Exercise 1

A notebook battery pack is marked with "9.6 V, 4000 mAh". Assume that in NiCd and Li-ion batteries the capacity of storing energy are about 40 Wh/kg and 135 Wh/kg, respectively.

a) How much energy is stored in the battery pack?

b) Estimate the weight of the battery pack for NiCd and Li-ion, respectively.

Exercise 2

A cellular phone manufactured has the weight of 93 g. The standby time is up to 300 h and the talk time is up to 9 h. The battery is build of Li-ion with 140 Wh/kg and 380 Wh/L. The battery has the dimensions of 5 mm, 35 mm and 65 mm.

a) Estimate the capacity (in Joule) and the weight of the battery.

b) Estimate the average power consumption in the respective operation modes.

Exercise 3

The maximum standby time of a cellular phone is 300 h and the maximum talk time is 10 h. The phone is powered by a battery with the dimensions 5 mm, 30 mm and 60 mm. Assuming the battery is of Li-ion type with an energy per volume of 380 Wh/l, estimate the remaining talk time if a call is received after two days of stand-by operation since the last full recharge.

Exercise 4

Lithium-ion batteries are popular in mobile equipment as the energy density is high. In Table 1, average voltage and specific capacity are shown for different lithium-ion battery technologies.

Material	Voltage	Capacity
$LiCoO_2$	3.7 V	140 mAh/g
$LiMn_2O_4$	4.0 V	100 mAh/g
$LiNiO_2$	3.5 V	180 mAh/g
$LiFePO_4$	3.3 V	150 mAh/g

Table 1: Average voltage and specific capacity for Li-ion batteries.

a) Order the battery technologies with respect to energy density.

b) A laptop battery with an average voltage of at least 18 V should be designed. The battery should last for approximately 4 h with an average power consumption of 30 W. Calculate the weights of a battery based on the different technologies above.

Exercise 5

a) Describe how to reduce power in stand-by/sleep mode for a processor.

b) Describe two ways for a system to decide when to go to standby mode.

c) Two components in a system consume 90% and 2% of the total power. How much is the total power consumption reduced if the power for one of these components is reduced by 70%?

Exercise 6

A certain processor running at 1.6 GHz has a power supply voltage of 1.8 V and an average input current of 34.7 A. The processor contains of 22 million transistors and is implemented using a 0.18 µm process. Assume that the average transistor have a width of 2 µm and that C_{ox} = 0.01 F/m^2. The gate input capacitance for each transistor can be approximated as $C_g \approx C_{ox}W_tL_t$. The interconnect capacitance adds approximately 125% of C_g to each gate of the transistors.

a) Do a rough estimation of the number of transistors that are switching during one clock cycle.

b) Estimate the total capacitance C_{tot}, the switch activity a, and switched capacitance C_{sw}.

Exercise 7

a) A notebook with the power consumption described in Table 2 needs a battery that can supply the computer for approximately 4 hours. What amount of Wh should the battery have?

	Power	Comment
Hard drive:		
Operating	2.5 W	drive reading or writing
Idle	0.8 W	motor running
Standby	0.25 W	motor turned off
Sleep	0.1 W	hard drive control unit and cache turned off.
Screen:	10 W	
CPU:		
500 MHz	1.0 W	Battery power
700 MHz	2.0 W	AC adapter

Table 2: Power table for a notebook.

b) Estimate the weight of the battery when a Li-ion battery with the capacity 135 Wh/kg is used.

Exercise 8

If the motor in a hard disk can be turned off when not in use, a lot of energy may be saved. On the other hand it takes a considerable amount of energy and time to spin up the disk again. If the time between the readings/writings is shorter than a critical time, no power will be saved by turning of the motor. Calculate the critical time for the hard disk in Table 3. Assume that the motor is turned off in the standby mode.

Capacity	80 GB
Number of disks	4
Size	12.5x70x100 mm^3
Rotational speed	5410 RPM
Average seek time	12.0 ms
Read power	2.5 W
Write power	2.7 W
Idle power	0.9 W
Standby power	0.23 W
Sleep power	0.1 W
Spin-up time	1 s
Spin-up energy	4.4 J

Table 3: Data of a hard disk.

