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POWER SUPPLY ALTERNATIVES IN ELECTRONIC SYSTEMS

Systems Laboratory (LABSI)

December 2021

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Summary

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1. Introduction
2. Battery characteristics
3. SOC estimation
4. Battery technologies
5. Power management

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Introduction

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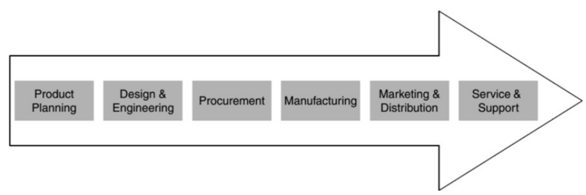
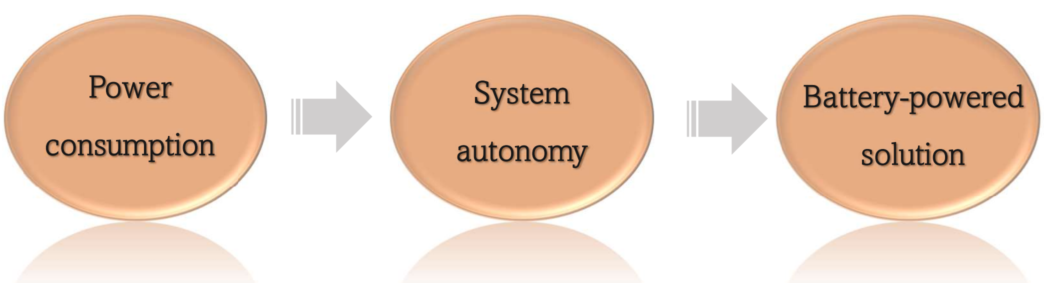
Design and development of electronic mobile devices





Introduction

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Power Budget

Determines where all the possible power will be used by a device by breaking it down into components and categories

Example for a drone module with

- Position/attitude tracking and control
- Environment data acquisition

Components	Voltage	Current	Power	Qt.	Total Power
Atmega 328	5 V	16 mA	80 mW	2	160 mW
LED	2 V	8 mA	16 mW	4	64 mW
DS18S20 Digital Termometer	5 V	2 mA	10 mW	1	10 mW
APC220 Wireless Radio Module	5 V	30 mA	150 mW	1	150 mW
GY87 Inertial Measurement Unit	5 V	4 mA	20 mW	1	20 mW
DHT11 Humidity Sensor	5 V	3 mA	15 mW	1	15 mW
SD-Card Module	5 V	50 mA	250 mW	1	250 mW
OV7670 CMOS Camera	3 V	20 mA	60 mW	1	60 mW
BMP180 Altitude Sensor	2,5 V	2 mA	5 mW	1	5 mW
GPS Module	3,3 V	70 mA	231 mW	1	231 mW
Total	–	205 mA	837 mW	14	**965 mW**

Total current: 245 mA

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Calculating battery capacity

Maximum current consumption over a period of time

- Our system has a maximum current consumption of I_M
- We want the system to run for t hours straight.
- We can then obtain the battery minimum capacity in Ampere · hour

$$C = I_M \times t$$

Previous application example (Drone Module)

Power Budget	Current	Power	Qt.	Total Power
Total	245 mA	837 mW	13	965 mW

If we want our system to continuously run for 40 hours, the battery minimum capacity comes:

$$\mathrm{C} = 0{,}245 \times 40 = 9{,}8 \ \ A{\cdot}h$$

Introduction

Calculating battery capacity

What if the power consumption is not constant ?

- Determine the average current or power consumption per hour
- Consider a repetitive cycle of 1 hour

Example: a system has a current consumption of 20 A in the first second, and 0,5 A for the rest of the hour. The average current consumption is:

$$\tilde{I} = 20 \times \frac{1}{3600} + 0{,}5 \times \frac{3599}{3600} = 0{,}505\ A$$

Introduction

Calculating battery capacity

Battery lifecycle considerations

- It is not advised to completely discharge a battery during a cycle
- Example: a lead acid battery charge should never be less than 20% of the total charge, to increase its life-cycle

$$C' = \frac{C}{0{,}8}$$

- However, some battery technologies, such as NiCd can be discharged to 100%

Summary

Battery Characteristics

Capacity

- Capacity is a measure of the battery charge in Amp · h $1\ Coulomb = 1\ \ A \cdot s$
- Represents the maximum amount of energy that can be extracted from the battery in a specific time interval
- Installing a battery with a higher capacity results in a longer runtime, affecting the system's autonomy
- The charging time of a battery with high capacity will take longer that a battery with lower capacity

