Power supply

Design considerations
Outline

• DC-DC conversion and voltage regulation
  • Buck: Regulating wall-wart/battery output to desired voltage
  • Boost: Size constrained systems (Run off single AAA, for example)

• Sources
  • Plugged-in
    • AC-DC conversion
      • Short answer: use third party supplies
    • DC-DC conversion
  • Battery-based
    • High current draw vs. Low current draw
    • Rechargeable vs. non-rechargeable
Voltage regulation – Why?

• Variable voltage drop based on current draw
  • Internal resistance, wire resistance
• Spurious resets on current spikes
• Signals are typically in supply range
  • Rail-to-rail ➔ Ground to VCC
    • Narrower range is common
  • Supply noise ➔ Noisy signals
Imaginary perfect regulator

- Efficiency = 100%
  - Input power = output power
- $V_{in} \times I_{in} = V_{out} \times I_{load}$
  - Vout is constant; no ripple

- What do we have to give up in practice?
  - Efficiency, High quality (low ripple), low cost/footprint
  - Pick any two.
Linear regulators (including LDOs)

- Two major categories
  - Linear regulators (including LDOs)
  - Switching regulators (aka switchers)
- Linear regulators
  - Wasteful (thermal waste of energy)
  - Power dissipation = $V_{in} \times I_{load}$
  - Useful work = $V_{out} \times I_{load}$
- Small voltage buck and/or low load current
  - $5V \rightarrow 3.3V$, 

Diagram:
- Efficiency
- Low ripple/quality of regulation
- Cost/footprint

Linear regulators

Efficiency  
Low ripple/quality of regulation  
Cost/footprint
Switching regulators

• High efficiency
  • 85%-96%

• Noisy
  • Average voltage is well-regulated
  • A/C noise component
Tips

• For fixed voltage with very low dropout, look for custom regulator
  • E.g. MCP 1700 with < 180mV dropout, up to 250mA
    • Can get 3.3V regulation on LiPo batteries (3.7V)
• Good old 78xx (fixed and variable regulators in family)
  • 2V dropout
• Switching regulators
  • Pre-packaged drop-in regulator (e.g., OKR-T/3-W12-C)
  • 7805 drop-in replacement (e.g., Murata 78xxSR)
• Using discrete regulator ICs
  • Delicate designs. Use passives and layout recommended in datasheet
Heat Sink

• Pay attention to heat thermal issues
  • More important in Linear regulators
  • Follow datasheet recommendations
    • Will need understanding of current demands of your project
Boost DC/DC conversion

• Common case: Buck (step-down) regulation

• Extreme low power:
  • Operate on 1 AA battery or button cell
  • Boost to more reasonable supply.

• Typically low-current draw
  • Maybe a sensor or low-duty cycle application
  • Lots of boost converter ICs
  • Attiny43U (Microcontroller with built-in boost converter)
    • Operates down to 0.7V
Battery power: Terminology

• “Cell” single chamber of electrochemical reaction
• Battery: array of cells
  • Array size possibly 1
• Primary: irreversible chemical reaction
  • Chemical energy $\Rightarrow$ electrical energy
  • Non rechargeable
• Secondary: chemical energy $\Leftrightarrow$ electrical energy $\Leftrightarrow$ chemical energy
  • Rechargeable
Characteristics of interest

• Form factor: AA, AAA, 18500, 2032 etc
• Voltage
• Current draw

• Capacity
  • Not simple; depends on current draw

• Leakage/Self-discharge
  • Energy loss on the shelf

• Energy density, power density
Chemistry

• Primary
• Alkaline
  • Cell voltage 1.5V
• Button cell
  • 1.35-1.55V (Silver/Zinc/Mercury)
• Lithium – Family of chemistries
  • 1.5-3.7V

• Secondary
• Lithium-ion (totally different from Lithium) 3.6-3.7V
• NiCad 1.2V
• NiMH 1.2V
• Lithium-ion polymer (LiPo) 4.2-2.7V (Nom: 3.7V)
• LiFePO4 3.2-3.3 V
Capacity

• 500 mAH @ 3.7V
  • 50 mA for 10 hours
  • 25 mA for 20 hours
  • 500 mA for 1 hour
  • 5A for 6 minutes
  • No!

