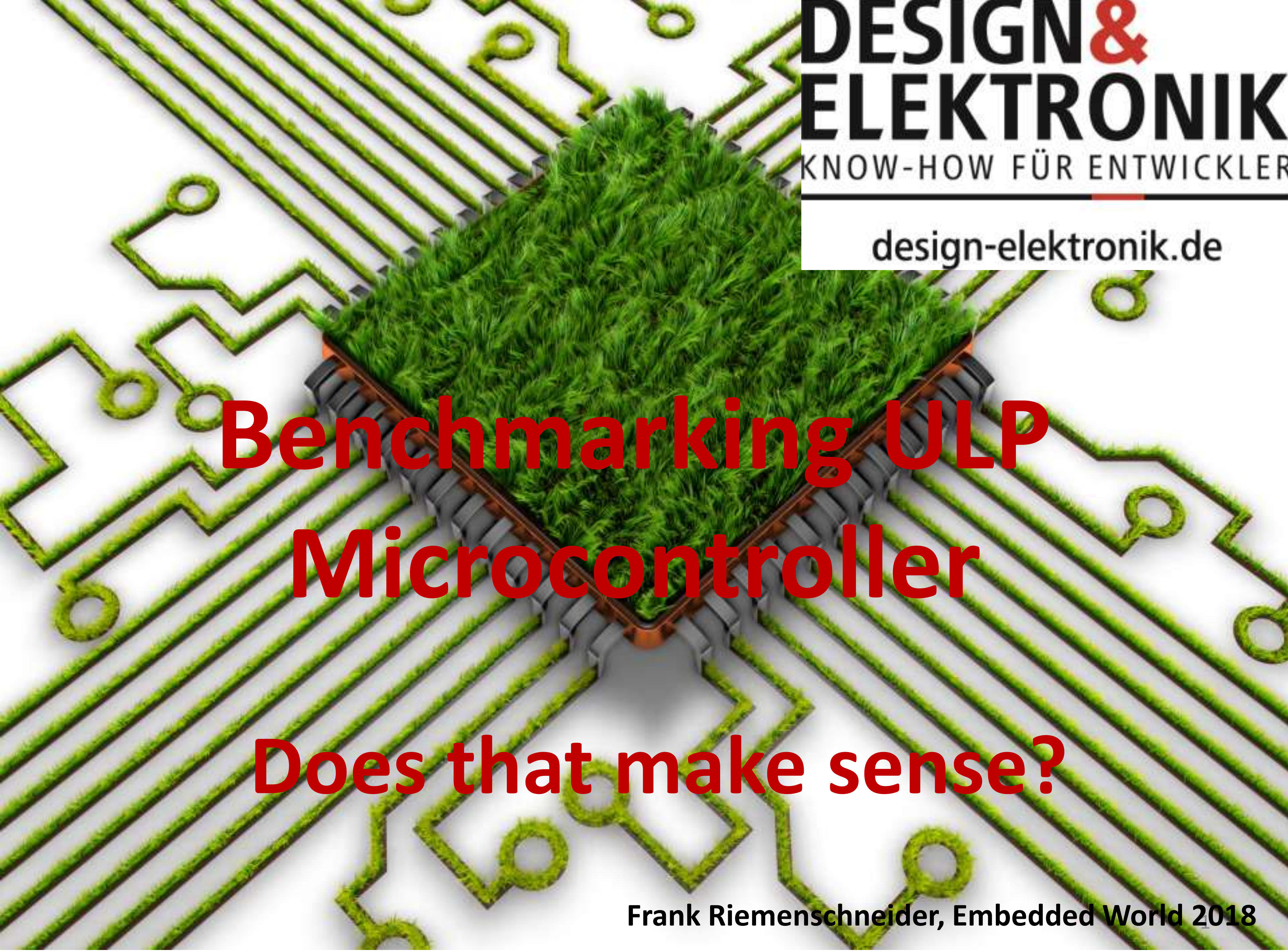

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Benchmarking ULP Microcontroller

Does that make sense?

Frank Riemenschneider, Embedded World 2018

The „Nerd magazine for embedded developers“ provides technical content only

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- Unique: Editorial stuff technicans only (Ph.D./M.Sc. in Physics, M.Sc./B.Sc. In electrical engineering)
- Unique: Operating own test lab equipped with leading edge measurement tools
- Unique: Organizer of embedded world Conference
- Unique: Performed successful market studies e.g. embedded systems study 2017
- Unique: Performed unique deep technical talks with industry experts
- Unique: Attending the wordwide most relevant exhibitons and conferences and invited to developer conferences of worlds leading semiconductor- and IP-suppliers.

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Please check out:

- Image movie provides information regarding target audiences, differentiation from competition:

  http://www.elektroniknet.de/video/design-amp-elektronik-das-nerd-magazin-fuer-entwickler-stellt-sich-vor-1310-video.html?pth=ibx

- Very technical focussed DESIGN&ELEKTRONIK newsletters are different from other newsletters (please register here):

  http://classic.elektroniknet.de/newsletter/

This presentation is focussed on the most widespread benchmarks for microcontrollers provided by Embedded Microprocessor Benchmark Consortium (EEMBC)

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- EEMBC ULPBench (early 2014, rebranded to ULPMark-CP in late 2017)
- EEMBC ULPMark-PP (late 2017, BLE version not ready yet)
- Scores measured by DESIGN&ELEKTRONIK (due to missing officially published scores and/or limited EEMBC hardware)

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EEMBC

Embedded Microprocessor Benchmark Consortium

ULPBench

- Measures CPU and memory subsystem
- Low cost energy monitor developed by TI
- Fixed V_{dd} (3.0 V)
- Fixed clock frequency (by vendor)
- Fixed temperature (by vendor)

ULPBench scores for selected MCUs (published in 2016)