Battery Characteristics

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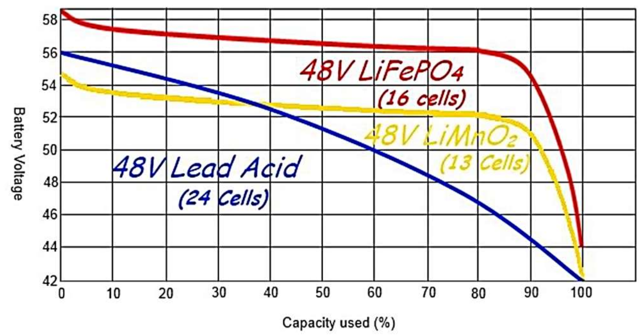
Nominal Voltage

- Nominal voltage is determined by chemical reactions that involve the flow of electrons from one material (electrode) to another
- This flow of electrons generates an electrical current
- The battery voltage is a function that changes with the charge level, meaning that the nominal voltage should always be checked before connecting the battery

Battery voltage curve for:
- Lead Acid Batteries
- Lithium Iron Phosphate Batteries
- Lithium Manganese Dioxide Batteries



Battery Characteristics

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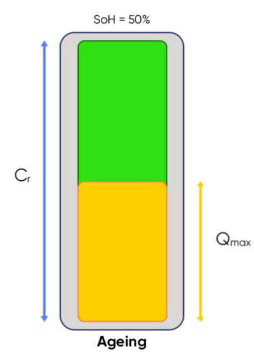
State of Health – SoH

- The SoH of a battery describes the difference between a battery being studied and a fresh battery.
- It considers the cell aging parameter.
- It is defined as the ratio of the maximum battery charge to its rated capacity

$$\mathrm{SoH}/\% = 100\frac{Q_{\mathrm{max}}}{C_{\mathrm{r}}}$$



Battery Characteristics

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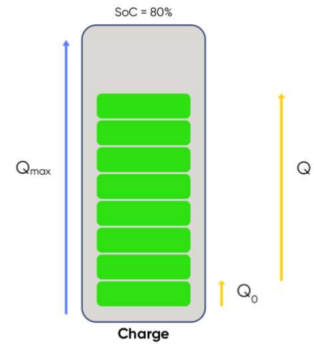
State of Charge – SoC

- The SoC of a battery describes the difference between a fully charged battery and the same battery in use
- It is associated with the remaining quantity of electricity available in the cell
- It is defined as the ratio of the remaining charge in the battery, divided by the maximum charge that can be delivered by the battery.

$$\mathrm{SoC}/\% = 100\frac{(Q_0 + Q)}{Q_{\mathrm{max}}}$$



Battery Characteristics

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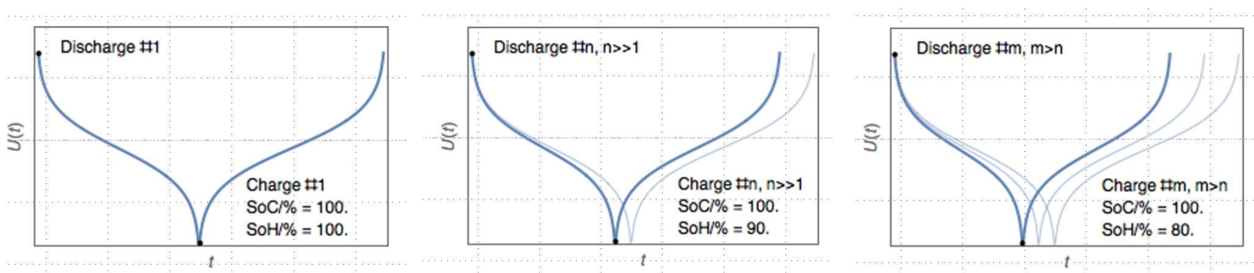
SoC and SoH relation

- The discharge profile of a secondary battery is affected by its state of health
- The lower the SoH, the faster the battery is discharged/charged



Battery Characteristics

Charging / Discharging rates

Represent the battery capacity as a function of the time in which it takes to fully discharge or charge the battery

