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Design for low power application and consideration of component selection

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About the Presenter

Graduated from QIT – 1986

Digilin Pty Ltd:

- Graduate Engineer: January 1986 – December 1986
- Engineer: December 1986 – December 1990
- Engineering Manager: December 1990 – February 2003

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- Director: June 2011 –

Outline

- Batteries
- Care with selecting passive components
- Active component selection
- Microcontroller selection
- General guidelines for low power design

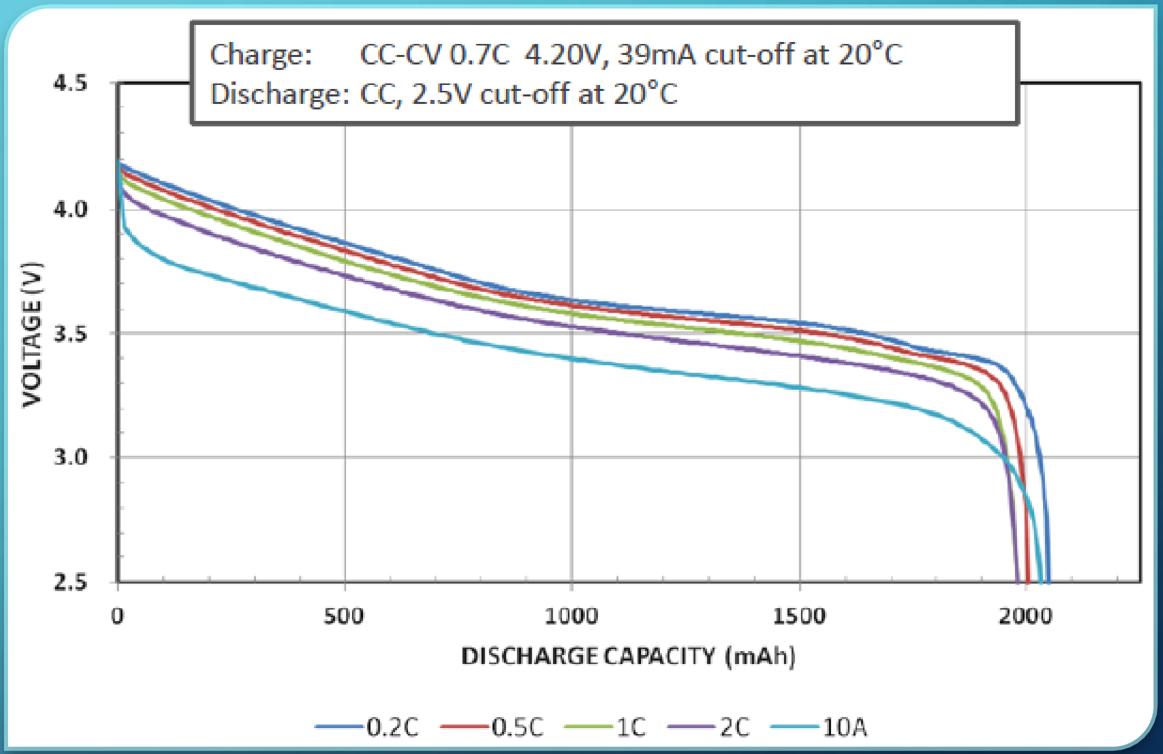
Batteries

- Most low power applications are battery powered
- Battery options are:
  - Rechargeable
    - Li-Ion
    - LiFePO4
  - Primary (non-rechargeable)
    - Alkaline
    - Coin cell
- Considerations
  - Run time
  - Operating voltage
  - Charging / battery replacement