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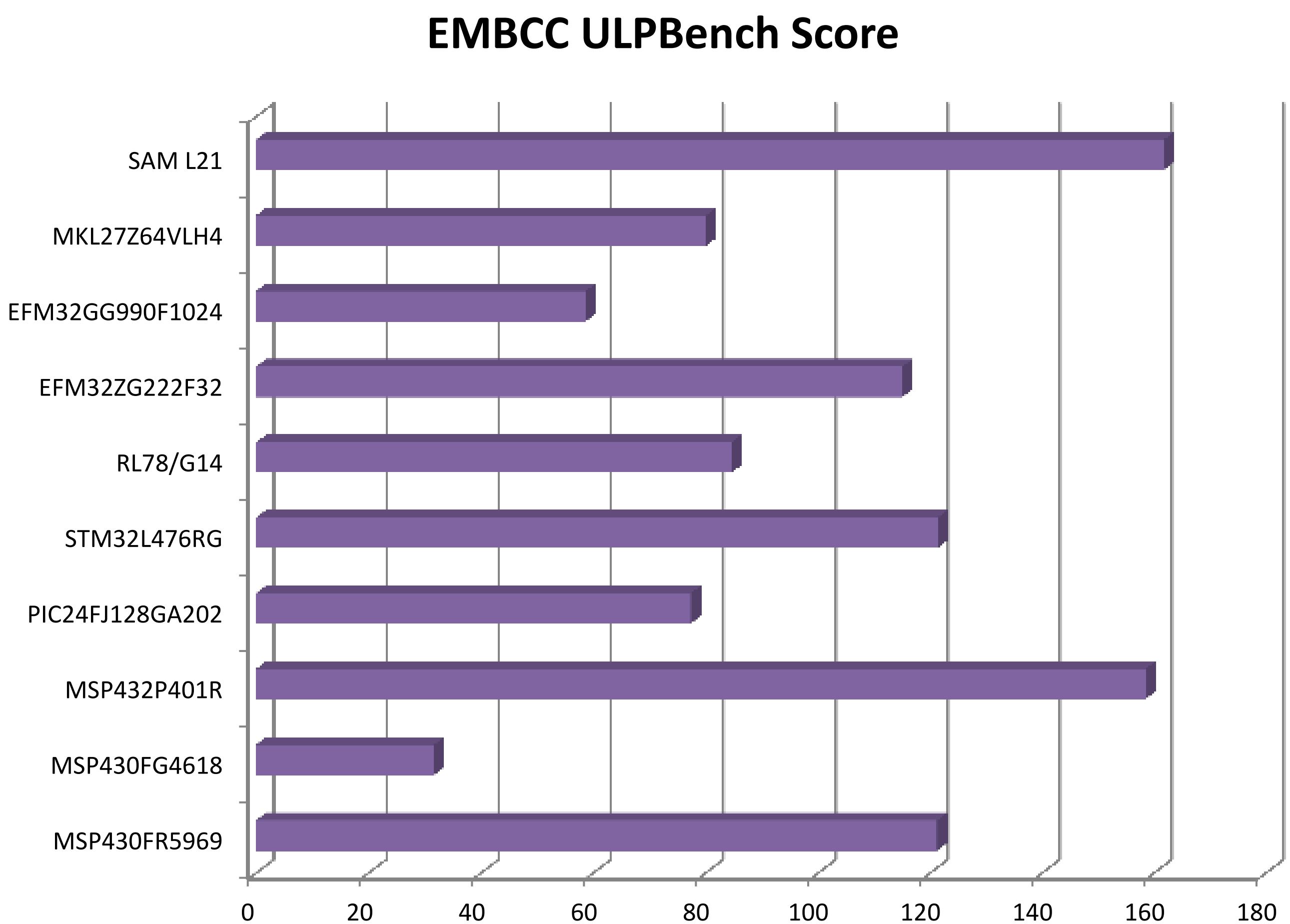

Weaknesses of ULPBench

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- No peripherals measured
- V_{DD} below 3.0 V in many ULP applications starting with 1.8 V
- Temperature in real ULP applications higher than 25°C in many cases (e.g. smart meter 50-60 °C)
- Devices operated in different frequency ranges in reality

Own measurements Example 1:

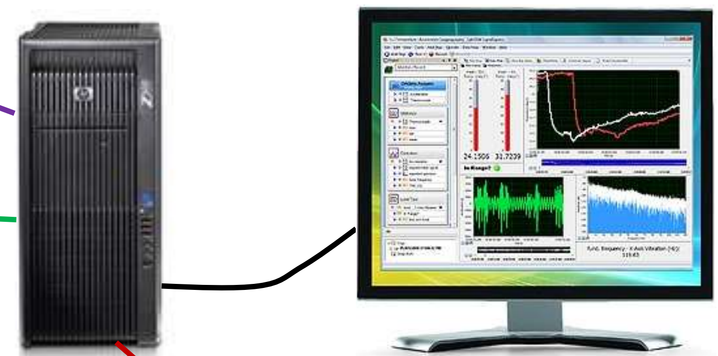
Measurement at different V_{DD}

Device Under Test

USB

NI USB 6353

USB



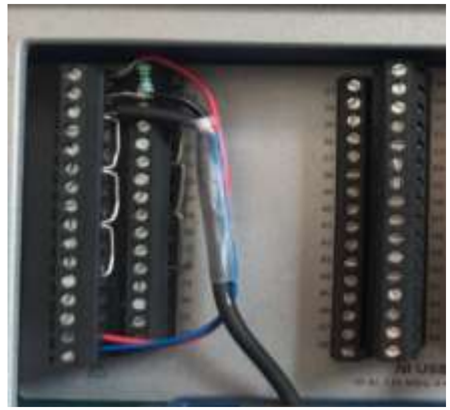
Start/Stop test.
Consolidate data (Statistic post processing)
Display data

Configure acquisition, get samples (max 1Msample/s)

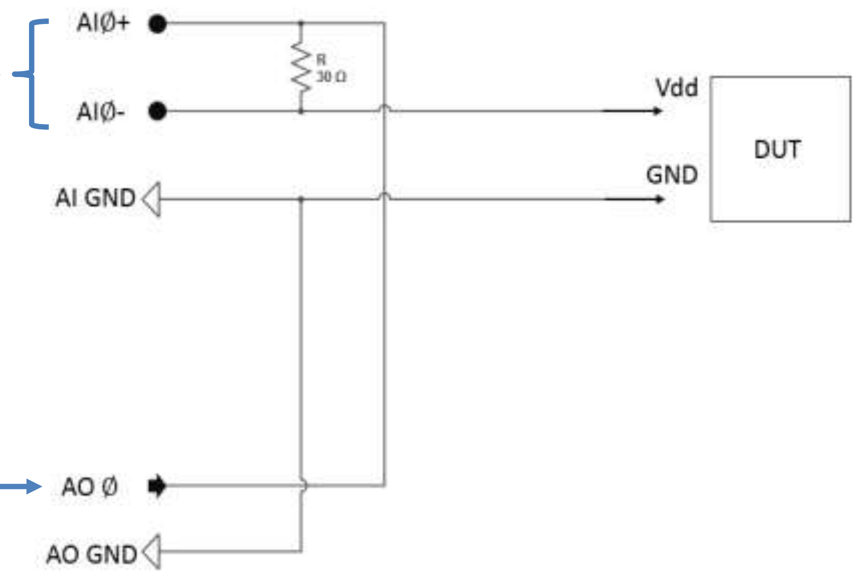
Same 2 wires connections (V_{dd}, Gnd) as the EEBMC Energy Monitor

Own measurements Example 1:

Measurement at different V_{DD}



Current measurement
(+-100 mV 16 bit ADC up to 1 Msps)



V_{dd} supply 1.8 – 3.0 V
(16 bit DAC)

ULPBench Scores
V_{DD}= 1.8 V...3.0 V
(published in early 2017)

