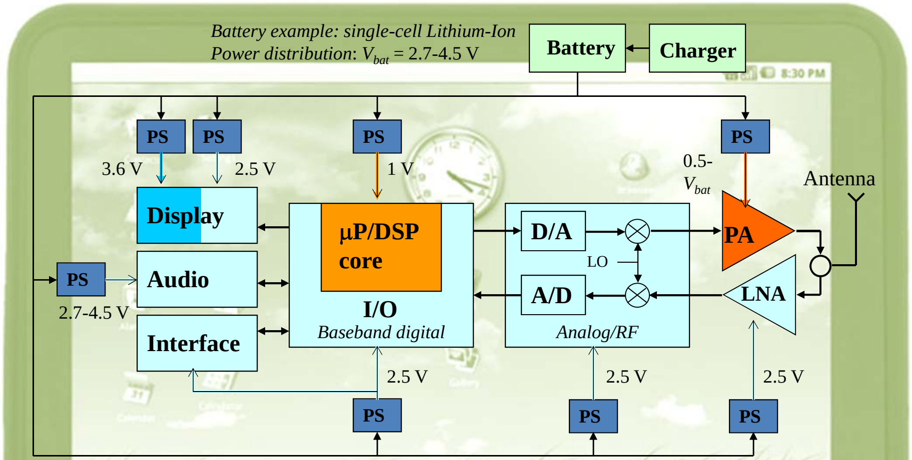
Power system of an earth-orbiting spacecraft



An electric vehicle power and drive system



Power management in mobile electronics



- Major power consumers: baseband digital, display, multiple radio channels
- Power supply demands: small footprint area & integration, high efficiency over wide range of loads, power management interface

Future Applications: Hyperloop

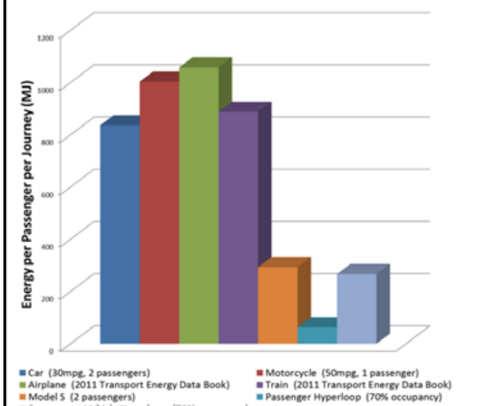
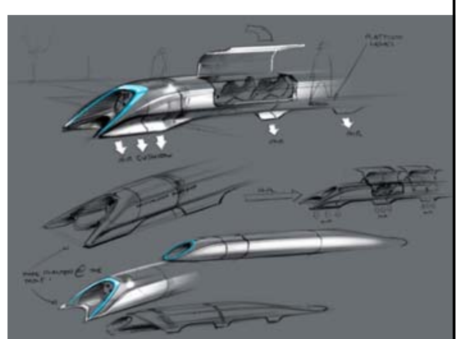
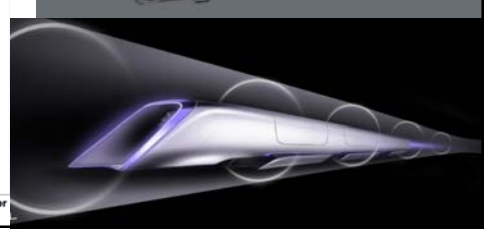


Figure 1. Energy cost per passenger for a journey between Los Angeles and San Francisco for various modes of transport.





Proposed Power Conversion Architecture

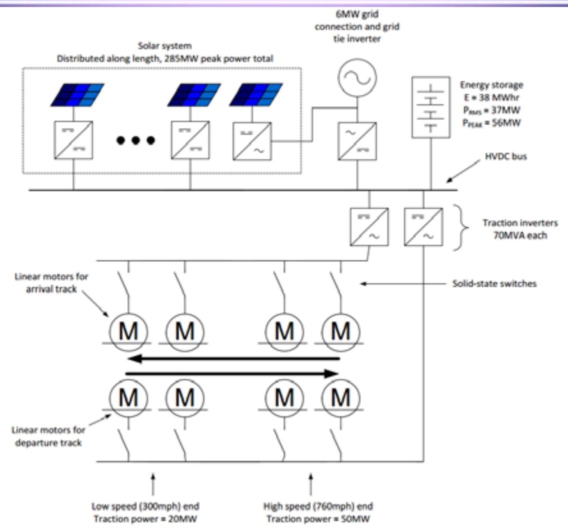


Figure 22. Linear accelerator concept for capsule acceleration and deceleration between 300 and 760 mph (480 and 1,220 kph).

