2.996/6.971 Biomedical Devices Design Laboratory

Lecture 4: Power Supplies

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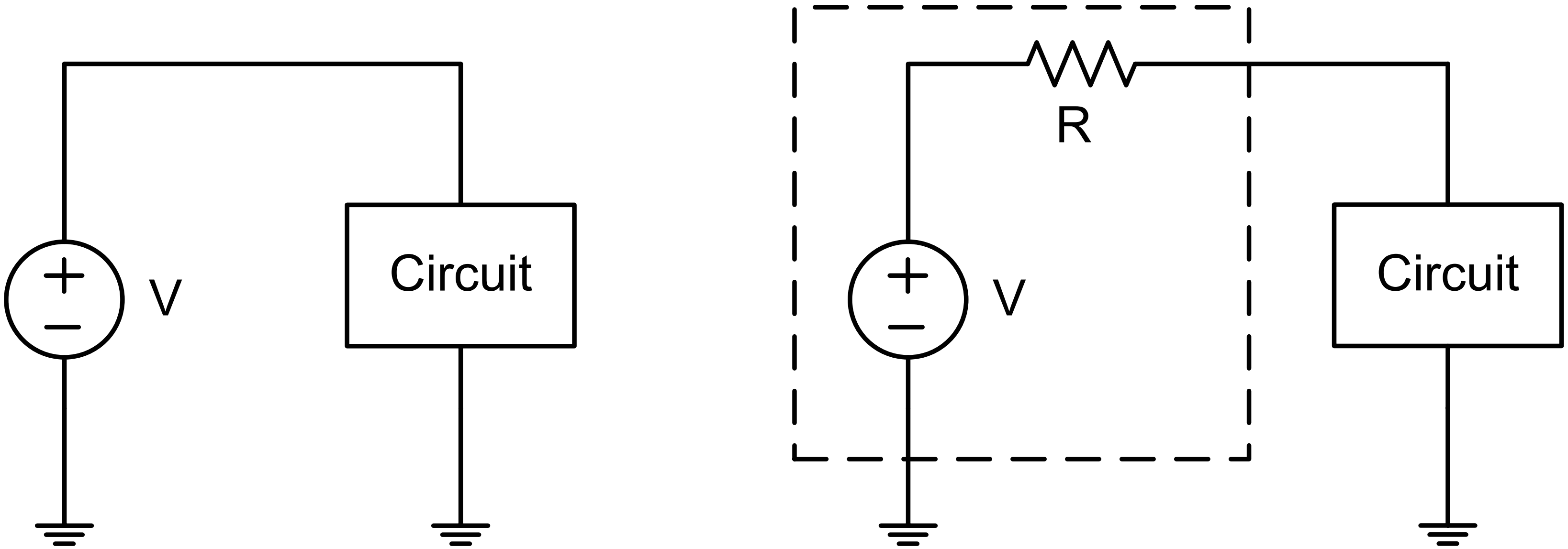
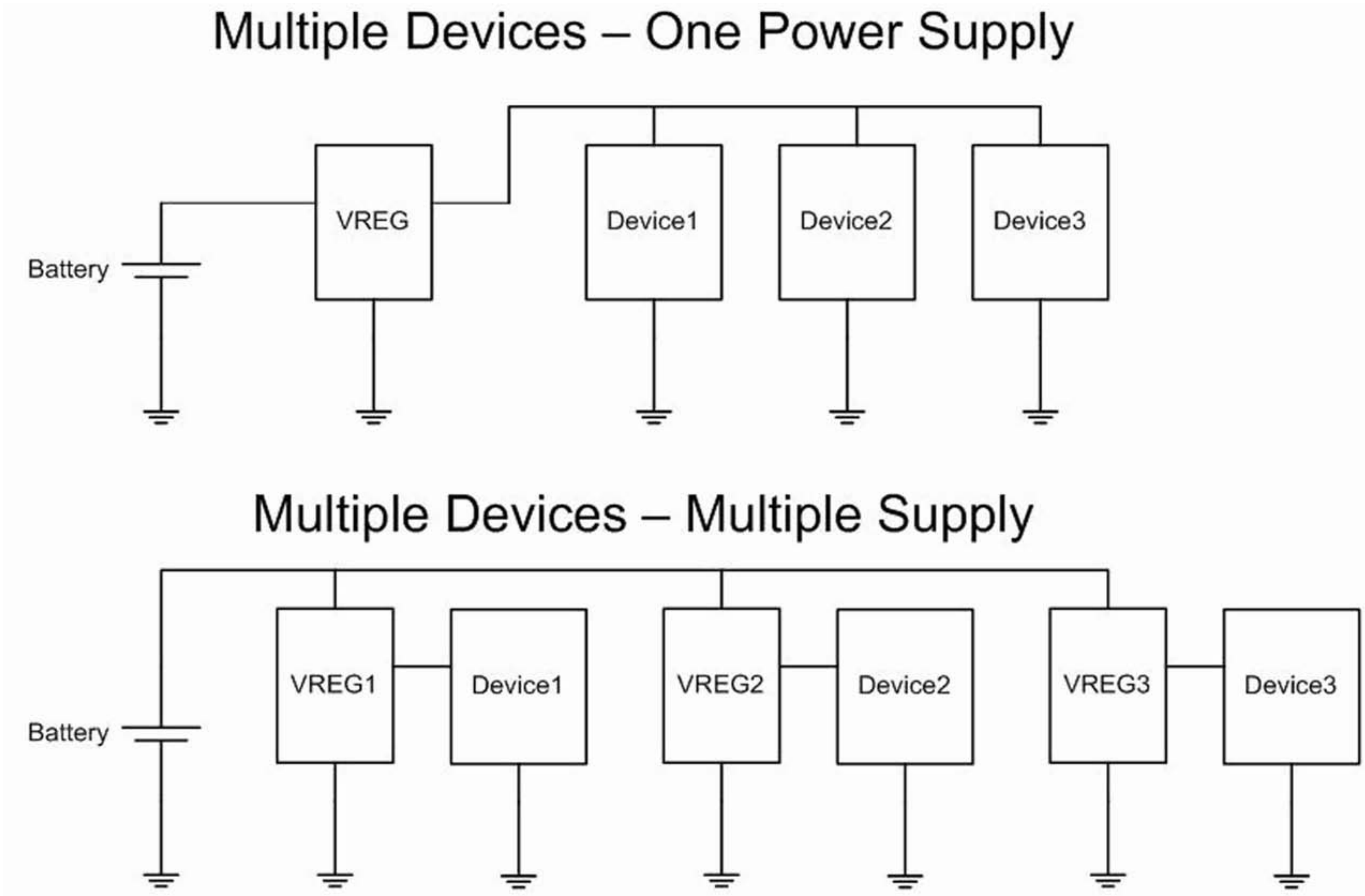
Sept. 19, 2007

Key Problem



- Ideal voltage sources do not exist!
- Voltage regulators – use feedback to reduce source impedance

Trends in Power Supply Design



iPod Breakdown

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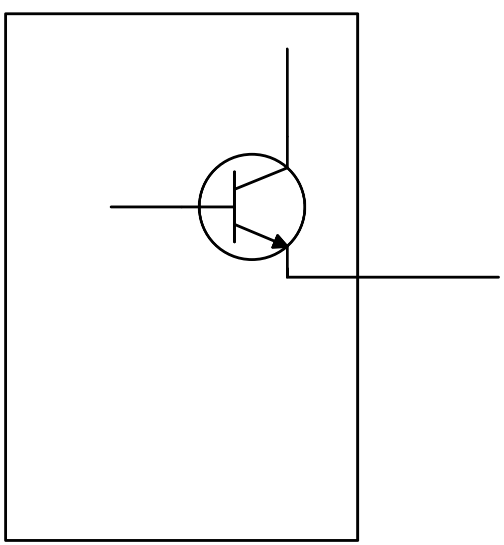
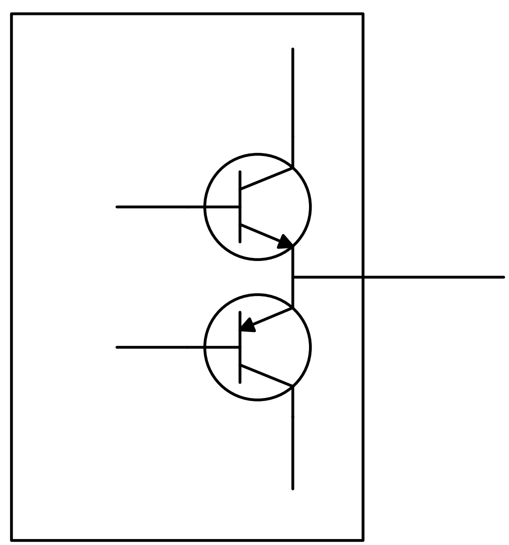
iPod circuitboards.

- C1: Linear tech (LT4055) USB power controller / Li-ion battery charger
- C6: PortalPlayer (PP5002) CPU
- C8: Broadcom (BCM2722) multimedia processor
- C9,C10: Philips (TEA1211, PCF50605) DC-DC power supplies
- C11: Cypress Semi (CY8C21) 8-bit microprocessor

Bench Power Supplies

- Stable, low noise
- Beware: Not all supplies are push-pull
- Long cables can introduce noise
  - Good practice to braid cables





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Commercial Power Supplies

Parameters

- Wattage?
- Regulated or unregulated?
- Protected against short circuit?
- Stability at different loads?

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"Wall-warts"

- Ubiquitous among consumer electronic devices
- Spec'ed for voltage and power output
- Output can be very inaccurate!