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V_{DD} (V)		3,0	2,9	2,8	2,7	2,6	2,5	2,4	2,3	2,2	2,1	2,0	1,9	1,8
STM32L433		172,58	180,54	188,44	198,01	208,42	217,35	229,34	242,14	254,97	270,26	287,25	305,97	325,78
STM32L476		149,48	156,87	164,72	172,42	181,03	188,82	199,23	209,81	223,32	234,01	246,85	261,45	280,15
SAM21L21	Rev A	147,08	155,30	163,00	168,57	174,90	180,16	186,21	196,25	202,28	211,46	220,41	229,81	240,11
STM32L0		129,99	135,74	140,92	147,47	154,84	161,04	167,41	175,93	184,55	192,99	203,35	214,75	226,67
SAM21L21	Rev B LPEFF Off	127,00	136,00	142,24	148,49	154,88	161,71	167,20	172,78	180,89	189,28	199,71	207,31	215,79
MSP432	LDO	117,88	124,17	128,40	134,88	140,59	147,09	154,45	161,41	169,42	178,64	188,03	197,58	208,82
Kinetis KL27		79,77	83,27	84,30	87,97	92,30	96,41	100,43	104,78	108,82	113,94	119,97	126,09	133,56
MSP430FR5969		120,50	125,17	129,96	135,25	140,73	146,50	152,89	159,41	167,06	175,17	184,07	194,32	n.A.
PIC24FJ64GA202		70,84	73,93	77,42	80,56	83,70	87,18	90,84	95,11	99,69	104,15	110,39	121,84	n.A.
SAM21L21	Rev B LPEFF On	137,33	142,68	151,43	154,00	158,41	167,06	170,95	178,39	183,21	187,16	186,01	n.A.	n.A.
EFM32 ZeroGecko		98,01	103,63	108,65	113,99	118,49	124,19	129,99	136,51	142,59	149,79	157,06	n.A.	n.A.
EFM32GiantGecko		58,68	61,55	64,33	67,02	70,01	73,46	76,91	80,42	84,51	88,73	94,14	n.A.	n.A.
MSP430FG4618		32,00	34,00	36,00	37,60	40,00	42,00	45,00	48,00	50,00	53,00	57,50	n.A.	n.A.
Apollo		329,92	339,30	354,95	367,05	382,94	395,18	410,63	436,62	459,51	472,42	n.A.	n.A.	n.A.
EFM32PearlGecko		106,25	110,44	112,29	113,51	114,85	115,82	115,63	119,31	122,33	127,06	n.A.	n.A.	n.A.
EFM32 WonderGecko		74,59	79,21	82,91	86,44	90,01	94,02	98,27	102,81	107,80	113,42	n.A.	n.A.	n.A.
MSP432	DC/DC	153,99	161,97	166,60	171,85	178,00	183,00	190,11	193,05	199,68	n.A.	n.A.	n.A.	n.A.

Own measurements Example 2:

Measurement at different temperatures

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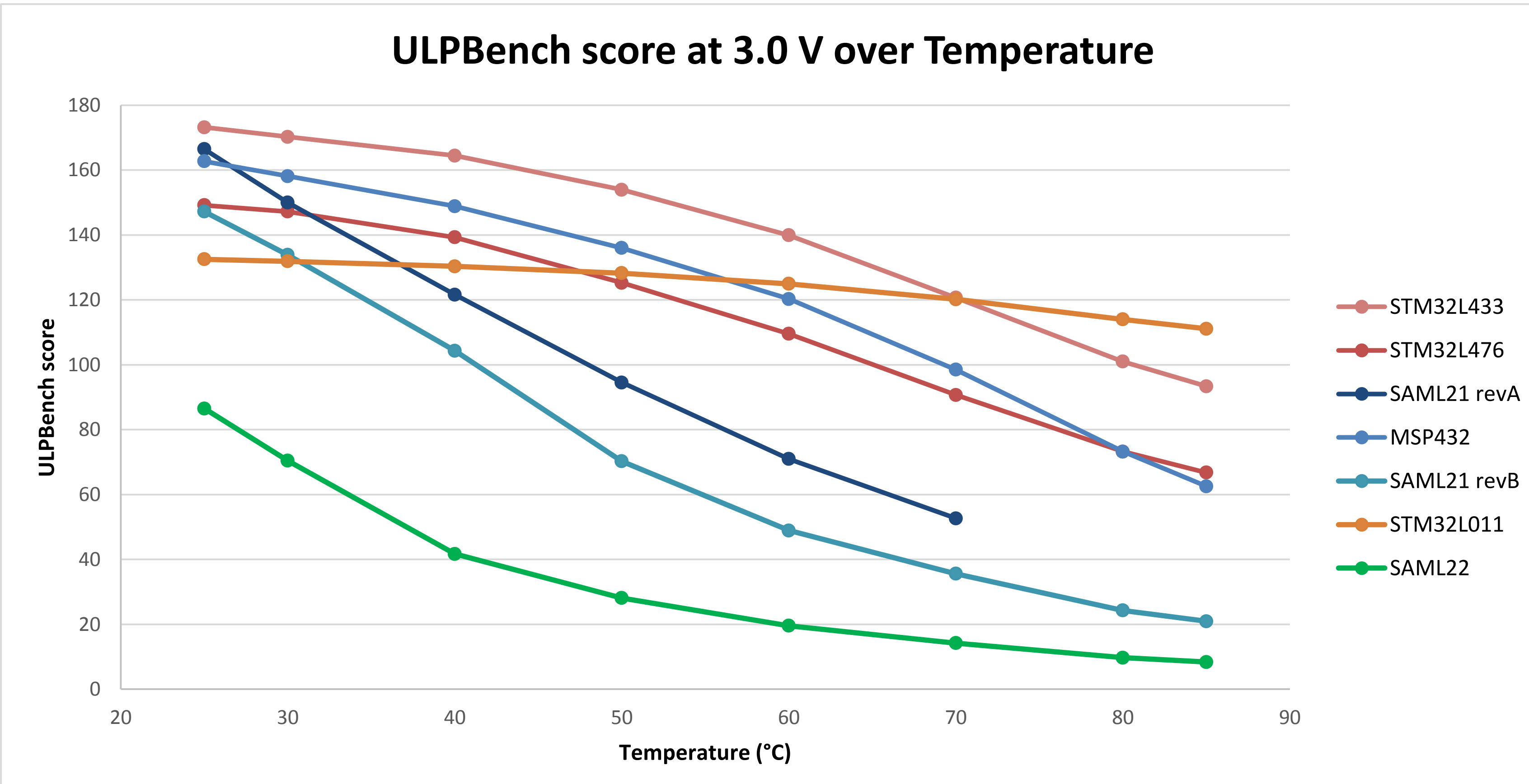

Own measurements Example 2:

Measurement at different temperatures

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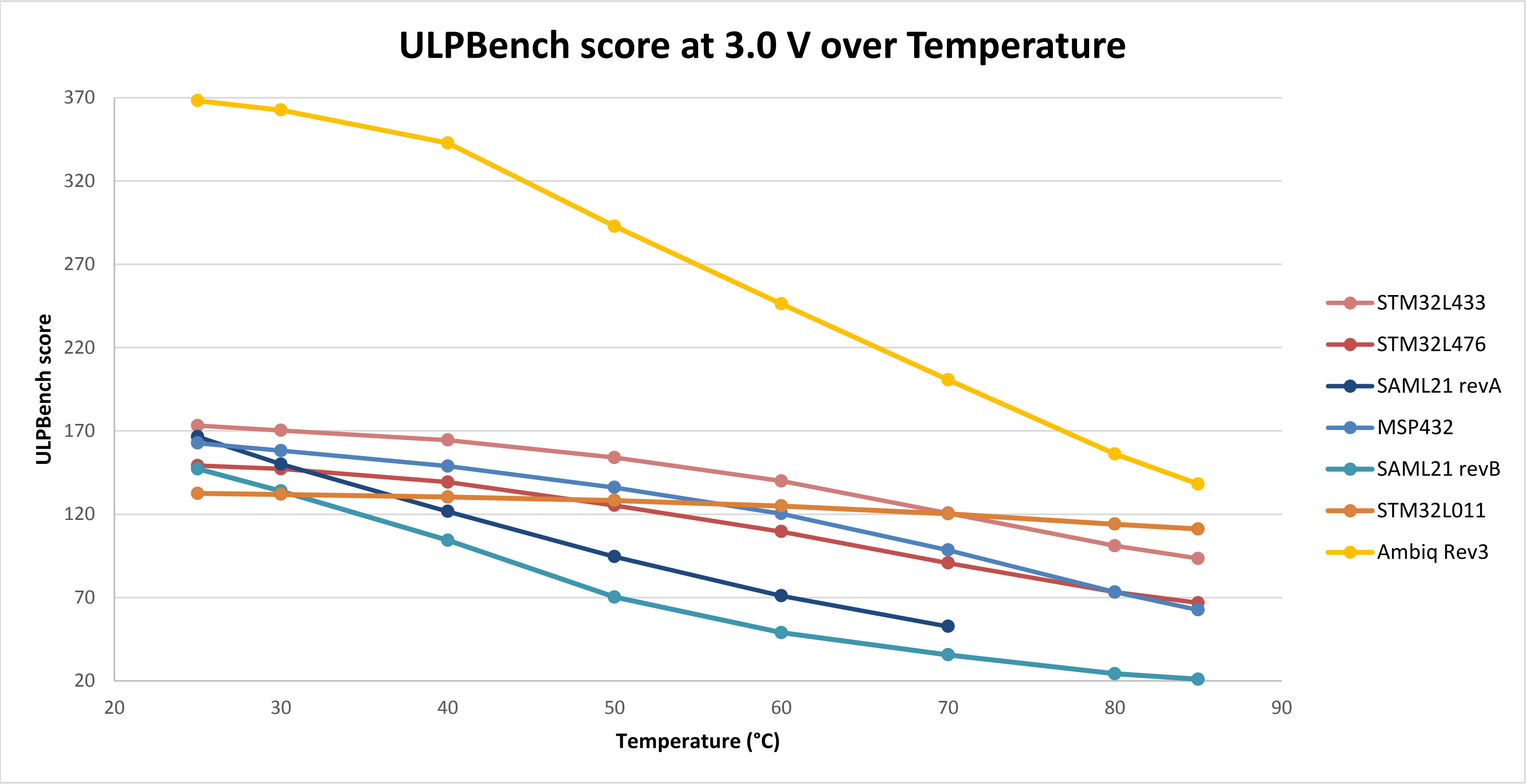

Own measurements Example 2:

Measurement at different temperatures

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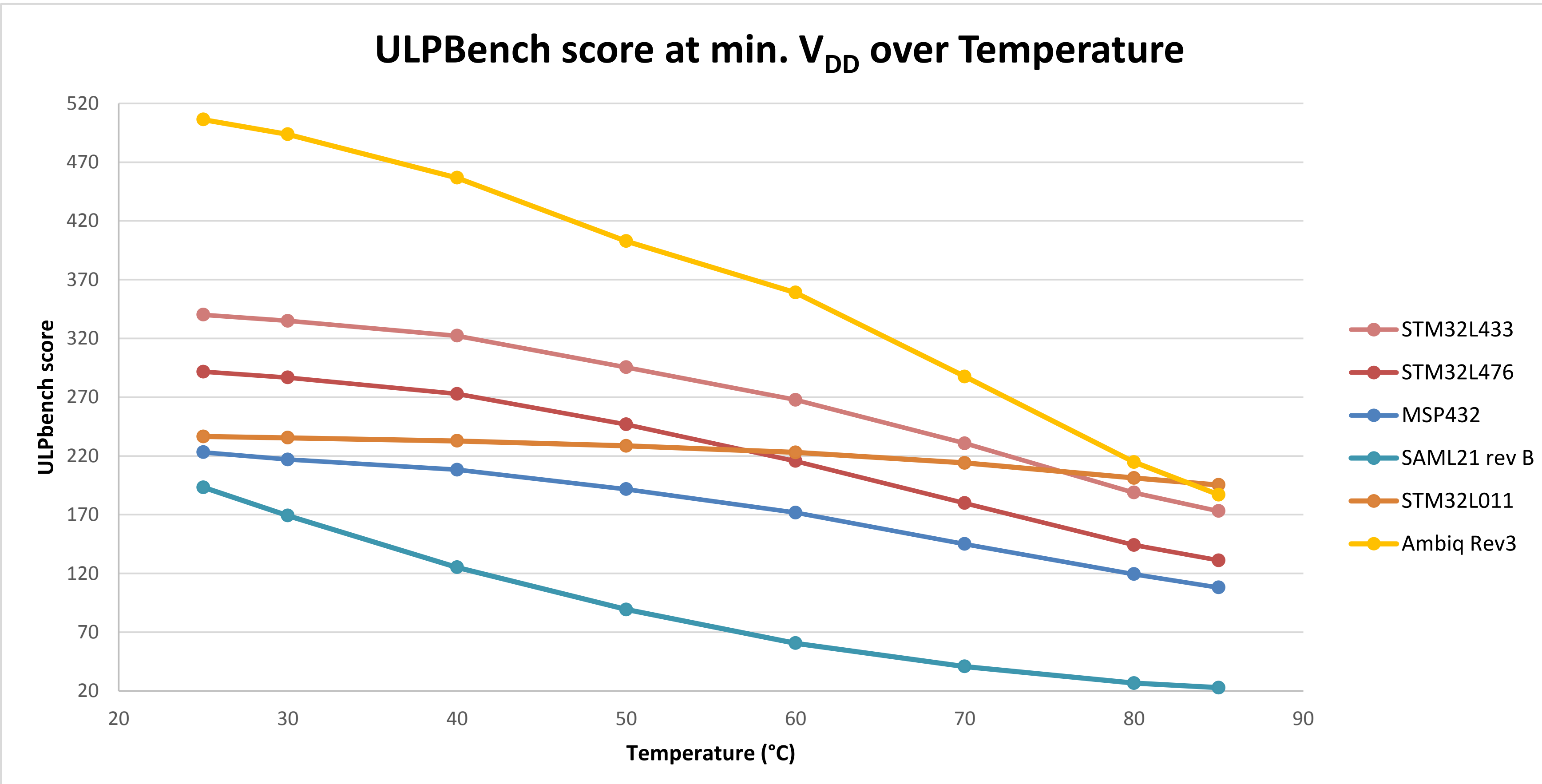

Own measurements Example 3:

Measurement at different clock frequencies

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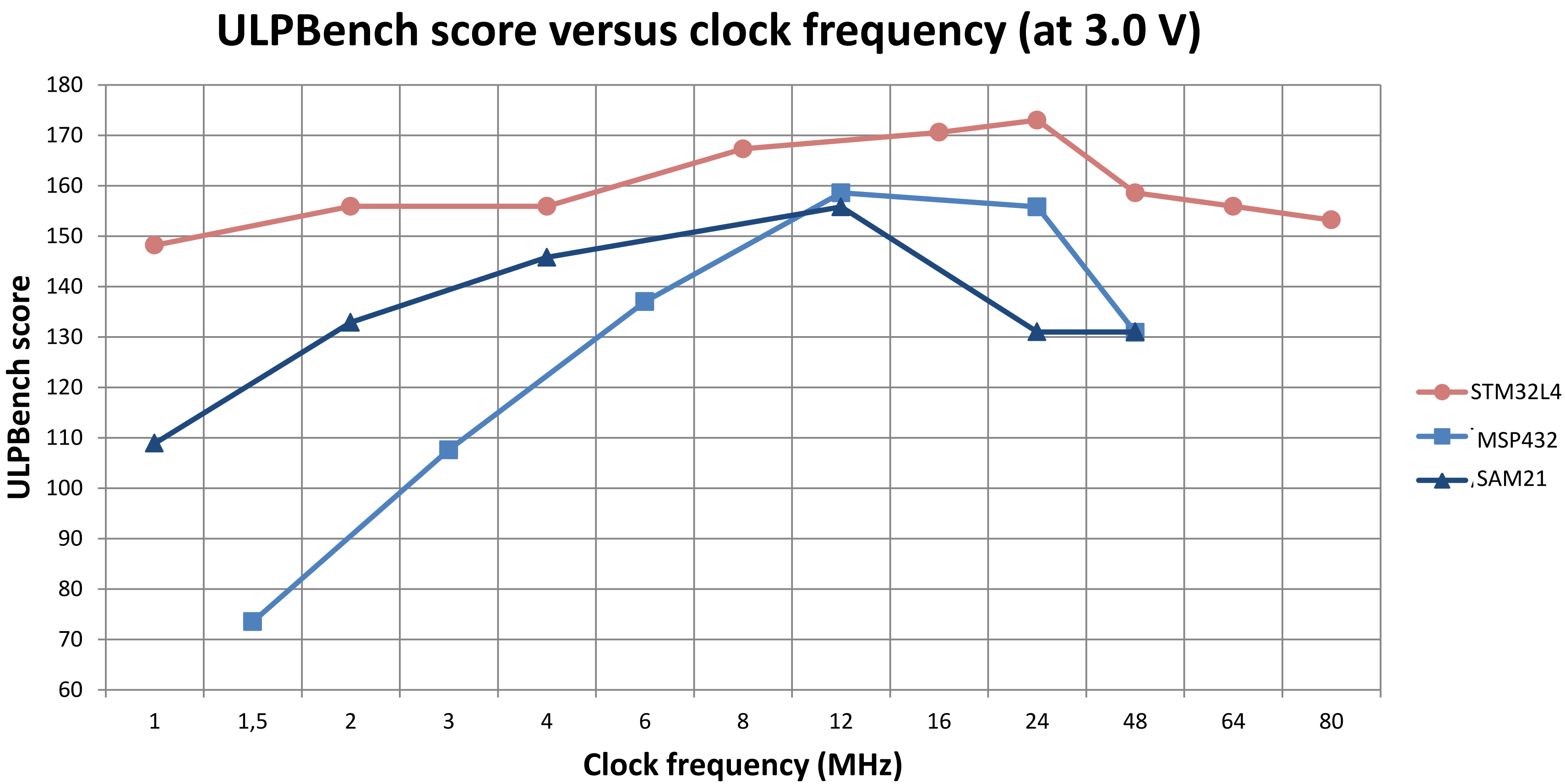

Own measurements Example 3:

Measurement at different clock frequencies

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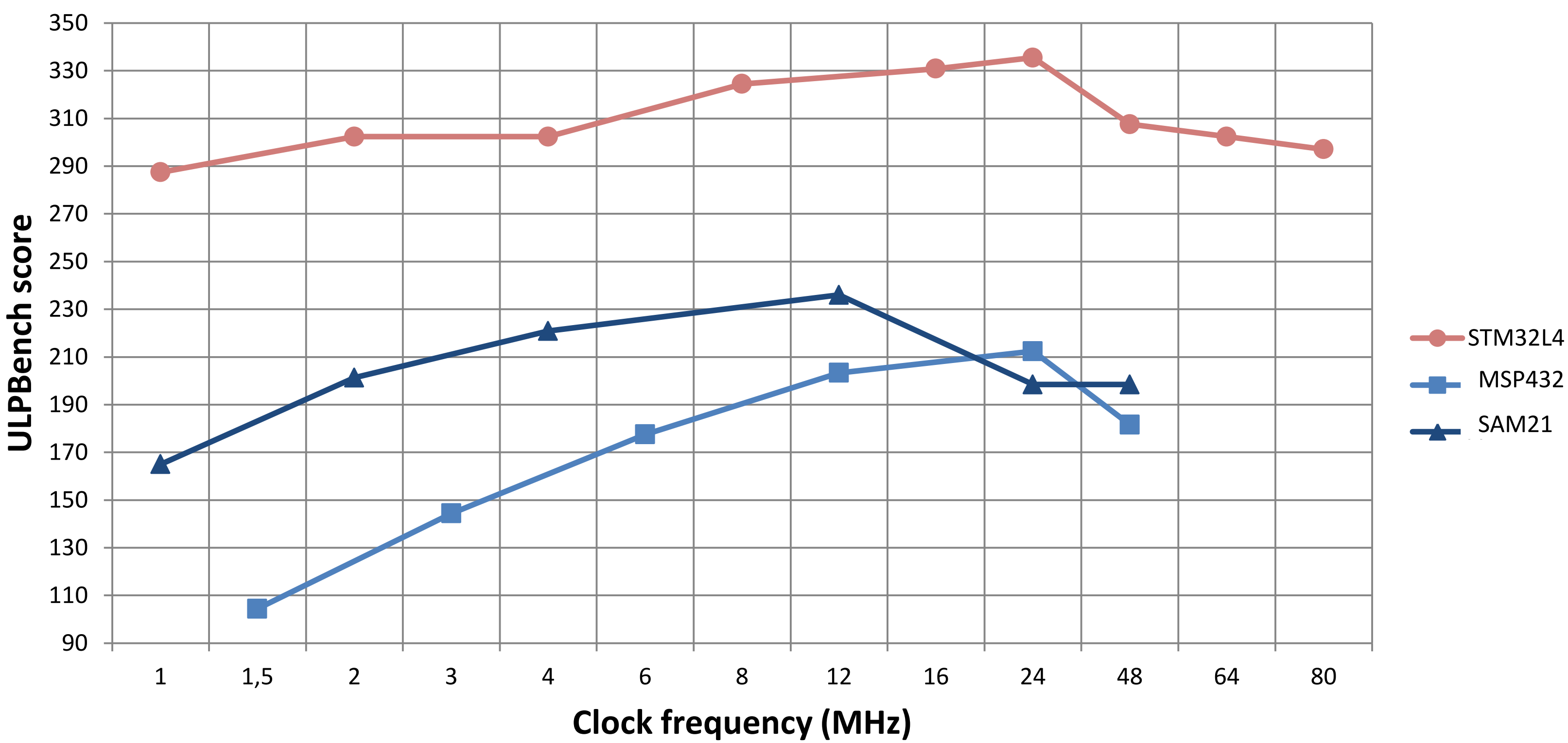
ULPBench score versus clock frequency (at 1.8 V)



Conclusion ULPBench (ULPMark-CP)

- ULPBench may give the developer a first idea, but provides no real value concerning MCU power consumption in a specific embedded application.

- Specially missing peripheral integration and the fixed operating point (V_{DD}, clock frequency, temperature) limit meaningfulness.

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ULPMark-PP

- Measures CPU, memory subsystem and some peripherals
- Power Shield developed by ST (see next slide)
- Flexible V_{dd}
- Still fixed clock frequency (by vendor)
- Still fixed temperature (by vendor)

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Much more sophisticated measurement tool used for ULPMark

Official EEMBC EnergyMonitor 2.0:

So called ST Power Shield

- Power board to measure from 3.3 V down to 1.8 V
- Measure a wide range of dynamic current 100nA ~ 50mA
- Measure a wide range of static current 1nA ~ 200mA
- Precision in the range of ~ 2 %
- Based on STM32L496VGT6
  - 3x 12-bit ADC @ 5Msamples/sec
  - MCU running @ 80MHz
  - Dynamic acquisition rate @ 761 ksamples/sec

How does ULPMark work?