Batteries

LiIon – 18550 cylindrical cell

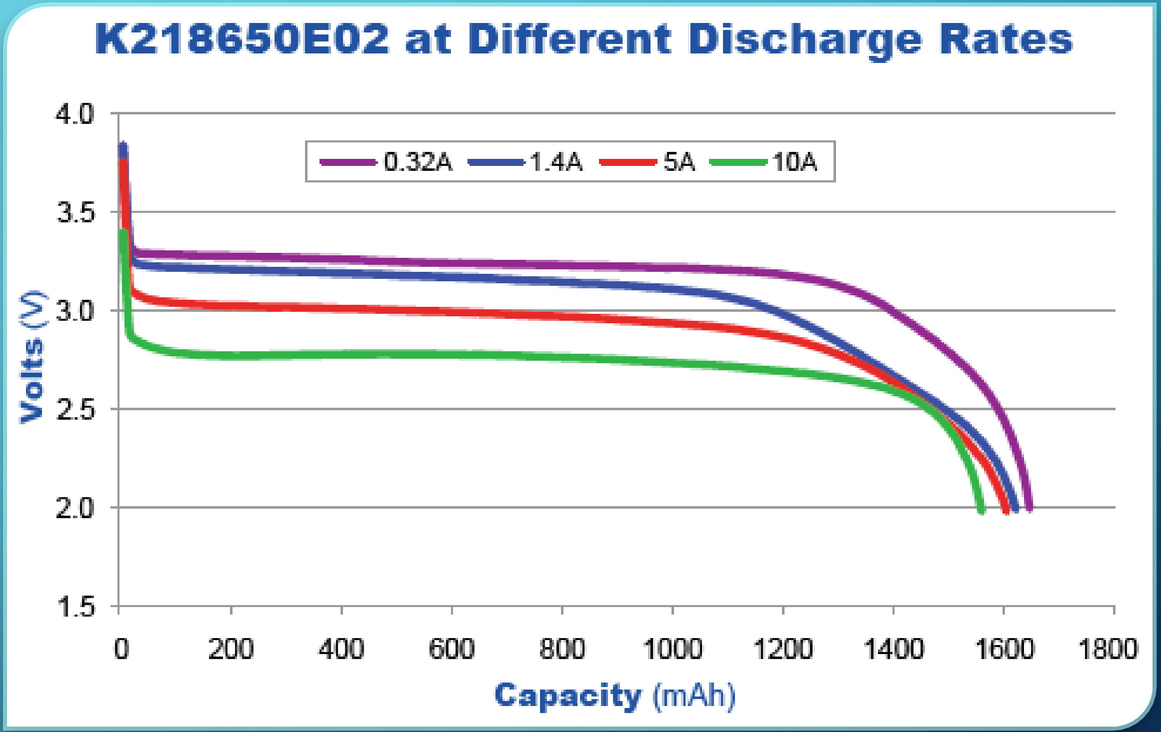
- 4.2Volts charge termination voltage
- Reasonably linear discharge curve
- Sharp cut-off at end of discharge