Exercise 9

When storing values for later access, the delay times when retrieving data is depending on which memory type the data is stored in. Compare briefly different kind of memories (CPU registers, Hard drive, Memory on chip, Cache on chip, and Memory off chip) with respect to size and accessing time.

Solution 1

a) 138 kJ (assuming constant voltage)

b) 0.96 kg and 0.28 kg, respectively

Solution 2

a) 15.6 kJ, 31 g

b) 480 mW when talking and 14 mW in standby mode

Solution 3

Battery volume = $5 \cdot 30 \cdot 60$ mm^3 = $9 \cdot 10^{-3}$ dm^3
Total energy = $380 \cdot 9 \cdot 10^{-3}$ Wh = 3.42 Wh
Power consumption in stand-by mode = 3.42/300 W = 11.4 mW
Energy remaining after 48 h stand-by = $3.42 - 48 \cdot 11.4 \cdot 10^{-3}$ Wh ≈ 2.87 Wh
Power consumption in talk mode = 3.42/10 W = 342 mW
Time remaing in talk mode ≈ 2.87/0.342 h = 8.4 h = 8 h 24 min

Solution 4

a) Energy density and rank of the battery technologies

Battery	Voltage	Capacity	Energy	Rank
$LiCoO_2$	3.7 V	140 mAh/g	518 Wh/kg	2
$LiMn_2O_4$	4.0 V	100 mAh/g	400 Wh/kg	4
$LiNiO_2$	3.5 V	180 mAh/g	630 Wh/kg	1
$LiFePO_4$	3.3 V	150 mAh/g	495 Wh/kg	3

b) Cells for V_{av} > 18 V and weight per battery to obtain energy 30 W for 4 h = 120 Wh

Battery	Voltage	Cells	Energy	Weight
$LiCoO_2$	3.7 V	5	518 Wh/kg	0.232 kg
$LiMn_2O_4$	4.0 V	5	400 Wh/kg	0.300 kg
$LiNiO_2$	3.5 V	6	630 Wh/kg	0.191 kg
$LiFePO_4$	3.3 V	6	495 Wh/kg	0.243 kg

Solution 5

a) A system can reduce clock frequency and supply voltage and just maintain functionality for low priority tasks. If the system does not do any work in stand-by mode, then the clock can be gated. If even more power needs to be saved, the supply power can be turned off. This would then render a system with long wake up time from sleep mode.

b) One easy way to decide when to go to standby mode is to use a so called inactivity threshold. When a system has been inactive for a certain amount of time (i.e. reached the threshold) the system switches to standby mode. A second way is to let the software report to the system what resources it needs in the future, and by that, the system can estimate when it is time for standby mode and for how long.

c) Modifying the first component yields a reduction by 1 – (0.9·0.3 + 0.1) = 63% while modifying the second yields only a reduction by 1 – (0.02·0.3 + 0.98) = 1.4%.

Solution 6

a) Gate capacitance: $C_g \approx C_{ox}W_tL_t = 0.01 \cdot 2 \cdot 10^{-6} \cdot 0.18 \cdot 10^{-6}\text{ F} = 3.6\text{ fF}$

Interconnect capacitance: $C_w = 1.25C_g$

Capacitance contribution per transistor: $C_t = C_g + C_w = 2.25C_g$

Total number of transistors: $N = 22 \cdot 10^6$

Transition activity for a switching transistor: $\alpha_{01,s} = 0.5$

Transition activity for a non-switching transistor: $\alpha_{01,ns} = 0$

Total power consumption:

$$P = afCV_{dd}^2 = \frac{[n\alpha_{01,s} + (N-n)\alpha_{01,ns}]C_t}{C_{tot}}fC_{tot}V_{dd}^2 = n\alpha_{01,s}C_tfV_{dd}^2 = IV_{dd}$$

The number of switching transistors in each clock cycle is

$$n = \frac{I}{\alpha_{01,s}C_tfV_{dd}} = \frac{34.7}{0.5 \cdot 2.25 \cdot 3.6 \cdot 10^{-15} \cdot 1.6 \cdot 10^9 \cdot 1.8} = 2.97 \cdot 10^6$$