Cx

The notation to specify battery capacity in this way is written as *Cx*, where *x* is the time in hours that it takes to discharge the battery

Example:

- ✓ C20 battery (or 0.05C)
- ✓ Capacity of 500 Ah

Discharge rate:

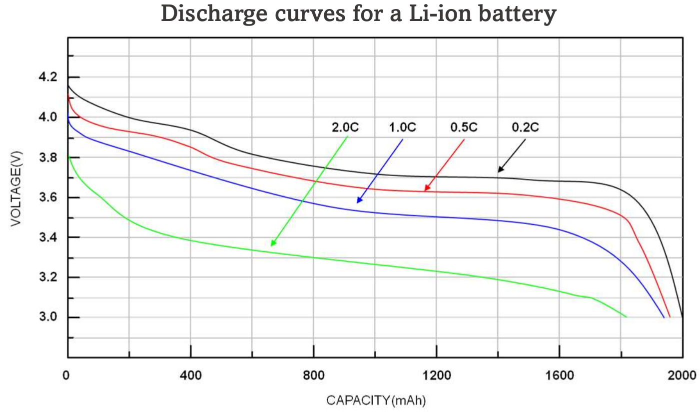
500 Ah / 20 h = 25 A

Battery Characteristics

Charging / Discharging rates

- **Flat discharge curves**: the battery voltage remains constant throughout the discharge cycle
- **Sloping discharge curves**: the battery voltage is closely related to the remaining charge in the cell
- Flat discharge curves require more complex methods of estimating SoC

Discharge curves for a Li-ion battery



Battery Characteristics

Self-discharge

- Even in the absence of a connected load, the discharge reaction will proceed to a limited extent
- This means the battery will discharge itself over time
- The self-discharge rate depends on:
  - The materials involved in the chemical reaction
  - The temperature of the battery

Typical self-discharge by battery type

Battery	Self-discharge
Lithium metal	10 years
Alkaline	5 years
Zinc–carbon	2–3 years
Lithium-ion	2–3% per month
Lithium-polymer	5% per month
Lead–acid	4–6% per month
Nickel–cadmium	15–20% per month
Nickel–metal hydride (NiMH)	30% per month

Battery Characteristics

Battery lifetime

- Involves gradual degradation in battery capacity
- Typically given as the number of charge/discharge cycles which it can undergo and still maintain its original capacity
- In systems such as in uninterruptable power supplies, battery lifetime is more appropriately specified in years

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SoC Estimation

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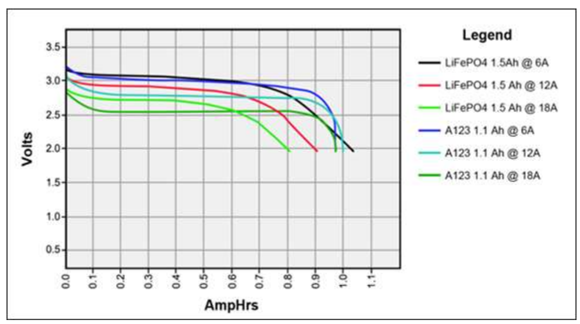
Voltage Method

Measuring state-of-charge by voltage is the simplest method, but it can be inaccurate

- ✕ The battery needs to rest in the open circuit state for at least four hours
- ✕ Some discharge curves are very flat during approximately 80% of the discharge.
- ✕ Cell materials and temperature affect the voltage at the battery terminals

Li-phosphate (LiFePO) batteries discharge profile



SoC Estimation

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Hydrometer

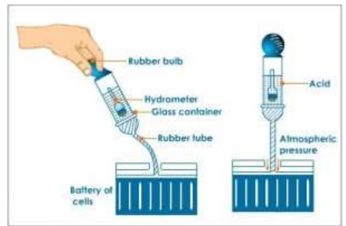
Specific gravity = Relative density

The hydrometer offers an alternative to measuring SoC of flooded lead acid batteries

This device can measure the Specific Gravity (SG) of a fluid

Lead acid battery accepts charge → Sulfuric acid gets heavier → Specific gravity increases

Lead acid battery discharges → Sulfuric acid removes itself → Specific gravity gets lower



SoC Estimation

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Hydrometer

- ✗ The SG of the same battery in full charge or discharge may vary from 1.270 to 1.305 and 1.097 to 1.201 respectively
- ✗ The electrolyte needs to stabilize after charge/discharge before taking the SG reading
- ✗ Temperature alters the specific gravity reading