Batteries

LiFePO4 – 18550 cylindrical cell

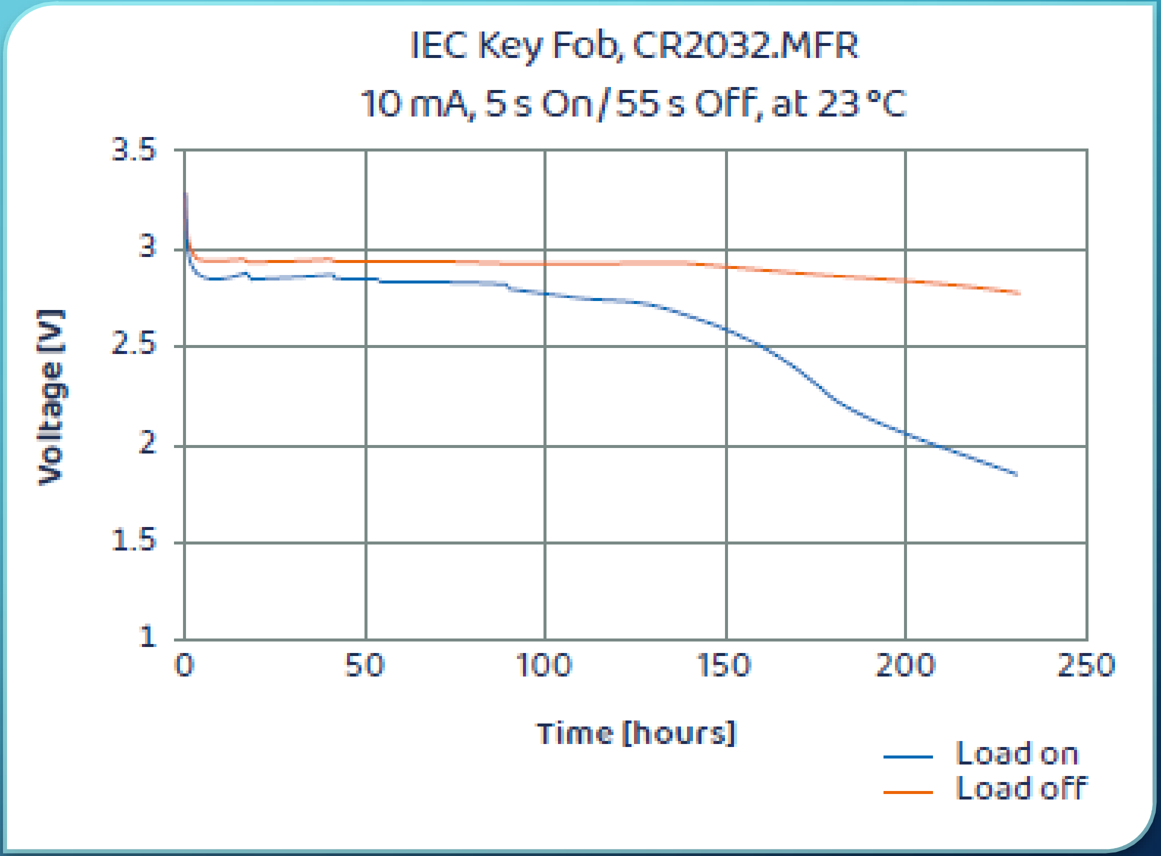
- 3.6Volts charge termination voltage
- Flat discharge curve
- Gradual cut-off at end of discharge
- Final discharge voltage around 2Volts



Batteries

Coin Cell – CR2032 Li / MnO_2

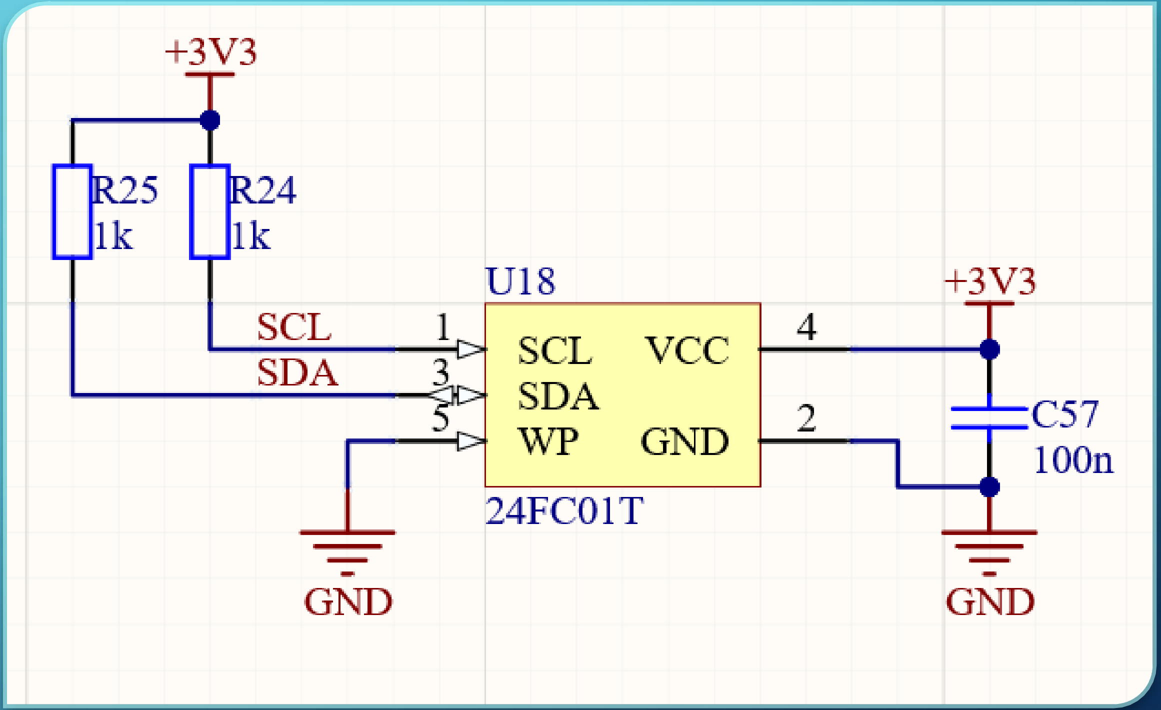
- Nominal 3Volts
- Usable capacity dependent on load
- Be mindful of internal resistance, especially with pulse loads