Batteries

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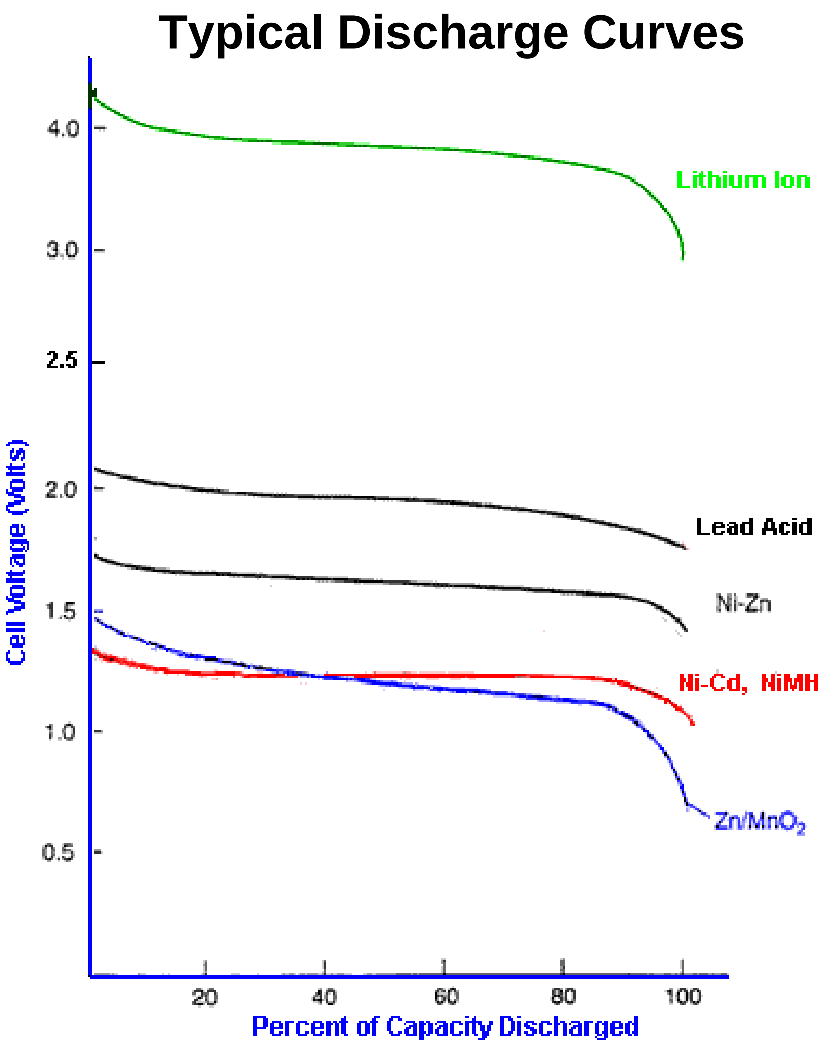

- Very quiet
- Output voltage is not constant
- Steep fall beyond the knee
- Rechargable batteries cannot be recovered once discharged beyond the knee
- Internal resistance: mΩ → Ω

USB Ports

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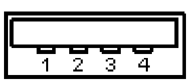
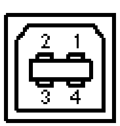


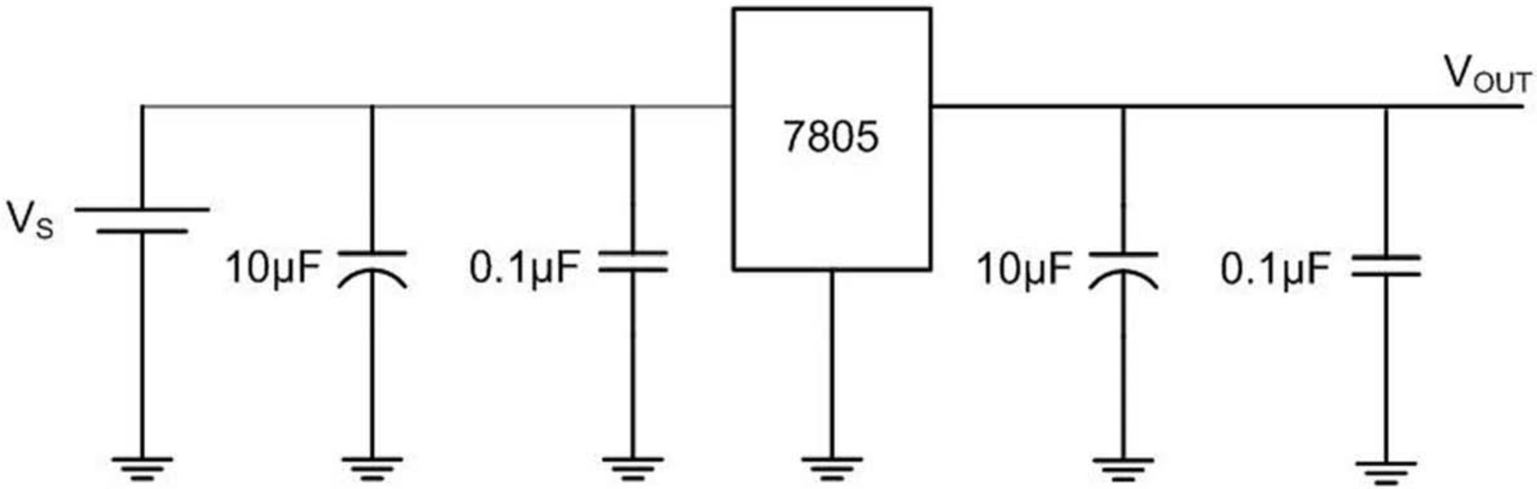
Type A – PC



Type B – peripheral

- Output range from 4.4V to 5.25V
- Self-powered hub: 500mA
- Bus powered hub: 100mA
- Suspend-mode max. 500μA
- Start-up requirements:
  - Device draw <100mA during enumeration
  - In-rush current control: power supply capacitance < 10μF
- Start-up strategies
  - Resistor
  - Regulator with enable

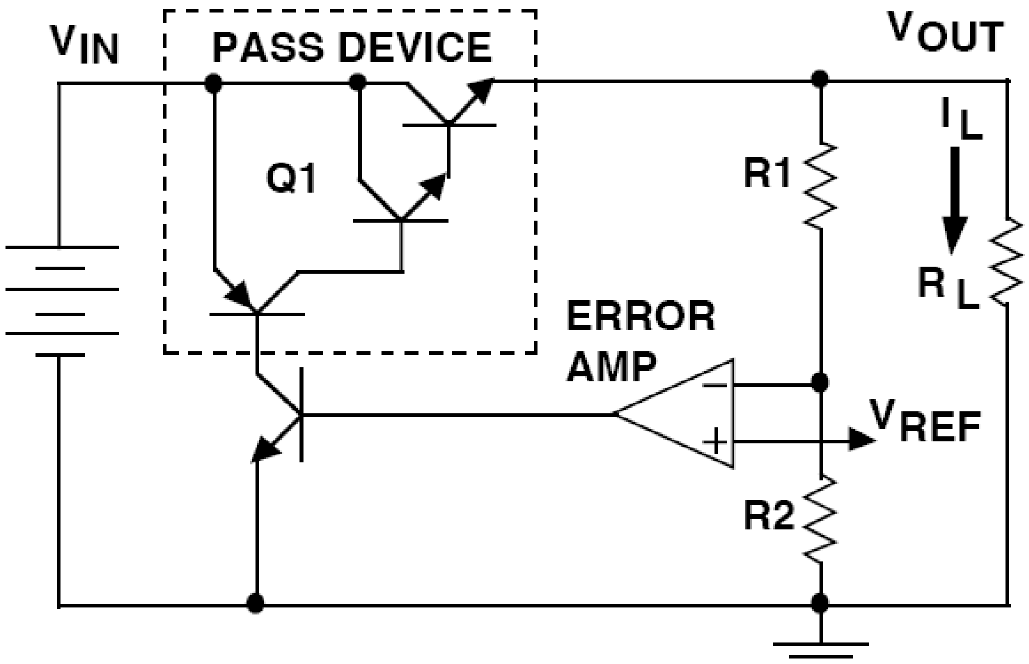
Linear Voltage Regulators

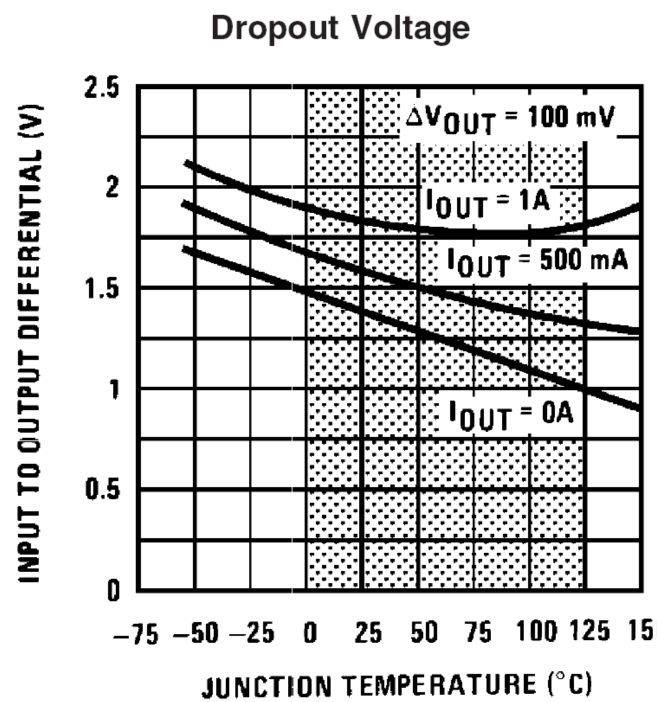


- 78xx series positive regulators
- 79xx series negative regulators
- Max output current ~ 1.5A
- Quiescent current draw ~ 5mA
- The good: easy to use, highly stable
- The bad: inefficient, heat dissipation