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- 10 steps (slots) with a spacing of one second each.
- A slot represents a specific task in which several peripheral units are involved.
- After each slot, triggered by an RTC trigger signal, the CPU is put into sleep mode while the peripheral blocks perform their programmed task.
- The result of the test is a total score, which corresponds to a weighted combination of the individual results from the ten steps.

How does ULPMark work?

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- 10 steps of 1 s each
  - Step#1 = x**64 b**ytes ADC acquisition (1 kHz) + **20** pulses PWM 32 kHz (**fix** duty cycle) + RTC
  - Step#2 = x**64 b**ytes ADC acquisition (1 kHz) + **40** pulses PWM 32 kHz (**up** duty cycle) + RTC
  - Step#3 = x**1 b**yte ADC acquisition + **40** pulses PWM 32 kHz (**fix** duty cycle) + RTC
  - Step#4 = x**1 b**yte ADC acquisition + x**64 b**ytes SPI (sent & receive) + **100** pulses PWM 32 kHz (**fix** duty cycle) + RTC
  - Step#5 = x**1 b**yte ADC acquisition + x**64 b**ytes SPI (sent & receive + **check** previous slot data) + **100** pulses PWM 32 kHz (**fix** duty cycle) + RTC
  - Step#6-7-8 = Step#5
  - Step#9 = x**1 b**yte ADC acquisition + x**64 b**ytes SPI (sent & receive + **check** previous slot data) + **30** pulses PWM 1 MHz (**up** duty cycle) + RTC
  - Step#10 = **check** previous slot ADC data (slot #3 to #9) + **check** previous slot SPI data + RTC (**check** and **stop**)

Porting EEMBC Code sounds simple, but is challenging without vendor support

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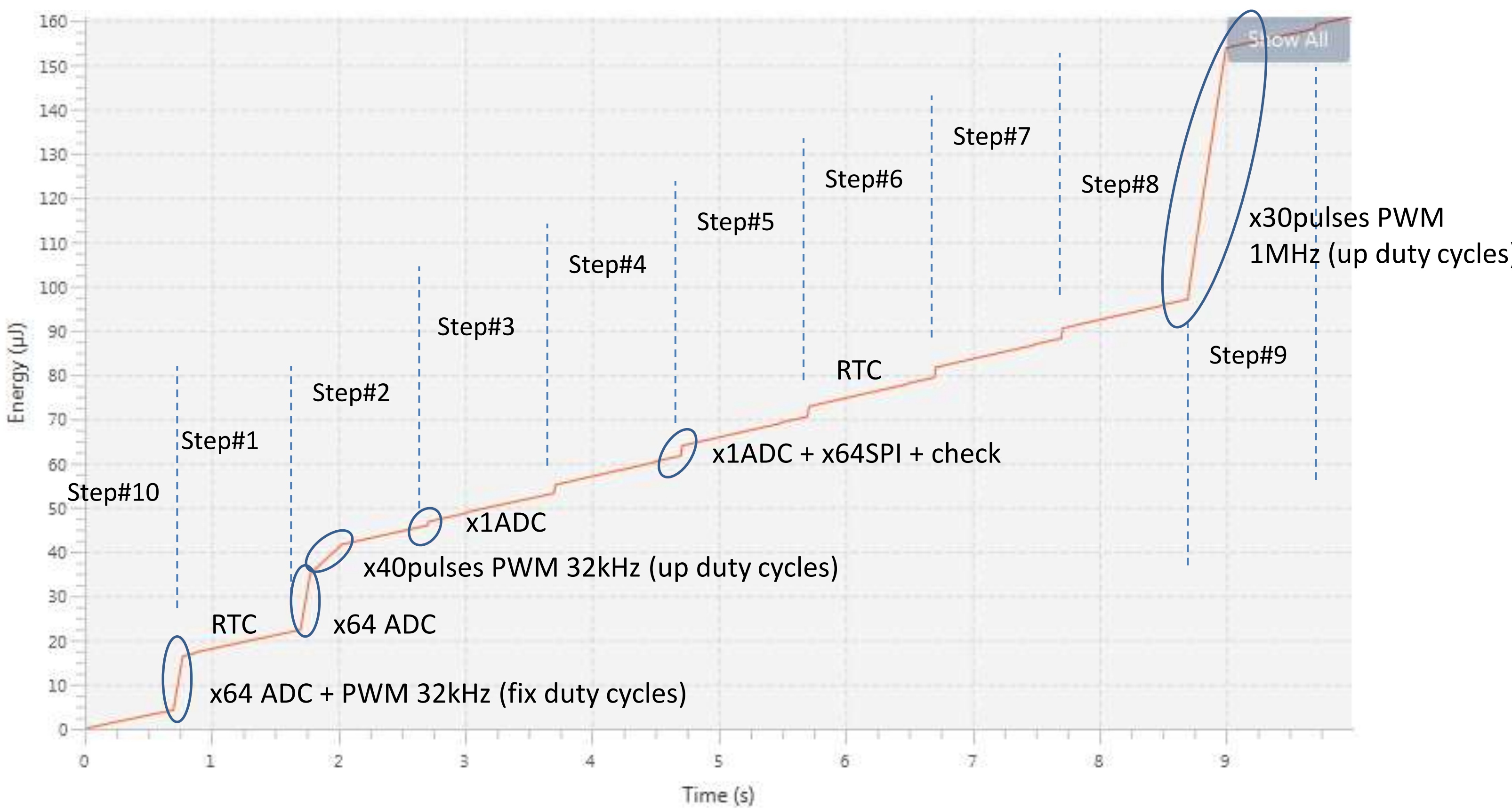
1. Create a new project.
2. Import benchmark from EEMBC.
3. Add include paths for the compiler.
4. Carry out porting:
   a. board.h: Definitions for the clock frequency and the ADU.
   b. hardware_setup.c: Clock settings, definition of pin assignment and deactivation of unused peripherals.
   c. Platform.c: Sleep function for low-power mode.
   d. Platform_ADC.c
   e. Platform_PWM.c
   f. Platform_RTC.c
   g. Platform_SPI.c
5. Build and Start (Compile, Link, Start).
6. Controller reset.
7. Benchmark is executed.

Failed @ NXP, Renesas and Microchip.

Example ULPMark-PP STM32L4



ULPMark-PP scores for selected MCUs (3.0 V, 25°C)