Passives – Resistors

Remember that every pull-up and pull-down resistor needs to be considered in low power design.

Sometimes, those resistors are "hidden" inside microcontrollers.



Passives – Capacitors

What are the decoupling capacitors doing to your power loss?

Factors that influence leakage:

- Dielectric material
- Case size
- Voltage rating

Dielectric	Typical Leakage at 10uF
C0G / NP0	100-1000 MΩ
X7R	5-100 MΩ
X5R	2-20 MΩ
Y5V / Z5U	0.5-5 MΩ

Passives – Capacitors (continued)

Wurth ceramic capacitors:

885012106006

10uF 6.3Volt X5R 0603

885012209014

10uF 16Volt X7R 1210

Electrical Properties:

Properties		Test conditions	Value	Unit	Tol.
Capacitance	C	0.5 ±0.2 V_{RMS}, 1 kHz ±10 % @ 25 °C	10	µF	±20%
Rated Voltage	V_R		6.3	V (DC)	max.
Dissipation Factor	DF	0.5 ±0.2 V_{RMS}, 1 kHz ±10 % @ 25 °C	15	%	max.
Insulation Resistance	R_{ISO}	Apply V_R for 120 s max.	0.005	GΩ	min.

Electrical Properties:

Properties		Test conditions	Value	Unit	Tol.
Capacitance	C	1 ±0.2 V_{RMS}, 1 kHz ±10% @25 °C	10	µF	±10%
Rated Voltage	V_R		16	V (DC)	max.
Dissipation Factor	DF	1 ±0.2 V_{RMS}, 1 kHz ±10% @25 °C	5	%	max.
Insulation Resistance	R_{ISO}	Apply V_R for 120 s max.	0.1	GΩ	min.

Passives – Capacitors (continued)

Real world example:

- Remote powered by CR2430 coin cell (285mAh)
- 2 x 220uF 6.3Volt X5R 1210 capacitors across battery
  - Design had Capacitor with 450kΩ leakage resistance (225kΩ load)
  - Alternate capacitor had 230kΩ leakage resistance (115kΩ load)
- Battery life reduced by a year!

Passives – Inductors

In switch-mode power supplies, the ESR is just loss.

Consider inductor for nPM1300

- Inductance: 2.2 uH
- DCR: <400 mΩ
- Isat: >350 mA
- Imax: > 200 mA

10 article in 28 product lines for Inductance 2.2 - 2.2 µH ✕ Length 1.6 - 2 mm ✕ Height 0.5 - 1 mm ✕ Reset all

	Order Code	Data-sheet	Simu-lation	Downloads	Status	L (µH)	I_R (A)	I_{SAT} (mA)	$R_{DC\ max.}$ (mΩ)
	74479320165222	SPEC	RE	9 files	New i	2.2 µH	–	–	87 mΩ
	74479276222	SPEC	RE	10 files	Active i	2.2 µH	2.1 A	1800 mA	140 mΩ
	74405020022	SPEC	RE	9 files	Active i	2.2 µH	1.25 A	2150 mA	170 mΩ
	74479275222	SPEC	RE	10 files	Active i	2.2 µH	2 A	1700 mA	190 mΩ
	74479775222A	SPEC	RE	9 files	Active i	2.2 µH	–	700 mA	250 mΩ
	74438343022	SPEC	RE	10 files	Active i	2.2 µH	1.1 A	2500 mA	270 mΩ

Selecting Active Components

Lowest quiescent current is a good starting point, but…

Consider a single NAND gate device running at 3.3Volts

Manufacturer	Part Number	ICC (µA)	Static Power (µWatts)
Onsemi	NC7SZ00	1-2	3.3-6.6
TI	SN74AUP1G00	0.5	1.65

Selecting Active Components

What if the gate has a 10MHz clock running through it?