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

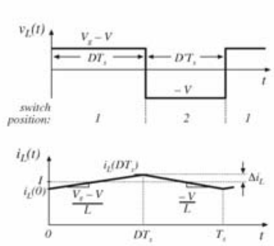
Fundamentals of Power Electronics 24 *Chapter 1: Introduction*

Part I. Converters in equilibrium

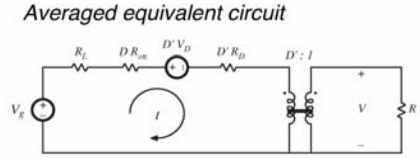
2. Principles of steady state converter analysis
3. Steady-state equivalent circuit modeling, losses, and efficiency
4. Switch realization
5. The discontinuous conduction mode
6. Converter circuits

Part I. Converters in equilibrium

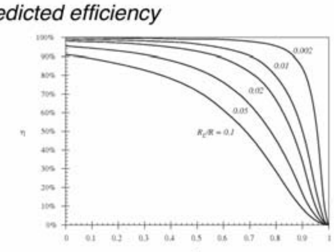
Inductor waveforms



Averaged equivalent circuit



Predicted efficiency

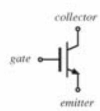


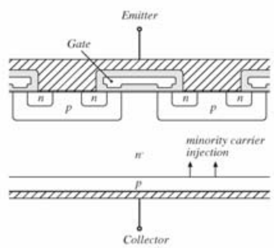
Discontinuous conduction mode

Transformer isolation

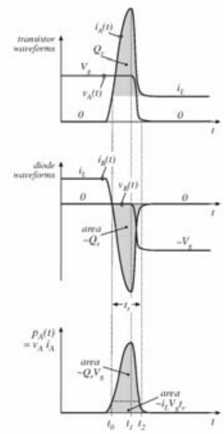
Switch realization: semiconductor devices

The IGBT





Switching loss

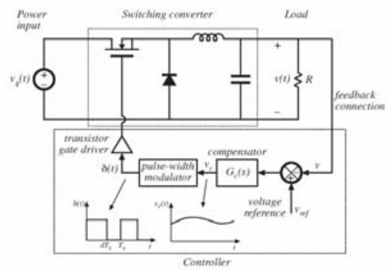


Part II. Converter dynamics and control

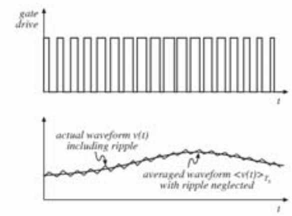
7. Ac modeling
8. Converter transfer functions
9. Controller design
10. Input filter design
11. Ac and dc equivalent circuit modeling of the discontinuous conduction mode
12. Current-programmed control

Part II. Converter dynamics and control

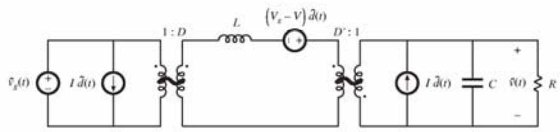
Closed-loop converter system



Averaging the waveforms



Small-signal averaged equivalent circuit

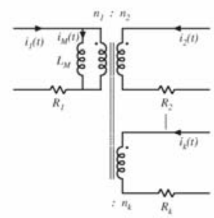


Part III. Magnetics

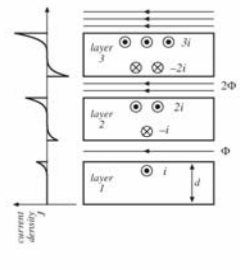
13. Basic magnetics theory
14. Inductor design
15. Transformer design

Part III. Magnetics

transformer design



the proximity effect



transformer size vs. switching frequency