Drop Out Voltage in Linear Regulators

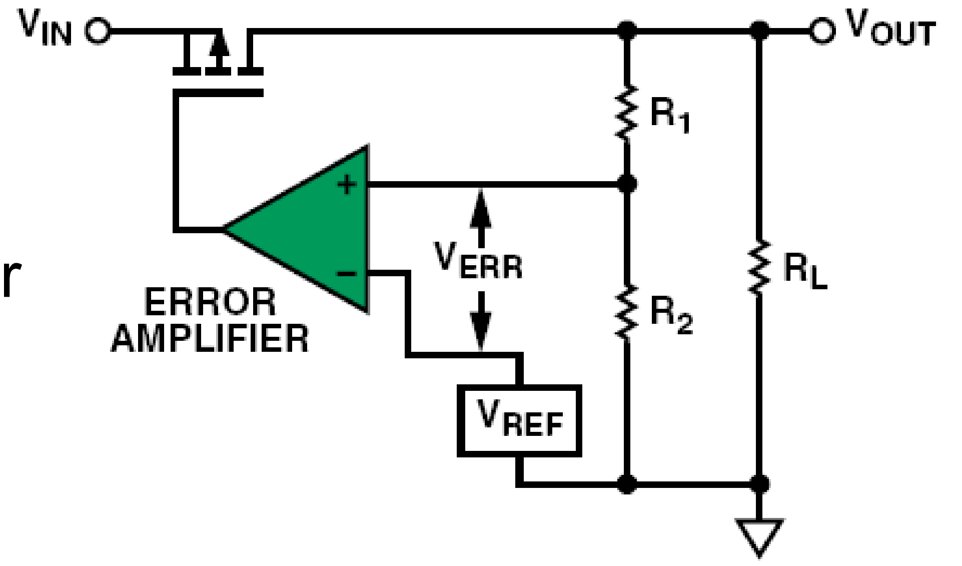
- Drop out voltage defined as when ΔV_{OUT} = 100mV
- Output stage – NPN Darlington pair
- ~2V of head room required

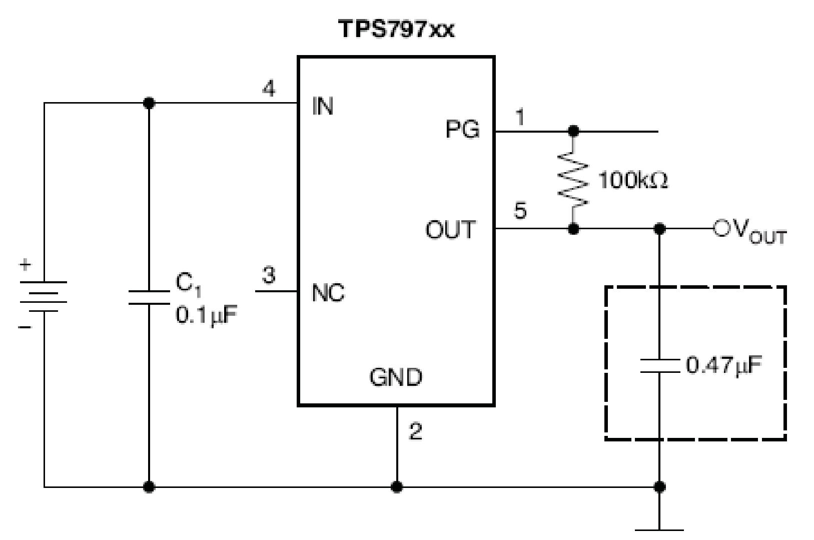




LDO: Low Dropout Regulator

- P-MOS output stage
- Act as a variable resistor
- Drop out as low as 50mV
- Output capacitor required for stability
- Other features:
  - Current limiting
  - Reverse battery protection
  - Power good output
- Example: TPS79733
  - 50mA max output
  - 105mV drop out
  - Current limited at 300mA
  - 1.2µA quiescent current
  - $0.34 in 1k quantity

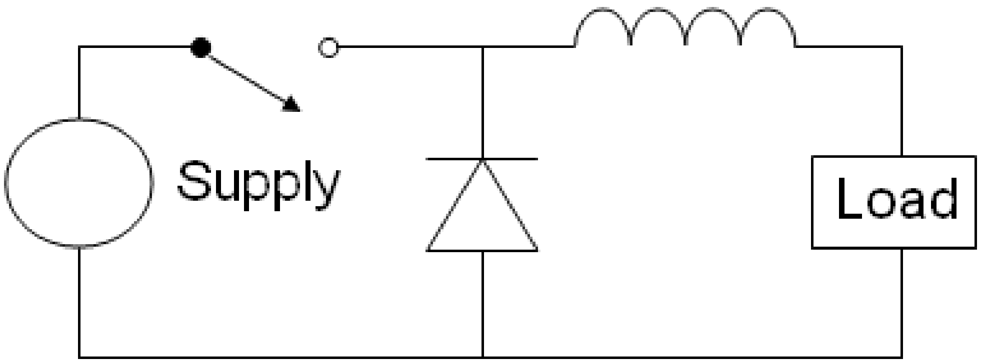


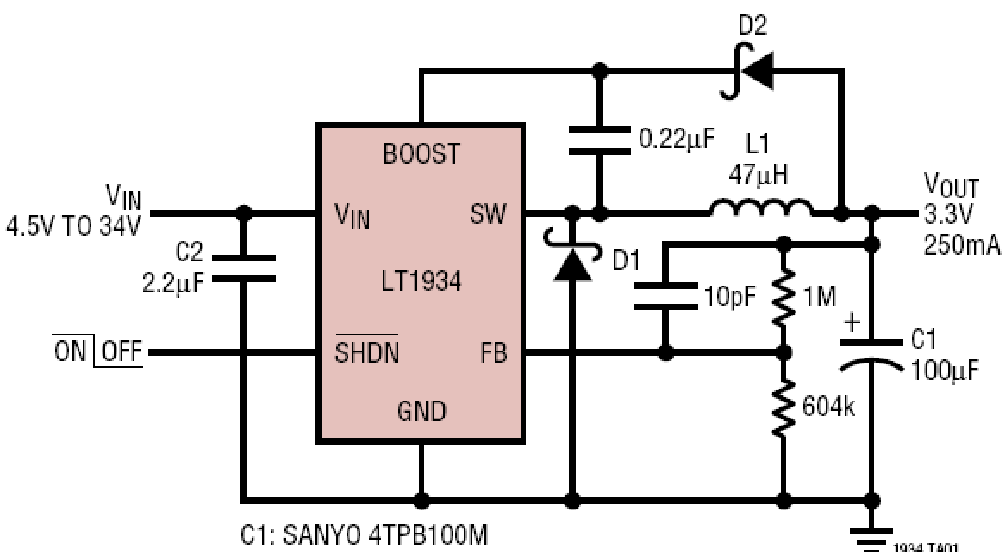


Switching Regulators

- Advantages
  - High efficiency (80% typical)
  - Low heat dissipation
- Disadvantages
  - Output switching noise
  - Layout and external component selection impacts performance
  - Higher cost / size

Step-Down (Buck) Converter

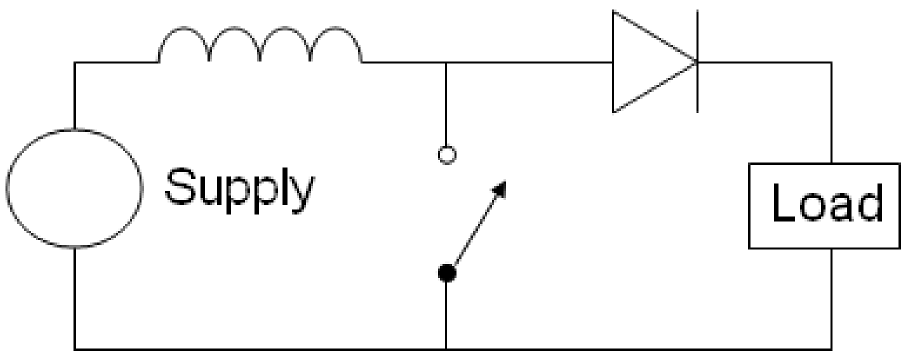




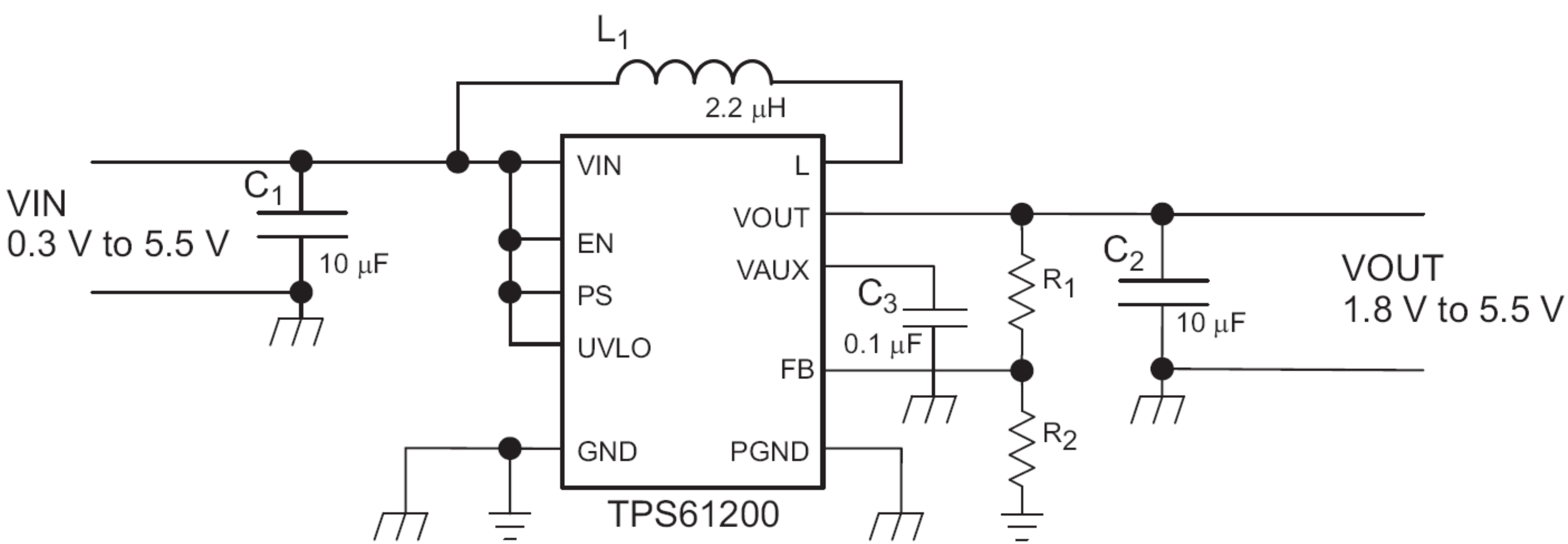
C1: SANYO 4TPB100M
C2: TAIYO YUDEN GMK325BJ225MN
D1: ON SEMICONDUCTOR MBR0540
D2: CENTRAL CMDSH-3
L1: SUMIDA CDRH4D28-470