This accounts for about 14% of the total number of transistors in the circuit.

b) Capacitances: $C_{tot} = NC_t \approx 178$ nF

Switch activity $a = \frac{[n\alpha_{01,s} + (N-n)\alpha_{01,ns}]C_t}{C_{tot}} = \frac{n\alpha_{01,s}C_t}{NC_t} = \frac{n}{N}\alpha_{01,s} \approx 0.068$

Switched capacitance: $C_{sw} = aC_{tot} \approx 12$ nF

Solution 7

a) (10W + 1W +0.25W)·4h = 45Wh, if the hard disk is in stand-by mode all the time. (10W + 1W +2.5W)·4h = 54Wh, if the hard disk is in operation mode all the time. The answer should be in between 45 Wh and 54 Wh, so a battery with ~50 Wh should be enough to supply the notebook for approximate 4 hours of continuous work.

b) 0.36 kg

Solution 8

Assume that the critical time t_c is equal to the time between read and writes. We should compare the energy $P_I t_c$ consumed by staying in the idle mode with the energy $P_S t_c$ consumed by switching to standby mode followed by spinning up the motor with the energy consumption E_{SI}.

$$P_I t_c = P_S t_c + E_{SI} \Rightarrow t_c = \frac{E_{SI}}{P_I - P_S} = \frac{4.4}{0.9 - 0.23} \text{ s} \approx 6.6 \text{ s}$$

Solution 9

Register, Cache, Primary memory (On chip/Off chip), Secondary memory (HD, Tape)

As shown in Figure 2 it takes least power to store data in a CPU register with the drawback that a register can not store large data. The hard drive can store a lot of data, but then it takes much more power to store and retrieve data and the access time is very long.

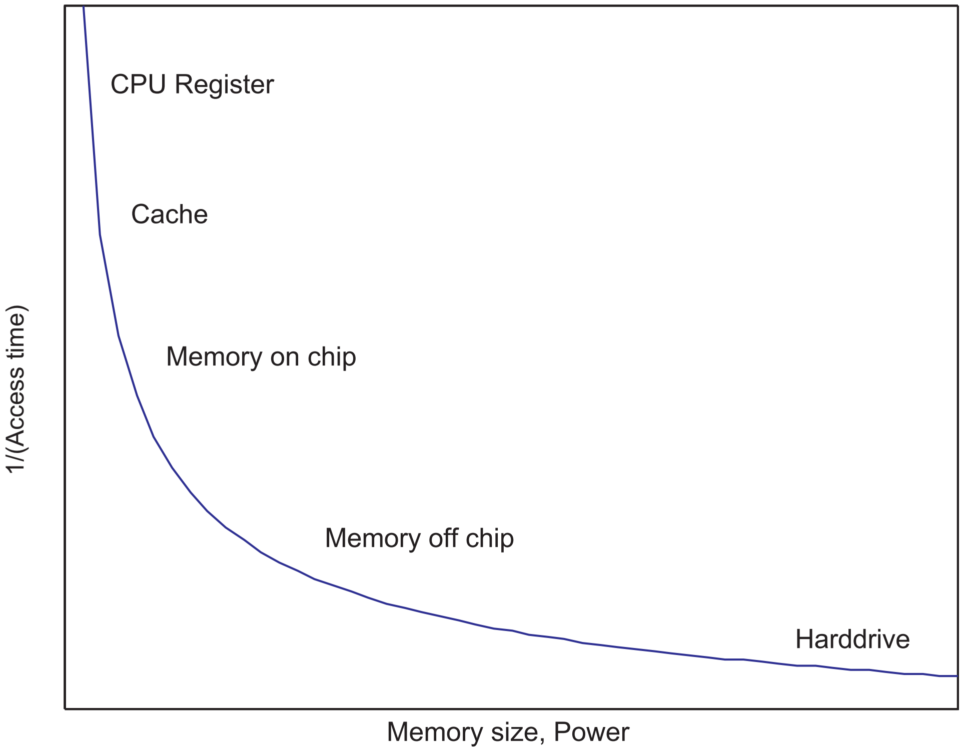

Figure 1. Graph over access time, memory size and power for different memory types.