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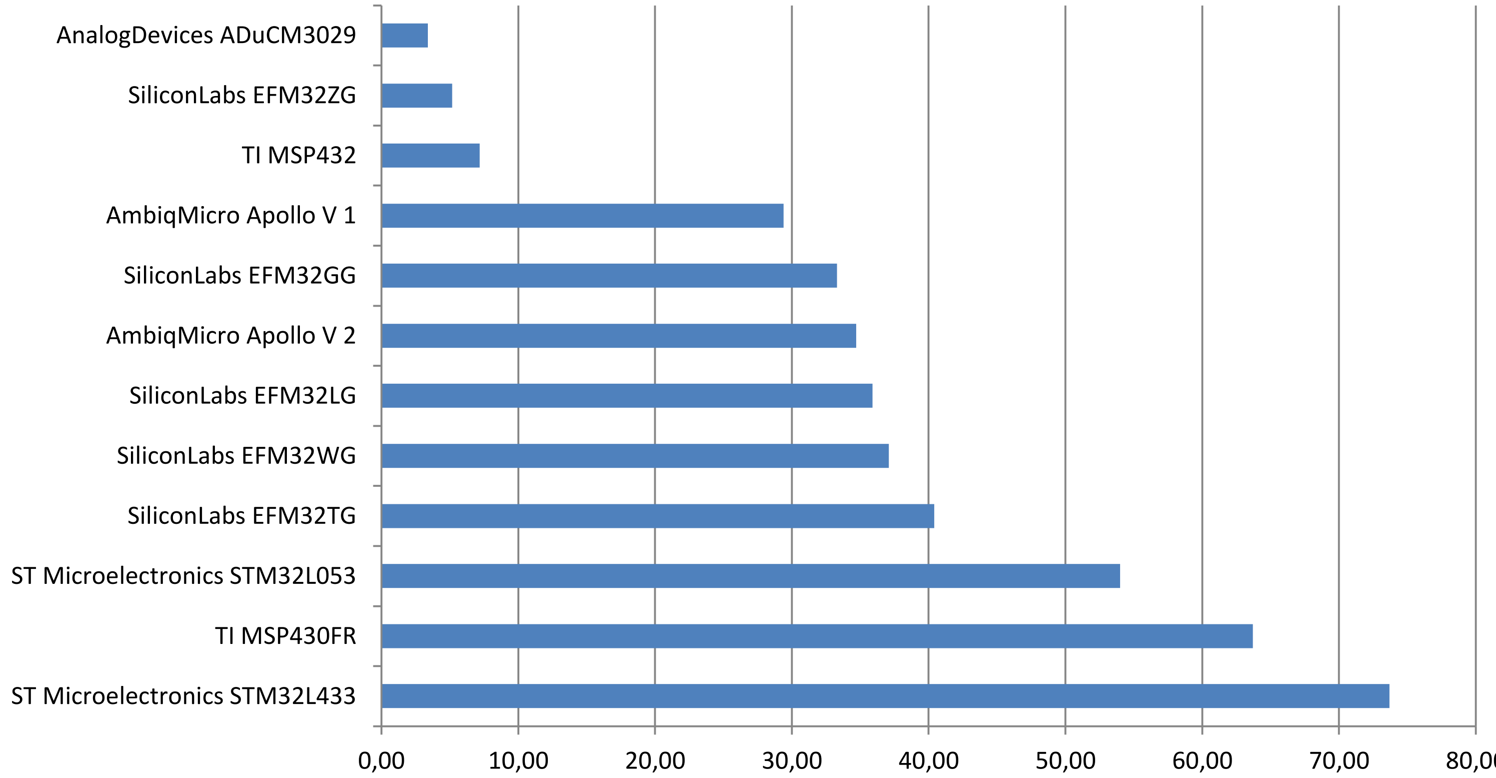

„Surprising“ result 1:

While MSP430FR was easily beaten by STM32L4 using ULPBench, the device is performing much better @ ULPMark PP

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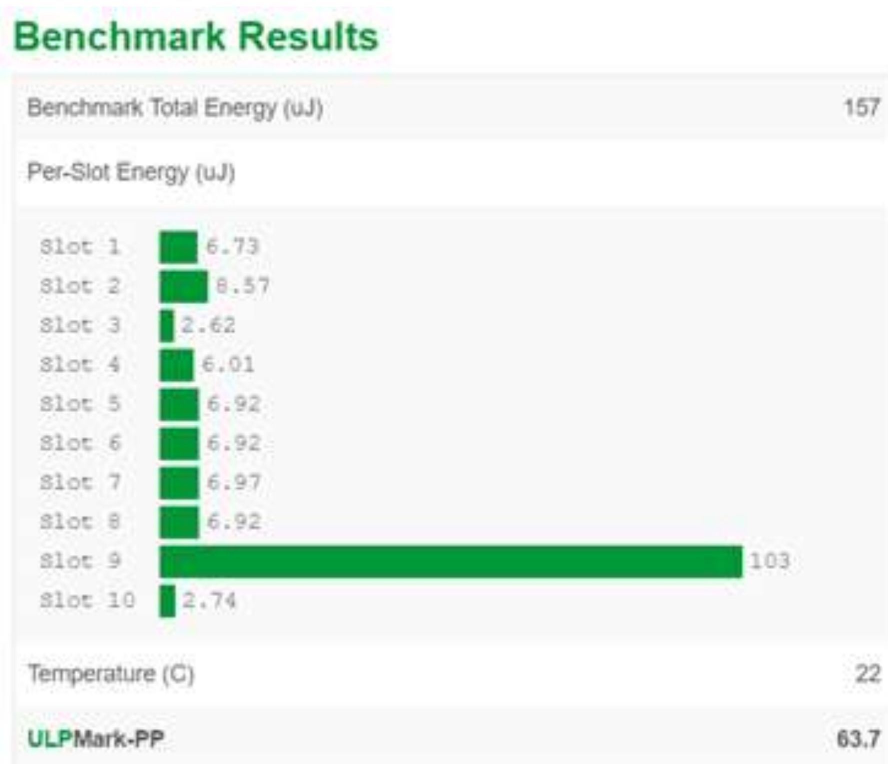

Benchmark Results

Benchmark Total Energy (uJ)	157
Per-Slot Energy (uJ)	
Slot 1	6.73
Slot 2	8.57
Slot 3	2.62
Slot 4	6.01
Slot 5	6.92
Slot 6	6.92
Slot 7	6.97
Slot 8	6.92
Slot 9	103
Slot 10	2.74
Temperature (C)	22
ULPMark-PP	63.7

TI MSP430FR ULPMark = **63.7**

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MSP430FR performs very well at ULPMark Steps 1-8/10, but poor at Step 9 – why???

Only the TI MCU can execute A/D conversion at a 32 kHz capture rate in stop mode, for which reason power consumption in the particular steps is substantially below that of the ARM controllers.

If the relatively weak 16-bit CPU has to be activated (step 9) because of the high capture rate, the result is immediately much poorer than for the faster 32-bit Cortex CPUs.

„Surprising“ Result 2:

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The sub-threshold-MCU Apollo is clearly leading ULPBench, but really terrible performing @ ULPMark

Step 1: 28,6 µJ = almost doubling energy consumed by competing ARM-based devices

- Ambiq Micro has not implemented DMA transfer - for the A/D converter you only find an 8-byte FIFO buffer
- After eight data captures the CPU is woken up, and must transfer data into SRAM (e.g. in STM32L devices this procedure is found in the operating modes LPSleep (A/D converter operation) and LPRUN (evaluate data))

Step 9: 210 µJ = tripling to quadrupling energy consumed by other ARM-based devices

- Apollo again has to be woken up into active mode every time
- Competing devices can remain in low power modes (e.g. STM32L4 in LPRUN mode)

Really bad peripheral-IP:

- SPI-IP consumes on average two to four times as much power as competing devices
- PWM is also much more power hungry than competing devices
- RTC-IP in opposite is pretty good → great ULPBench score