- $V_{OUT} < V_{IN}$
- Power switch can be internal or external
- Synchronous converter avoid diode losses
- Example: LT1934
  - Up to 34V input
  - 12µA
  - ~80% efficiency

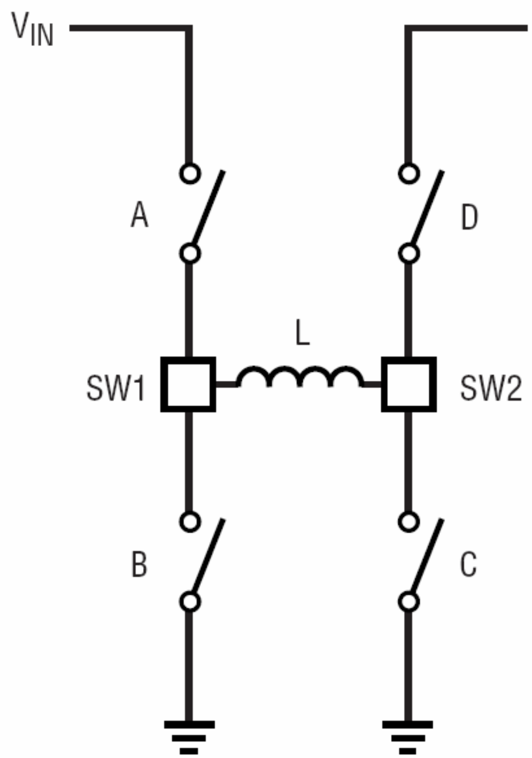
Step-Up (Boost) Converter

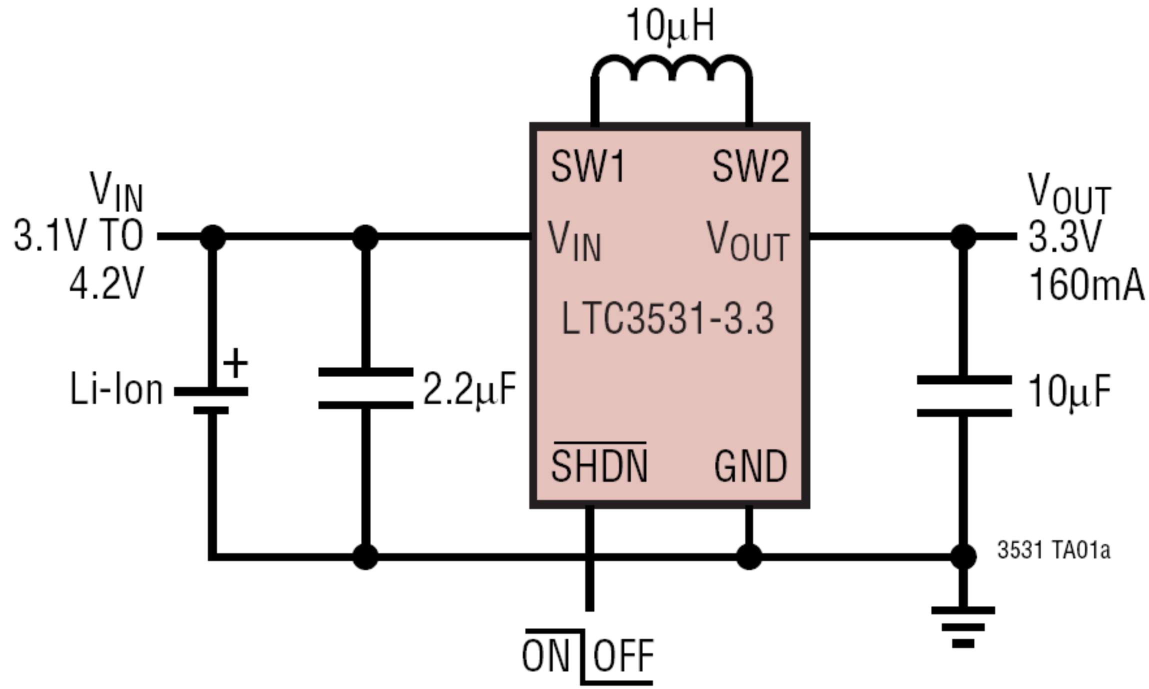


- $V_{OUT} > V_{IN}$
- TPS61201:
  - 0.3V min. input voltage!
  - 50% efficient

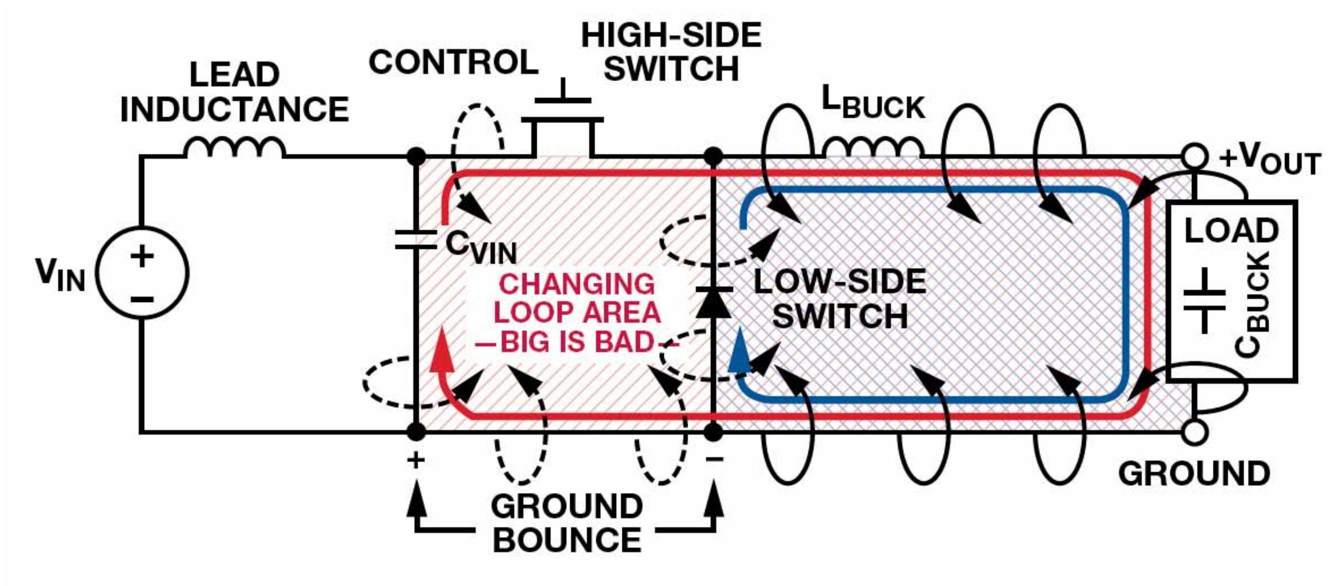


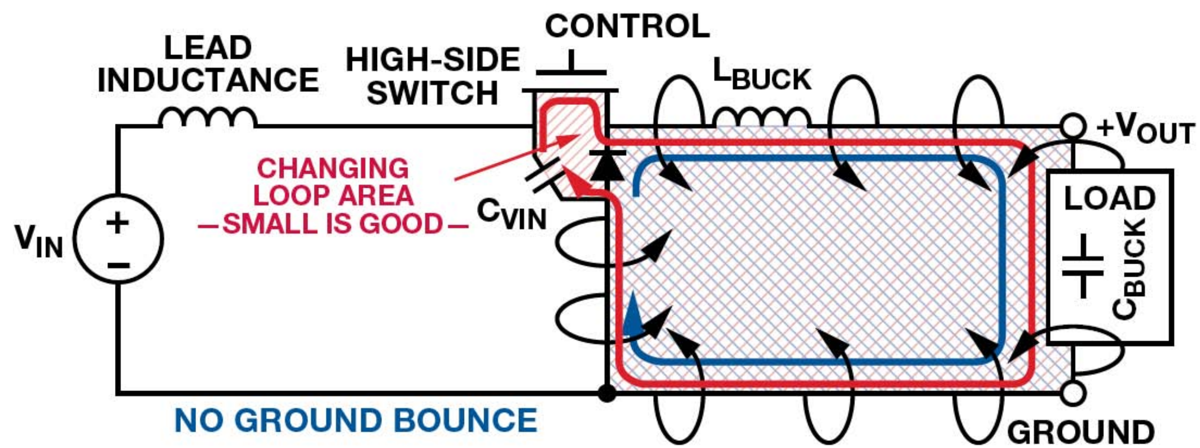
Buck-Boost Converter