Manufacturer	Part Number	ICC (µA)	Static Power (µWatts)	Cpd (pF)	Total Power (µWatts)
Onsemi	NC7SZ00	1-2	3.3-6.6	3.5	388
TI	SN74AUP1G00	0.5	1.65	6	655

The Lower the Frequency, the Better … Right?

Reducing the clock frequency gives a linear reduction in power consumption.

Operating voltage is a square term in dynamic part of the power consumption calculations, so lowering the power supply voltage has a much bigger impact.

Manufacturer	Part Number	ICC (µA)	Total Power @ 3.3Volts (µWatts)	Total Power @ 1.8Volts (µWatts)
Onsemi	NC7SZ00	1-2	388	115
TI	SN74AUP1G00	0.5	655	195

Microcontroller Selection

The number of options is vast!!

Things to consider:

- Communications requirements – Bluetooth LE, ZigBee, other RF, infrared
- Operating voltage – LEDs, other hardware, battery selection
- Sleep current
- Active current
- Benchmarking scores: e.g. EEMBC ULPBench Score
- Clock options and configurability
- Hardware features: e.g. asymmetric multi-processing, hardware accelerator

Microcontroller Selection – Sleep Current, Active Current, ULPBench

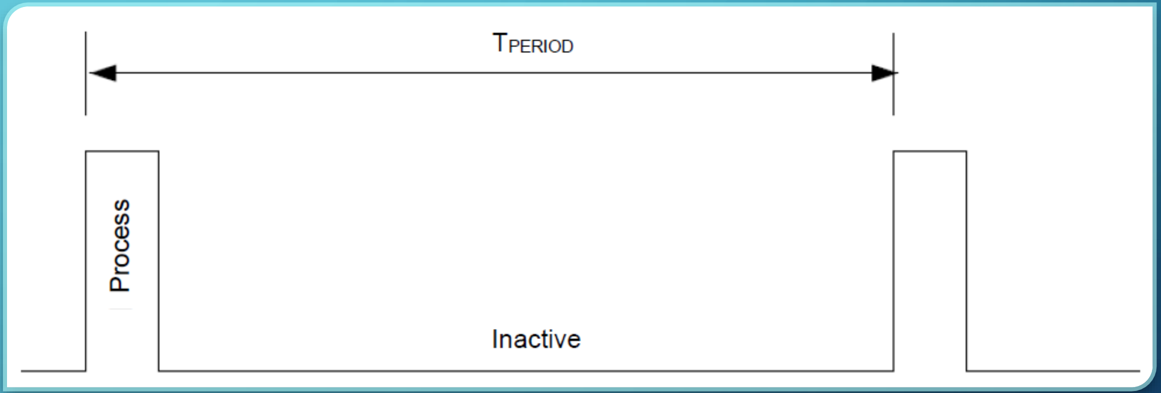
Microcontroller	Sleep Current	Active Current	ULPBenchScore
Renesas RE01	~20 nA	~12-25 µA/MHz	~705
STM32U3	~160 nA	~10 µA/MHz	Not published
Microchip SAM L21	~200 nA	~35 µA/MHz	185
Ambiq Apollo4	<1 µA	~3-6 µA/MHz	>1000
TI MSP430FR series	0.3-1 µA	~8-12 µA/MHz	~121
Silicon Labs EFM32 Gecko	~1.2 µA	~15-25 µA/MHz	~149

Microcontroller Selection – Lowering the Total Power Draw

To keep the overall power draw low, consider cycling the processor from Active mode into a Sleep (low-power) mode.