• Depends on discharge profile
Non-rechargeable

- Alkaline: Good old stuff
  - AA, AAA, C, D: 1.5V
- Lithium: Typically sold as ultra long-life

- Do not ignore

- Useful when:
  - Relatively long useful life
  - Relatively low current draw OR Relatively rare unplugged operation
Other advanced issues:

- **Wireless charging:**
  - Inductive coupling
    - Qi – broadly used in mobile industry
  - Solar charging

- **In-circuit recharging**
  - Careful - charging profiles
  - Serious safety issue (High energy density in personal devices)

- **Microcontroller-driven power management**

- **Battery monitoring issues**

- **Thermoelectric**
Backup battery

• Very common use-case
  • Normal use and battery recharge when plugged in
  • Battery operation when not plugged in
    • Seamless transition

• Two assumptions
  • Rechargeable battery
  • Safe charging

• What if non-rechargeable? (E.g., smoke alarms)
• What if trickle charging is inadequate?
Simple backup battery
Power Management ICs

• E.g. TI BQ24072 (For Li+)
• Charging + Dynamic power-path for battery backup
• Other similar ICs for other Chemistry

• Note: Thermistor input
Inductive coupling

• Air core coupling
  • High losses
  • Fairly widespread standard: Qi
    • Not available in small quantities
  • Some hobby parts available

• Magnetic material core
  • Equivalent to transformer, but with separable coils
  • Secondary coil in toothbrush; Primary coil and core in charging base
Solar charging

• Always use to drive battery charger
  • Use battery to provide stable power supply

• Size capacity to ensure statistical guarantees of availability
  • Assume panel sized to fully-charge battery in 4 hours
  • Probability of 4 hours of direct sunlight each day = 0.7 (say)
  • Probability of 4 hours of direct sunlight in two days = 0.91 = 1 - (1-0.7) (1-0.7)
  • Probability ...... 3 days > 0.97
  • If battery sized for three days of operation, 97% probability of never running out.

• Similar process for more sophisticated weather/climate models
Power management

• Sleep/low-power states
  • Important for battery-powered systems

• Selective
  • Some peripherals/sub-blocks in low-power states when not used

• Whole chip

• Questions to ask?
  • Programmed wakeup? Via interrupts? Need physical wakeup?
  • Is duty cycle low enough?
Voltage Regulator (Selected data)

- LM 117
  - Adjustable voltage regulator
  - $V_{out}^{Adj} = 1.25V$ (Invariant)
  - Negligible current through Adj
  - Everything else follows
    - Reason about voltage $V_{out}$
Other Linear regulators

• 7805 : Very similar
  • Simpler for fixed output
  • Vout-Adj voltage = 5V

• Very similar reasoning
  • Can be used to design adjustable regulators
  • Can be used as current regulators
    • Constant current source (LED drivers)
Drop-in Replacement Switching regulator (DC-DC)

• Pin compatible

• Examples
  • ReCom R-78Cxx-1.0
  • Equivalent parts from Murata
Step-Down Switching Converter: LM 2675

- (fixed) 3.3, 5, 12 VDC and (adjustable) 1.21 – 37 V versions
- Up to 1 amp
- Up to 96% efficient
- Five external components
Battery monitoring

• Simple voltage-based approach
• Plateaus in discharge curve
• Possibly depends on chemistry
• Fuel gauge ICs

Source: Energizer.com
Heat sink

- Idea of THERMAL RESISTANCE
  - Measured in °C/W (temperature rise per watt dissipated)
  - Lower thermal resistance is better

- Thermal resistance is ~ inversely proportional to price

- 1W dissipation

- Design goal: heat sink/junction temperature not to exceed 10º C above ambient temperature

- Need a thermal resistance of approx. 10º C/ 1 W ≈ 10

- Airflow reduces thermal resistance