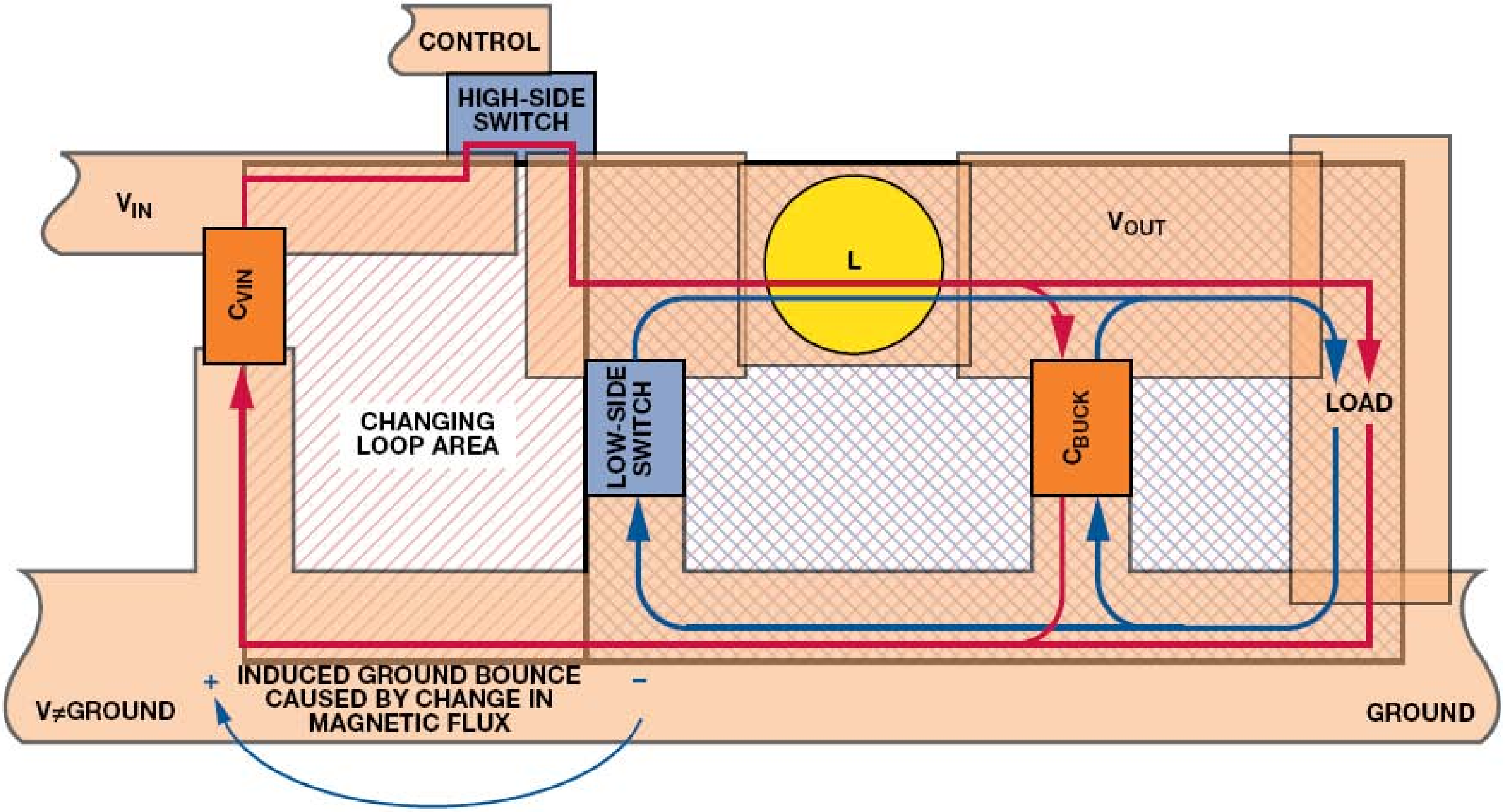
Layout for Switching Regulators 1/4





- Reference: J. Barrow "Reducing ground bounce in DC-to-DC Converters – Some Grounding essentials" Analog Dialogue 41-06

Layout for Switching Regulators 2/4



- Keep low-side switch (Schottky diode) close to C_{VIN} to reduce ground bounce

Layout for Switching Regulators 3/4

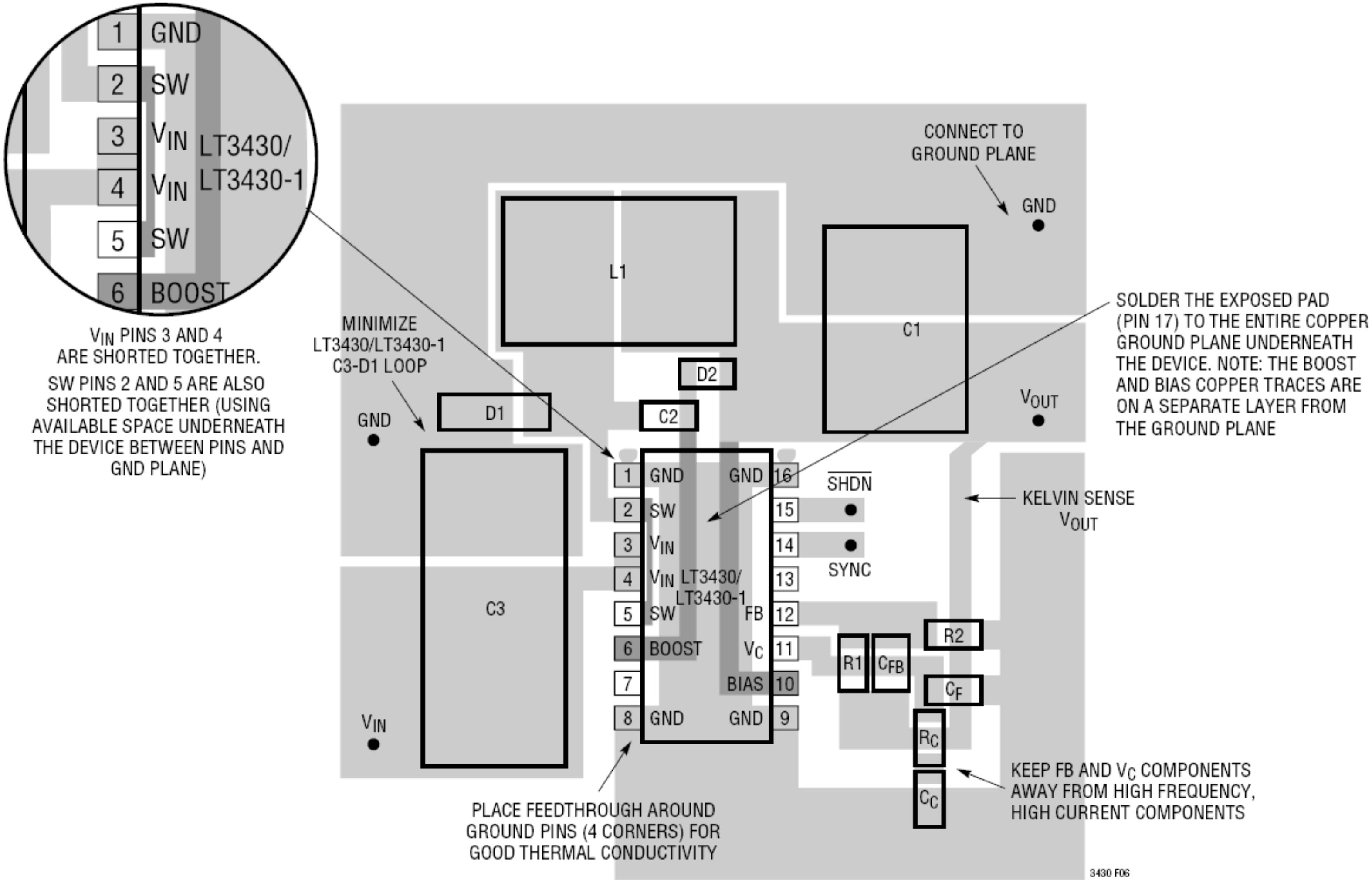
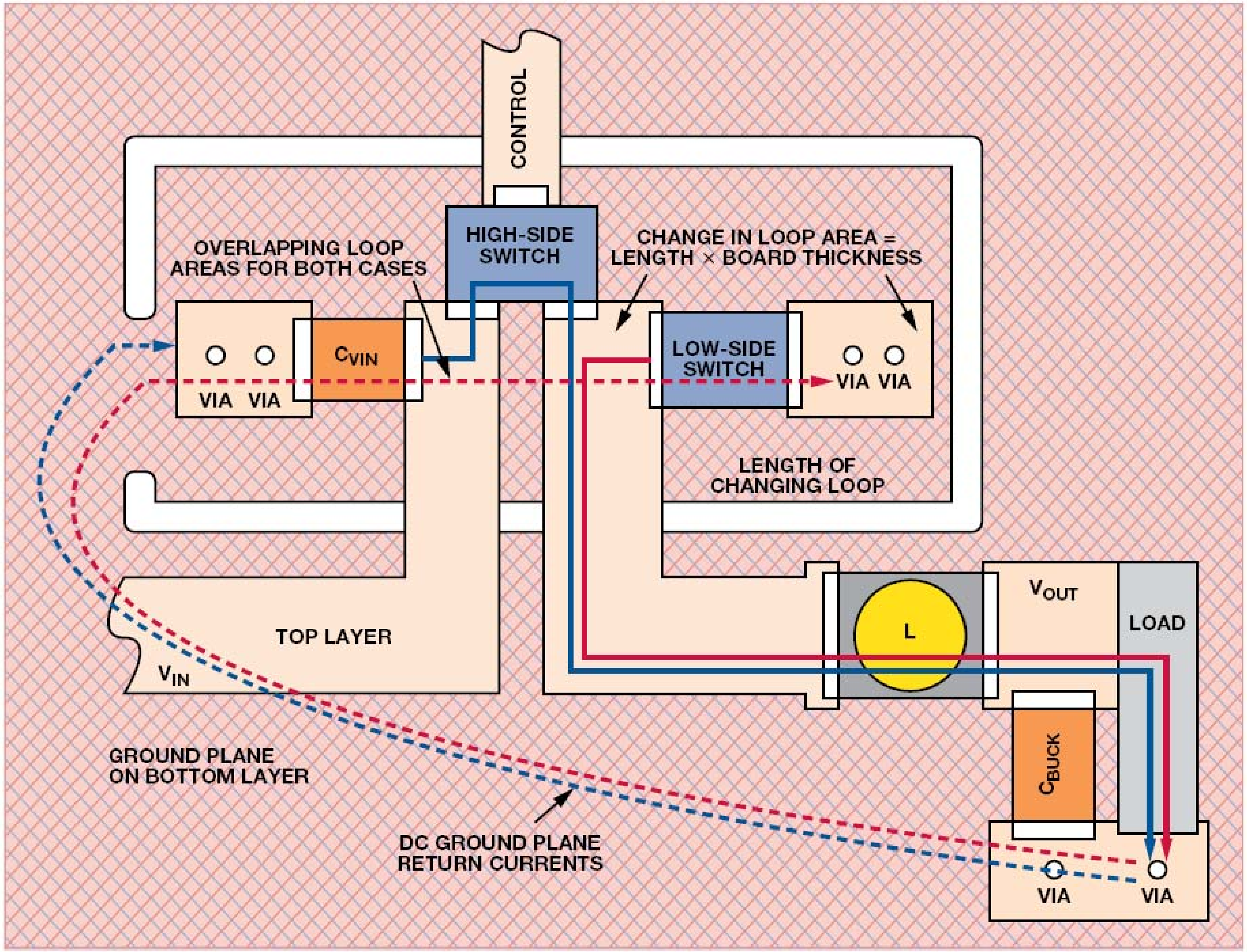
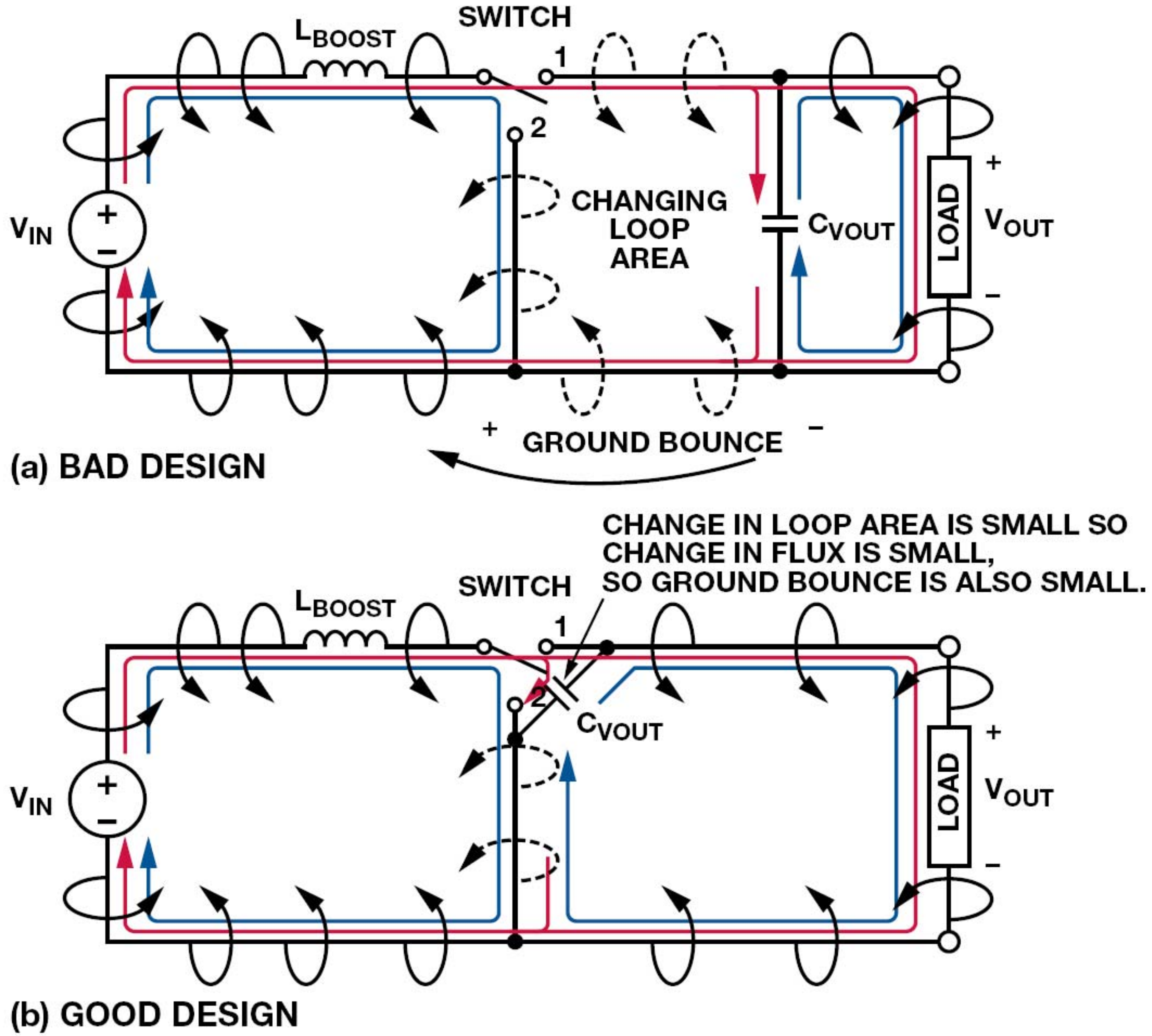