Approximate state-of-charge	Average specific gravity	Open circuit voltage 2V	6V	8V	12V
100%	1.265	2.10	6.32	8.43	12.65
75%	1.225	2.08	6.22	8.30	12.45
50%	1.190	2.04	6.12	8.16	12.24
25%	1.155	2.01	6.03	8.04	12.06
0%	1.120	1.98	5.95	7.72	11.89

SoC Estimation

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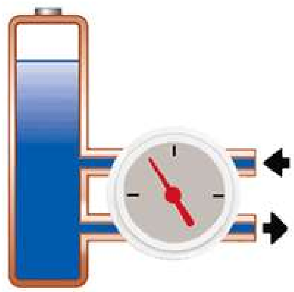
Coulomb counting

- Coulomb counting estimates SoC by measuring the in-and-out-flowing current
- This method is used by most laptops, medical equipment and other professional portable devices to estimate SoC
- How it works: a circuit measures the in-and-out flowing energy; the stored energy represents state-of-charge



- ✗ Since losses occur, the available energy is always less than what has been fed into the battery
- ✗ Requires periodical calibration to estimate how much energy the battery delivered during previous discharge

SoC Estimation

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So, how do we exactly now I much battery we have left ?

Short answer: We don't … Nothing in the battery world is absolute

Solution

We can combine this methods and create algorithms in order to efficiently estimate the battery state-of-charge

Other methods:

- Kalman Filtering
- Pressure method
- Electrical Impedance Spectroscopy
- Neural Networks
- Support Vector Machines

Summary

Battery Technologies

General considerations

The most common battery technologies are:

- Lead Acid (PbAc)
- Nickel-cadmium (NiCd)
- Nickel-Metal Hydrite (NiMH)
- Lithium Polymer (LiPo)

Warning:

Most of these rechargeable batteries show a voltage level of 10 to 15 % superior to the nominal voltage when fully charged

Series/parallel disposal of batteries result in different voltage levels and capacities.

- Lead Acid: 2 V per cell
- NiCd and NiMh: 1,2 V per cell
- LiPo and Li-Ion: 3,7 V per cell

Multiple batteries are often combined to produce desirable voltage levels or higher capacities

Battery Technologies

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Battery comparison

Lead Acid

- Usually found in cars, boats, solar energy systems
- Large and heavy
- Highest capacities: 5 – 150 Ah
- Typically available in 6, 8, 12 and 24 V
- Solution for electronics: deep-cycle and sealed batteries

NiCd

- Usually applied as supply to small electrical motors
- Long lifetime with thousands of charging cycles
- High self-discharging rate
- Low energy density
- Not suitable for mobile devices

NiMH

- High capacity 1 – 4 Ah for its size
- Fairly high self-discharging rate
- High energy density
- Used in mobile devices

LiPo

- One of the most recent technologies
- High energy density
- Flexible in size and shape for a variety of applications
- High capacity up to 5Ah
- Require specific cautions to avoid overheating

Battery Technologies

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Battery comparison

Each battery technology has its own advantages depending on the application

- LiPo batteries have the highest energy density
- Lead acid batteries are the cheapest
- NiCd and NiMH are suitable for most electronic projects
- LiPo batteries are the lightest

Type of Battery	Voltage	Volts/Cell	Cells	Price	Weight	Amp/Hours
Lithium Polymer	11.1v	3-7v	3	$32.00	14oz	5000mAh
NiCad	12v	1.2v	10	$49.99	32oz	5000mAh
NiMH	12v	1.2v	10	$49.99	32oz	5000mAh
Lead Acid (SLA)	12v	2.0v	6	$15.99	64oz (or 4lbs)	5000mAh

	Ni-Cd	Ni-MH	Li-ion	Li-polymer
Working voltage (V)	1.2	1.2	3.6	3
Energy density (Wh/L)	120	240	260	264
Energy density (Wh/kg)	50	60	115	250
Cycle life	300–800	300–800	1200	1200
Memory effect	Yes	Yes	No	No
Cost ($/Wh)	1	1.3	2.5	2