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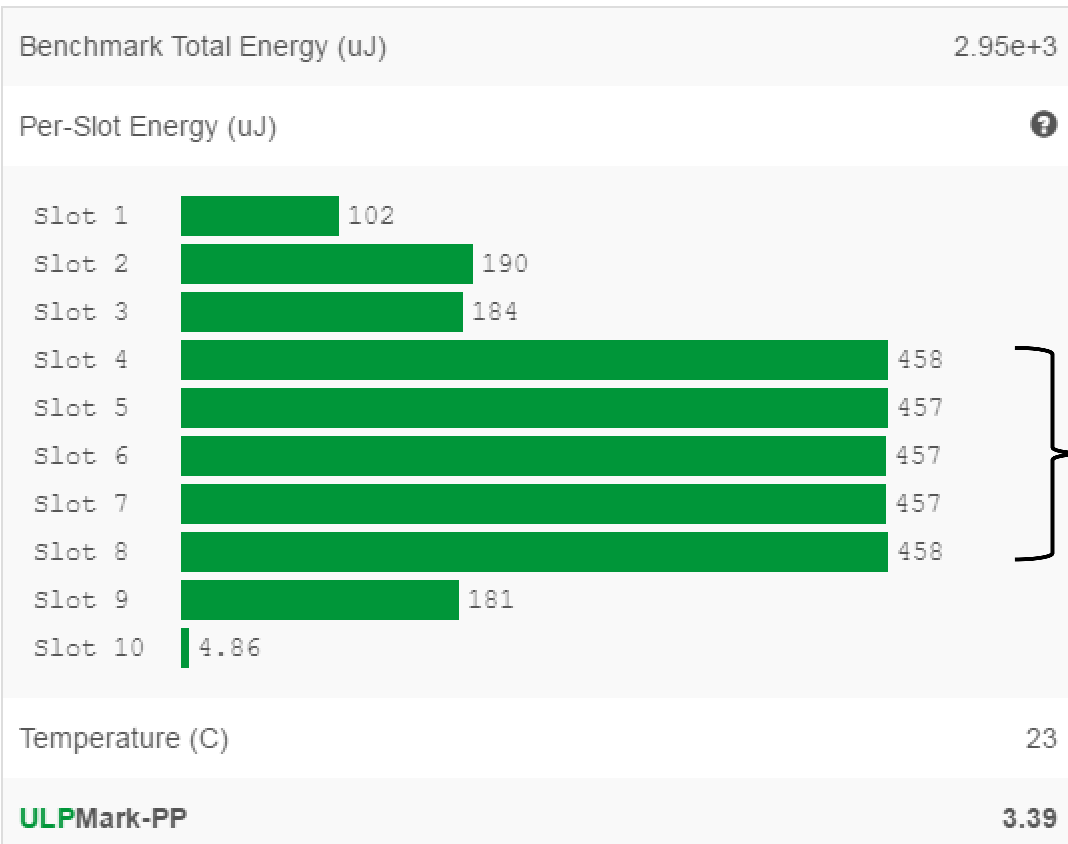
„Surprising“ Result 3:

AnalogDevices ADuCM3029

shows very poor performance in comparison

to other ARM Cortex-M-based MCUs



100 pulses PWM 32 kHz (**fix** duty cycle)

→ Missing low power mode for autonomous PWM generation leads to heavy CPU loads

Conclusion ULPMark-PP

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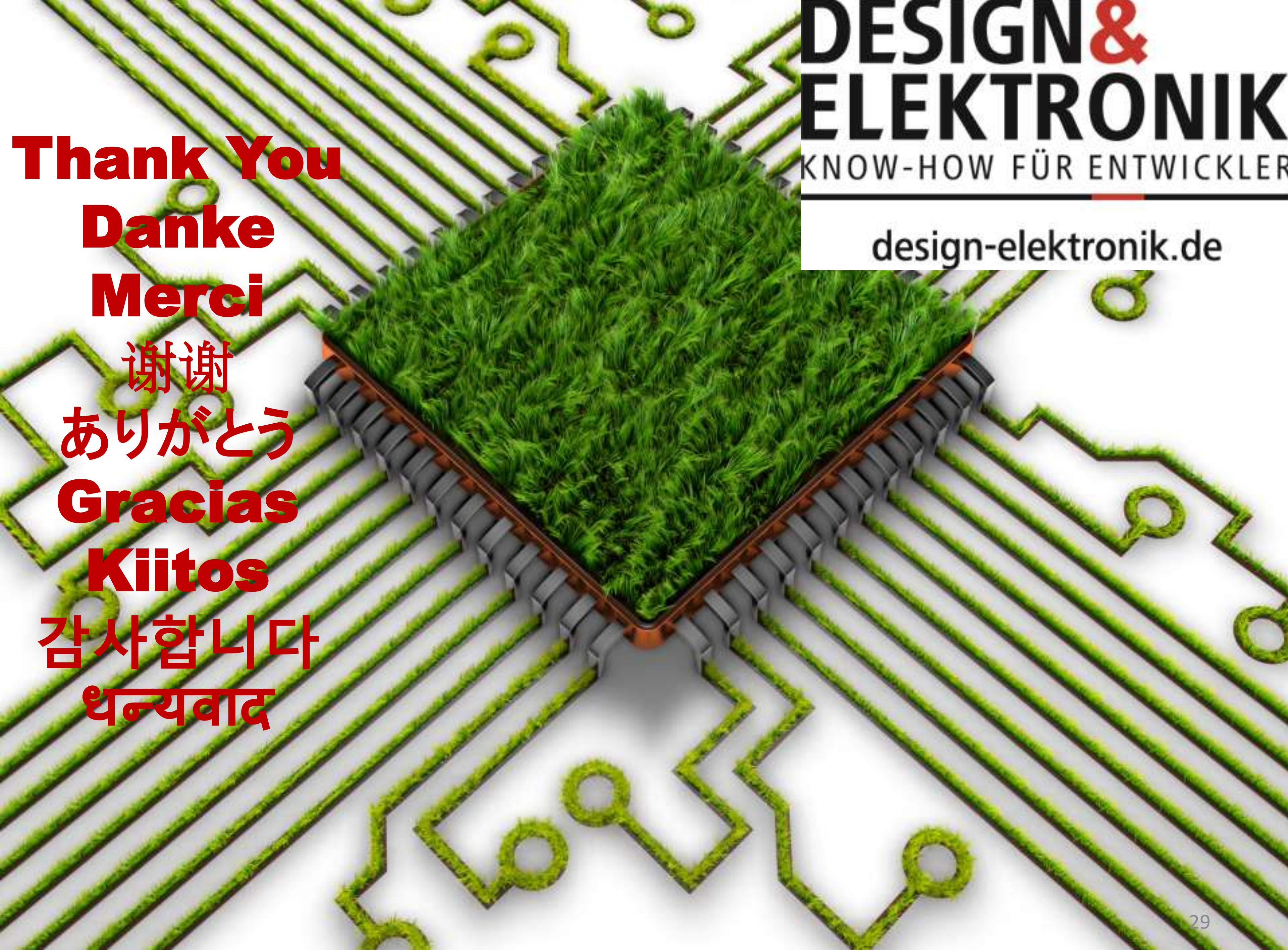
- ULPMark scores include not only CPU, memory subsystem and RTC, but also ADC, Timer and SPI.
- Scores are available for V_{DD} = 3.0 V down to 1.8 V
- Clock frequency and temperature are still fixed by MCU vendors.
- Scores are much more meaningful than ULPBench scores, nevertheless due to different peripheral implementations „real life“ comparisions are very difficult to achieve.
- STM32L433 is performing very well if the whole picture (CPU, memory subsystem, peripherals, varying V_{DD}s, temperatures and clock frequencies) is taken in consideration.


Thank You
Danke
Merci
谢谢
ありがとう
Gracias
Kiitos
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