Figure 6. Suggested Layout

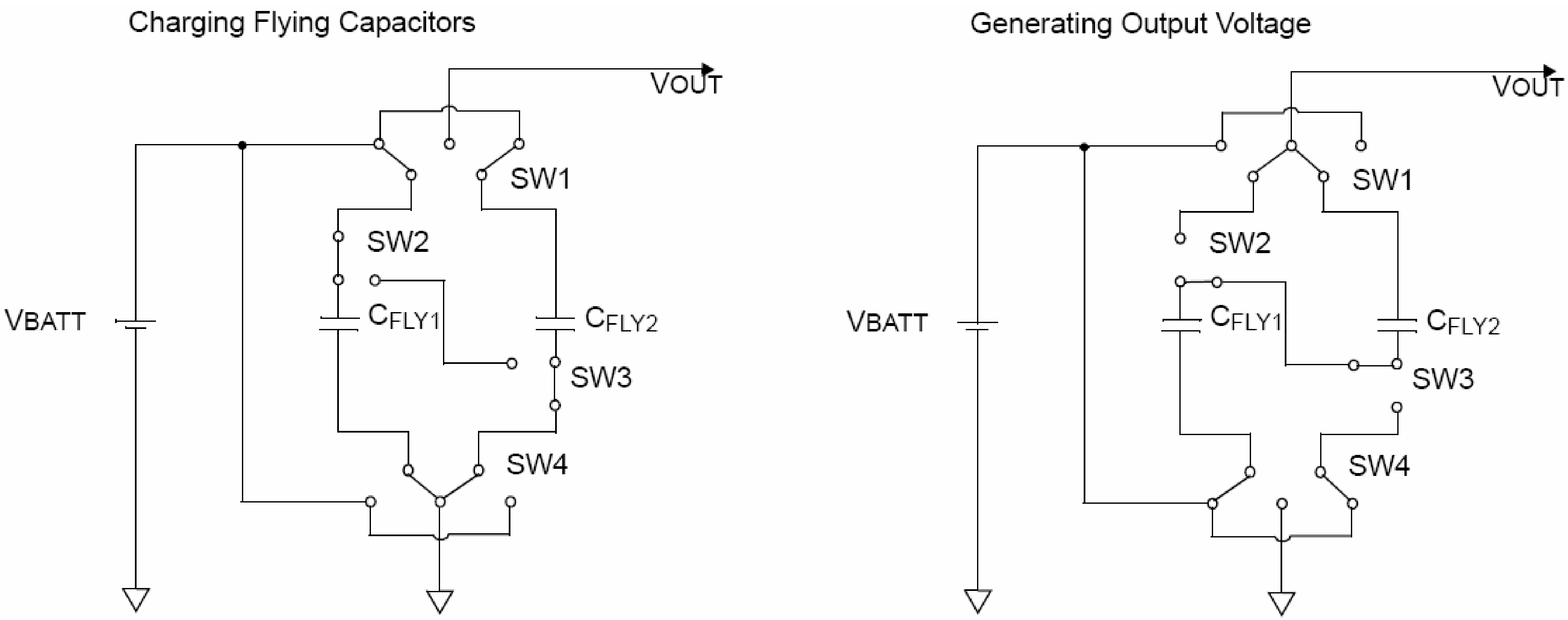
Layout for Switching Regulators 4/4



Layout for Boost Converter

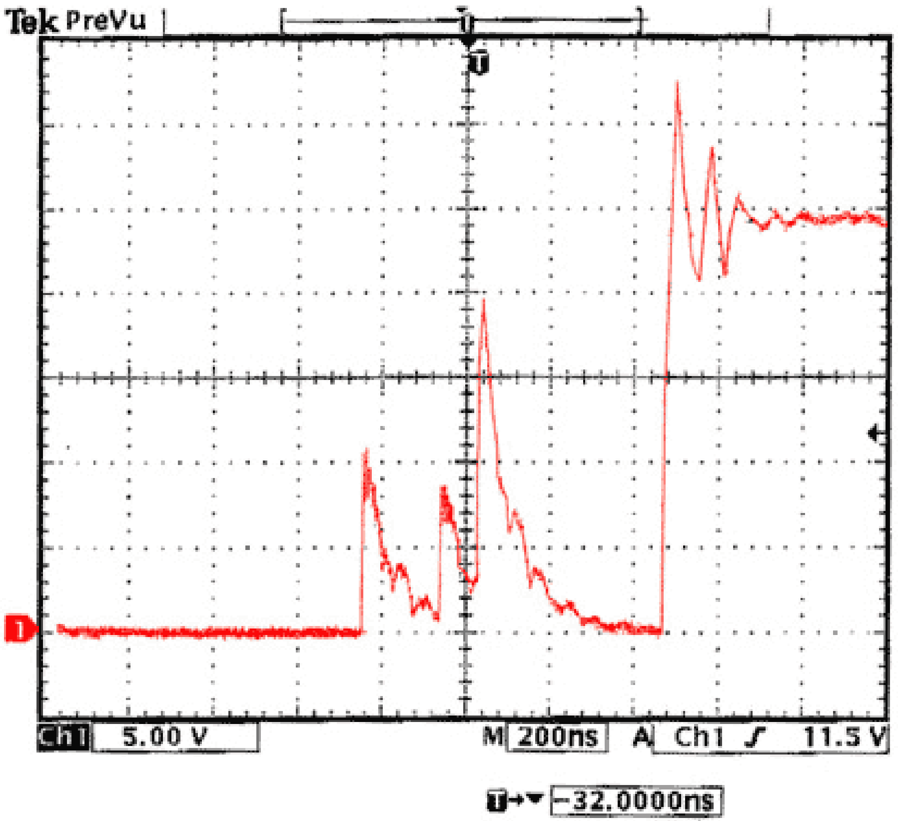


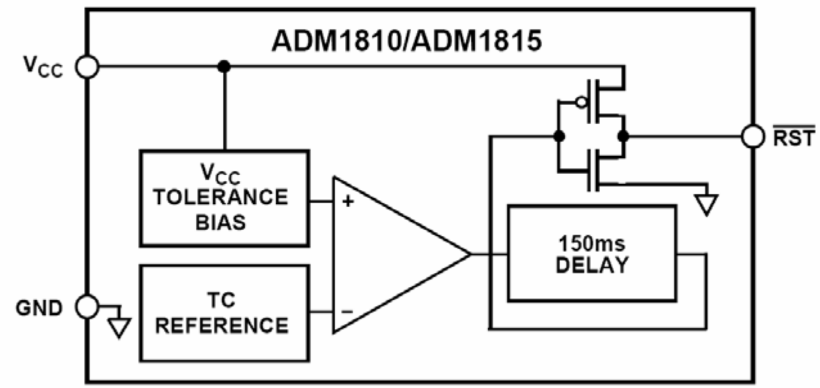
Inductorless DC/DC: Charge Pumps



- LT1044 – 95% efficiency
- Output ripple ~10mV_{PP} unregulated

Battery Insertion and Brown-out



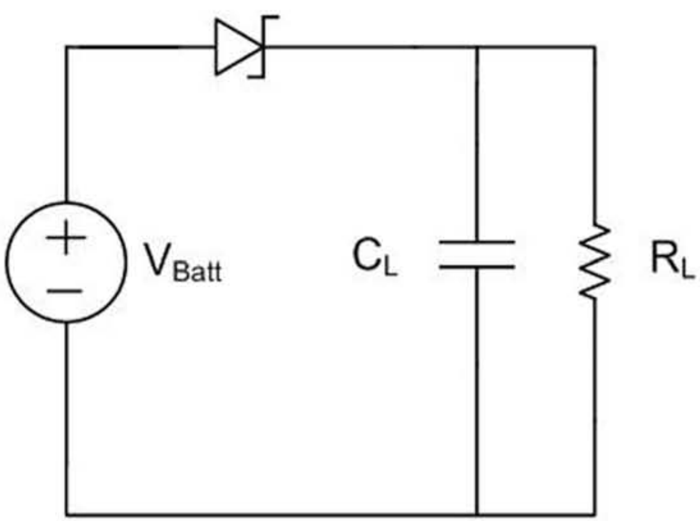


Solutions:

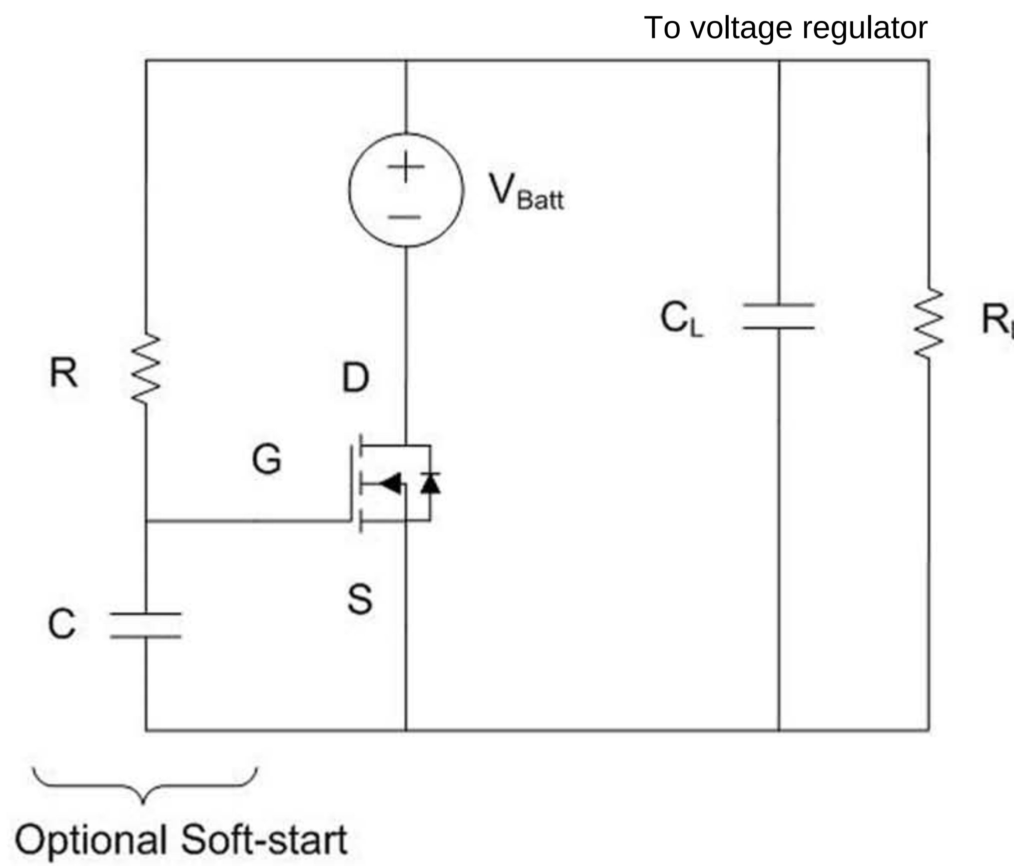
- Reset supervisor
- Soft-start

Reverse Battery Protection

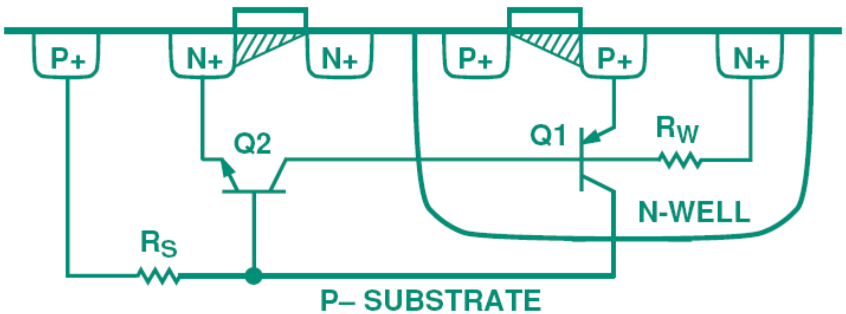
Using a Schottky diode

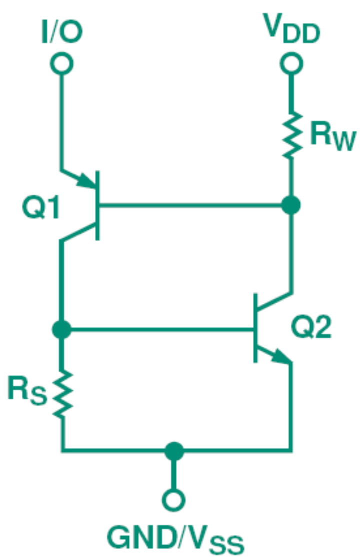


Using an N-Channel MOSFET



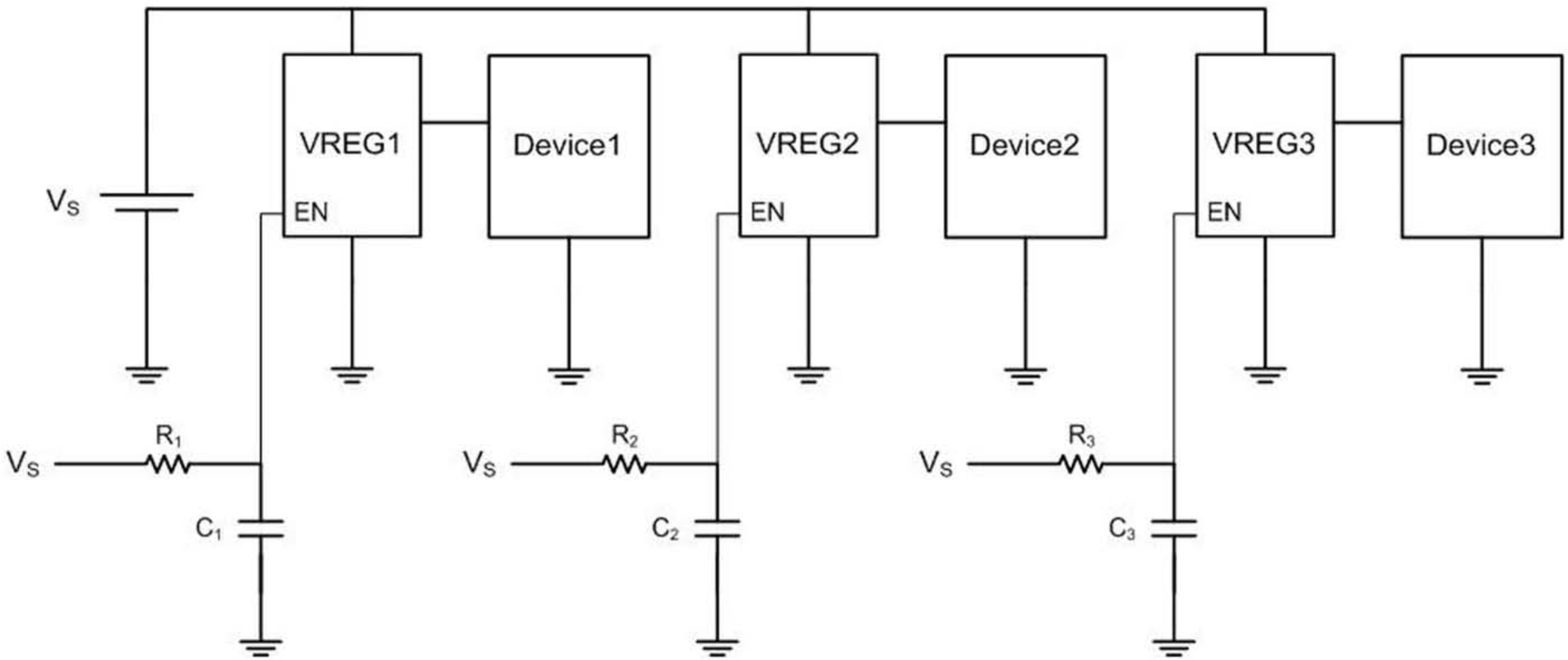
Latch-up





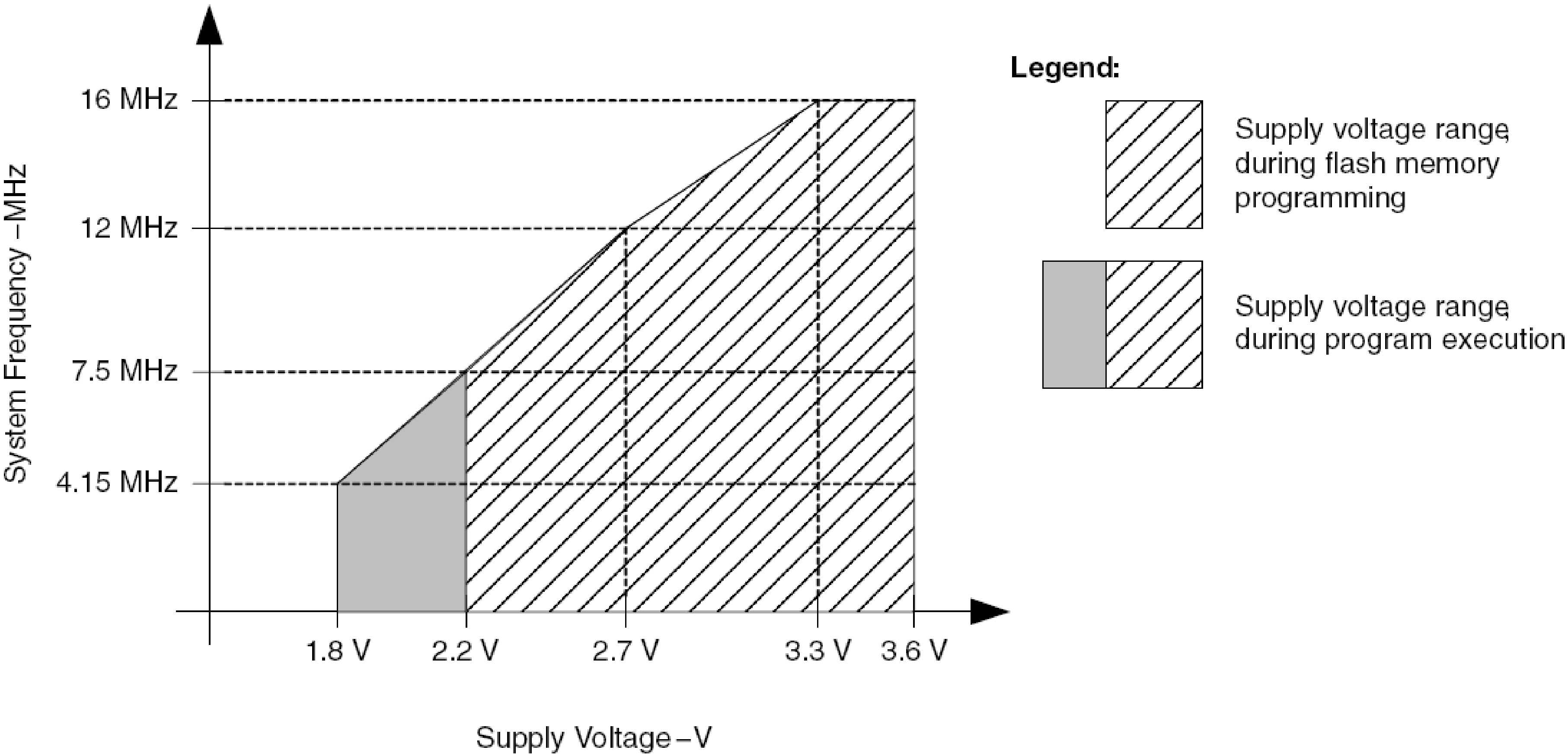
- Latch-up – a low impedance path between the supply rails
- Triggered by parasitic devices within the CMOS structure
- A concern when the input of digital components exceed 1 diode drop of its supply

Power Supply Sequencing

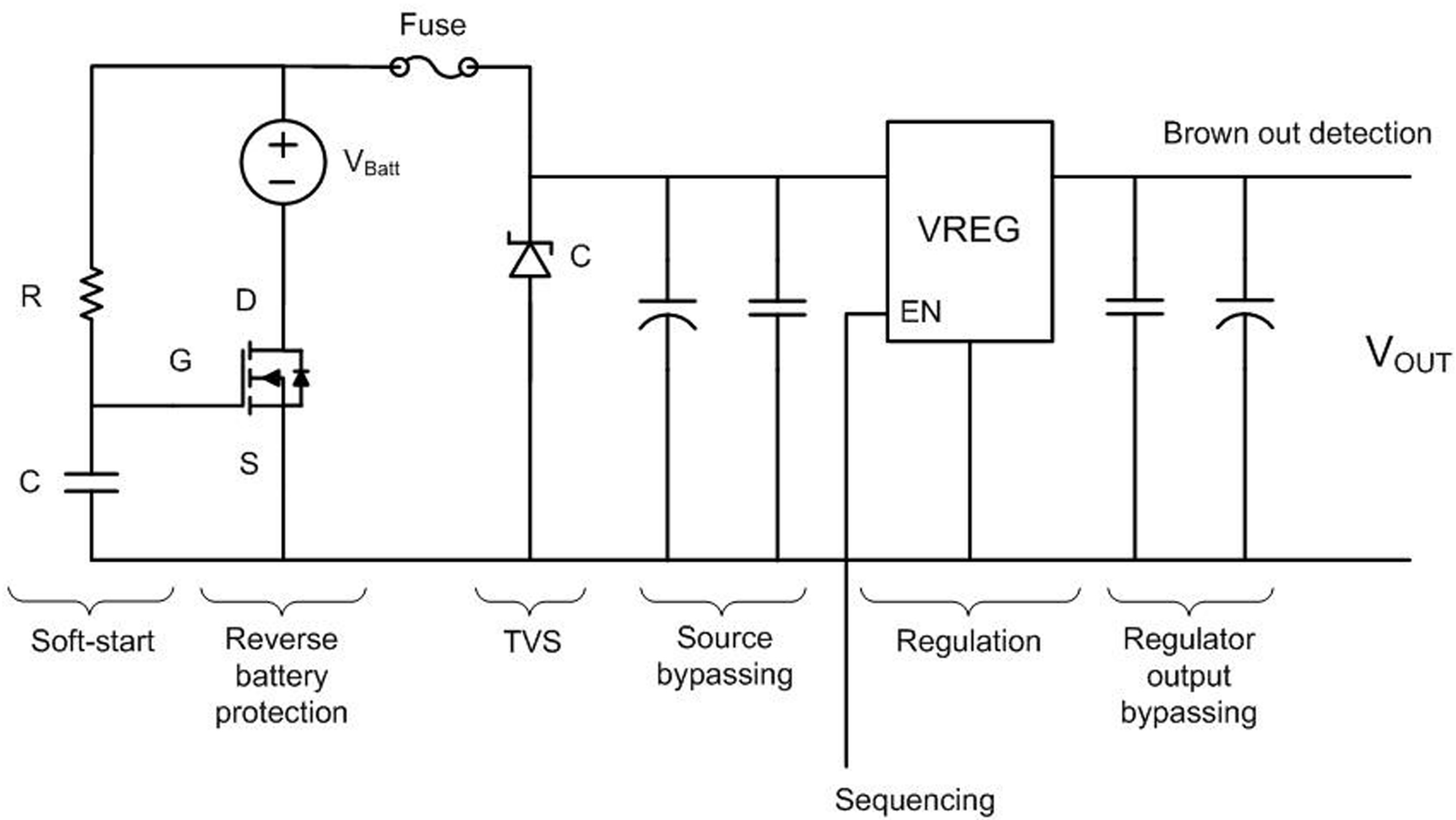


- Simple method: set different time constants for each enable pin
- Alternatively: use a microprocessor to manage startup sequence
- For complex digital systems, use dedicated power supply sequencers

Startup for MSP430 2xx Family



Power Supplies – the Complete Picture



Prior Art Search

What to Look for:

1. Exact device – same technology, same purpose
2. Solve the same problem, but in a different way
3. Uses the same method, but solve a different problem

Outline

- Problems associated with power supplies
  - Power supply voltage uncertainty: wall-wart, battery discharge
  - Source resistance, noise coupling
  - Battery insertion and brown-out
  - Power supply sequencing
  - Reverse power supply / battery
- Not all power supplies are created equal: push vs. push-pull
- Topologies: one supply vs. many supplies
- Linear power supplies – LDO: quiet, simple, low-cost
- Switching power supplies
  - Topologies: buck, boost, buck-boost
  - Key specifications
  - Layout techniques
- Inductor-less switching power supplies
- Reverse battery protection: diode, MOSFET
- Battery charging: NiCd, NiMH, Li, LiPolymer
- USB: in-rush current, 500mA for hubs with ext power, 100mA for unpowered hubs, 4.5-5.5V.

Non-ideal behavior of power supplies

- Source resistance
- Output voltage uncertainty
  - Battery discharge characteristics
  - Load, cable length, temperature dependence
- Battery insertion and brown-out
- Reverse battery
- Startup characteristics
- Power supply sequencing