Battery Technologies

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Battery comparison

	Lead-Acid	Ni–Cd	Ni-MH	Li-ion
Discharge	The limit is ~80% DOD	Can be discharged to 100% DOD	The limit is ~80% DOD; few deeper discharges are allowed	The safety circuit prevents full discharge. ~80% DOD is a safe limit
Typical charge methods	Constant voltage to 2.40 V, followed by float charging at 2.25 V. Float charge can be prolonged. Fast charge is not possible. Slow charge: 14 h. Rapid charge: 10 h	Constant current, followed by trickle charge. Fast-charge preferred to limit self-discharge. Slow charge:16 h. Rapid charge: 3 h. Fast charge: ~1 h	Constant current, followed by trickle charge. Slow charge not recommended. Heating when full charge is approached. Rapid charge: 3 h. Fast charge: ~1 h	Constant current to 4.1–4.2 V, followed by constant voltage. Trickle charge is not necessary. Rapid charge: 3 h. Fast charge recently reported: <1 h
Storage	To be stored at full charge. Storing below 2.10 V produces sulphation	To be stored at ~40% state of charge. Five years of storage (or more) possible at room temperature or below	To be stored at ~40% state of charge. Storage at low temperature is recommended, as this cell easily self-discharges above room temperature	To be stored at an intermediate DOD (3.7–3.8 V). Storing at full charge and above room temperature is to be avoided, as irreversible self-discharge occurs

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Battery Technologies

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Battery comparison

Battery Type	Sealed Lead-Acid	Nickel–Cadmium	Nickel-Metal Hydride	Lithium Ion
Nominal voltage	2.0 V	1.2 V	1.2 V	3.7 V
Pros	• For heavy duty use • Superior long-term reliability • Economical • Easy to recycle	• For heavy duty use • High mechanical strength • High efficiency charge • Charge cycle: 500 times • Easy to recycle	• For heavy duty use • No heavy metals • Relatively high capacity • Charge cycle: 500 times	• For heavy duty use • High 3.7 V voltage • No memory effect • Low self-discharge
Cons	• Relatively low cycle life • Low energy • High self-discharge in flooded batteries	• Low energy • Memory effect • Toxicity • High self-discharge espec. in sealed cells	• More expensive than Ni–Cd • Very high self-discharge	• The most expensive • Potential safety problems • Requires control of charge/disch. limits • Degrades at high temperature
Applications	• Automot. applications • Portable AV equipment • Lighting equipment • Stationary applications	• Portable OA equipment • Portable AV equipment • Power tools • Medical instruments • Stationary applications • Space applications	• Portable OA equipment • Portable AV equipment • Power tools • Medical instruments • Hybrid cars	• Portable OA equipment • Military and space appl. • Many consumer devices • Candidate for next-generation HEV • Power tools

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Summary

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Power management

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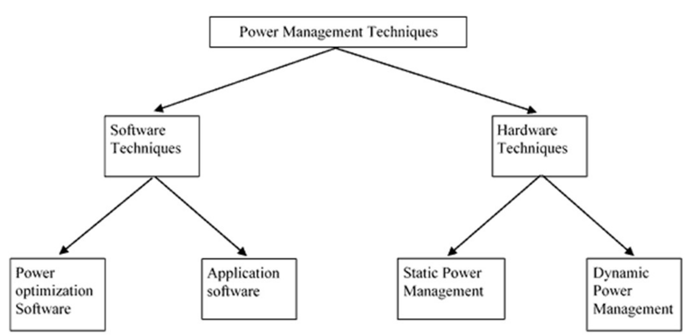
Power management

Process of controlling power use in a system by hardware or software

- ✓ Battery life improvement
- ✓ System's autonomy increase
- ✓ Better thermal behaviour
- ✓ Noise reduction
- ✓ Improved reliability (better MTBF)



MTBF: Mean time between failure

Power management

Power management techniques

Dynamic voltage and frequency scaling

Automatic adaption of CPU frequencies and voltages according to the system load.

The lower the frequency of operation, the lower the power consumption

Peripheral Power-down

Peripherals and subsystems may be switched on and off by the software, as required.

This applies to TIMERs, ADCs, SPI, I2C and similar components

Low power modes

When a device is not in use, it may be switched to a low power state:

- Standby: The CPU and peripherals are shut down, but power is maintained. Wakes up faster.
- Hibernate: The system is shut down and Timers are disabled. CPU has nothing to run, so there is no ongoing power drain

Questions

Thank you

For your attention