Things to consider:

- What peripherals must remain active (impacts clock and power domains)
- Real-time requirements (latency)
- Process time
- Cycle period



Microcontroller Selection – Operating Modes

Typical Operating Modes available:

- Run – mAs (everything operating)
- Sleep – <1mA (processor core stopped, everything else operating) – quick to revert to run state
- Stop – 1-100µA (processor core stopped, most clocks stopped, RAM state preserved, potentially lower power supply voltages) – slower to revert to run state
- Standby – <1µA (only RTC running, limited RAM preserved, most/all power supply voltages turn off) – longest time to revert to run state
- Shutdown (maybe RTC running) – revert to run state requires full boot

Microcontroller Selection – Clock Options

Three main oscillator types:

1. High frequency (typically >8MHz) using external crystal
2. Low frequency (typically 32.768kHz) using external watch crystal
3. Internal RC oscillators, can be low frequency (32kHz) or high frequency (MHz range)

Oscillator	Relative Start Up Time	Relative Current Draw
High Frequency Crystal	<10 msec	Medium – high
Low Frequency Crystal	>100 msec	Very low
Internal RC oscillators	10's – 100's µsec (low msec for kHz clocks)	Very low – medium

Microcontroller Selection – Clock Source (latency)

Tips for picking the clock source:

- Accuracy required
- Start-up time
  - In this example, the clock speed and current draw are almost the same, but the HSE clock takes longer to start than the MSI clock. 2msec cf. 4µsec

Table 32. **Current consumption in Run mode on SMPS, Coremark code with data processing running from flash memory, ICACHE ON in 1-way, prefetch ON**

The current consumption from SRAM is similar.

Symbol	Parameter	Conditions			Typ at V_{DD} = 1.8 V				Max at 1.71 V ≤ V_{DD} ≤ 3.6 V(1)(2)				Unit
		Voltage scaling		f_{HCLK} (MHz)	25°C	55°C	85°C	105°C	30°C	55°C	85°C	105°C	
I_{DD} (Run)	Supply current in Run mode	$f_{HCLK} = f_{MSI}$, all peripherals disable, flash memory bank 2 in powered down, all SRAMs enabled	Range 1	96	2.50	2.75	3.45	4.4	3.9	4.7	6.8	11	mA
			Range 2	48	1	1.2	1.75	2.5	1.6	2.1	3.8	6.1	
				24	0.56	0.75	1.3	2.05	1.1	1.6	3.3	5.6	
				12	0.35	0.54	1.05	1.85	0.8	1.3	3.0	5.4	
				6	0.24	0.43	0.96	1.7	0.64	1.2	2.9	5.2	
				3	0.19	0.37	0.9	1.65	0.57	1.1	2.8	5.2	
		$f_{HCLK} = f_{HSI}$, all peripherals disable, flash memory bank 2 in powered down, all SRAMs enabled	Range 2	16	0.58	0.77	1.3	2.1	1.1	1.6	3.3	5.7	
		$f_{HCLK} = f_{HSE}$ bypass mode, all peripherals disable, flash memory bank 2 in powered down, all SRAMs enabled	Range 2	48	1.05	1.25	1.8	2.55	1.6	2.1	3.8	6.2	

STM32U3 for example

Microcontroller Selection – Operating Frequency

Some tips for picking the clock frequency:

- Slowest isn't always best
  - In this example, 25% clock speed (4 times longer to process), but 35% of current

STM32U3 for example

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Microcontroller Selection – Hardware Features

Different manufacturers have added features for low power operation:

- Fine grained power domains to switch off elements not being used
- Asymmetric multi-processing. Eg: Cortex-M0/RISC-V + Cortex M-33
- Energy harvesting system for battery-less operation (Renesas RE01)
- Autonomous peripherals (advanced DMA functionality)
- Machine learning engines

Additional General Points for Low Power Design

In a microcontroller-based design:

- Reduce the supply voltage
- Know what the firmware is actually doing
- Don’t leave any GPIOs floating – driven outputs are a good idea
- Disable power and clocks to any peripherals not being used
- Reduce clock rates to peripherals, as much as possible
- Read the datasheet
- Evaluation boards can be helpful to allow parallel hardware and firmware development

Summary

There are many things to consider with low power design.

- If your system is battery powered, understand the characteristics of the battery
- Passive components should not be overlooked
- Quiescent current is important, but so is the power draw when switching
- Remember the oscillator start up time when cycling between Active and Sleep modes
- Microcontroller options are plentiful
- If it is not being used, disable it
- Start firmware development as soon as possible

Thank you!