Lecture 4: Power Supplies

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Key Problem

- Ideal voltage sources do not exist!
- Voltage regulators – use feedback to reduce source impedance
Trends in Power Supply Design

Multiple Devices – One Power Supply

Multiple Devices – Multiple Supply
iPod Breakdown

- 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

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iPod circuitboards.
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

- Very quiet
- Output voltage is not constant
- Steep fall beyond the knee
- Rechargeable batteries cannot be recovered once discharged beyond the knee
- Internal resistance: \( m\Omega \to \Omega \)
USB Ports

- 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

Type A – PC

Type B – peripheral
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 $\Delta V_{OUT} = 100\text{mV}$
- 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

- $V_{OUT} < V_{IN}$
- 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

- **VIN**
- **SW1**
- **SW2**
- **L**
- **Li-Ion**
- **2.2μF**
- **10μH**
- **SHDN**
- **GND**
- **VIN** 3.1V TO 4.2V
- **VOUT** 3.3V 160mA
- **3531 TA01a**
Layout for Switching Regulators 1/4

• 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

(a) BAD DESIGN

CHANGE IN LOOP AREA IS SMALL SO CHANGE IN FLUX IS SMALL, SO GROUND BOUNCE IS ALSO SMALL.

(b) GOOD DESIGN
Inductorless DC/DC: Charge Pumps

- LT1044 – 95% efficiency
- Output ripple \( \sim 10\text{mV}_{PP} \) unregulated
Battery Insertion and Brown-out

**Solutions:**
- Reset supervisor
- Soft-start
Reverse Battery Protection

Using a Schottky diode

Using an N-Channel MOSFET

Optional Soft-start

To voltage regulator
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

Legend:
- Supply voltage range during flash memory programming
- Supply voltage range during program execution
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