



A PULP Based Wireless Multi-Sensor Platform for Wearable Applications

Integrated Systems Lab, ETH Zürich, Switzerland

Manuel Eggimann, Stefan Mach, Michele Magno, Luca Benini

Wearable Devices

- Wearable devices are getting momentum
 - Sensors are common on a great number of wearables



Activity Trackers



Smartwatches



Smart eyewear



Smart footwear



Smart clothing

- For a variety of applications



Skin patch sensors



Motion capture clothing



Pressure sensor clothing



Healthcare

Current Trends:

- More functionality per area
- Greater HW/SW requirements
- **Shorter battery lifetimes**

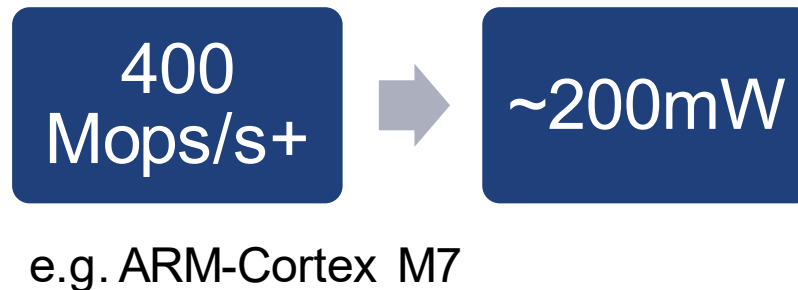


Biggest Challenge:

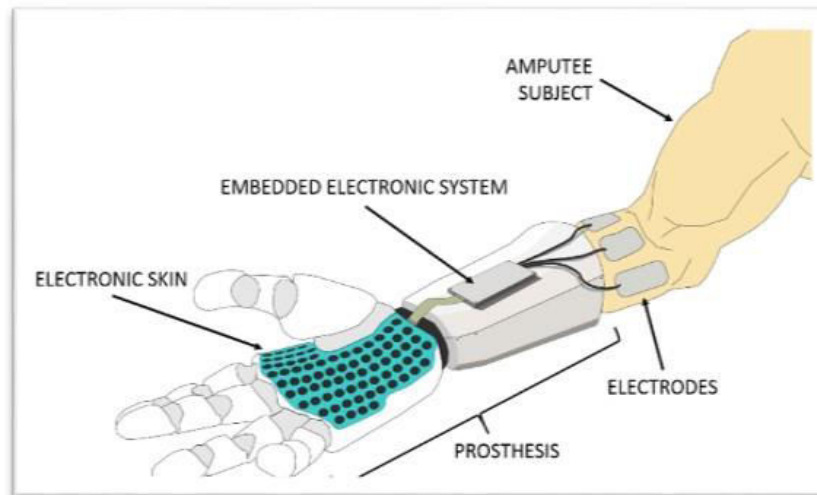
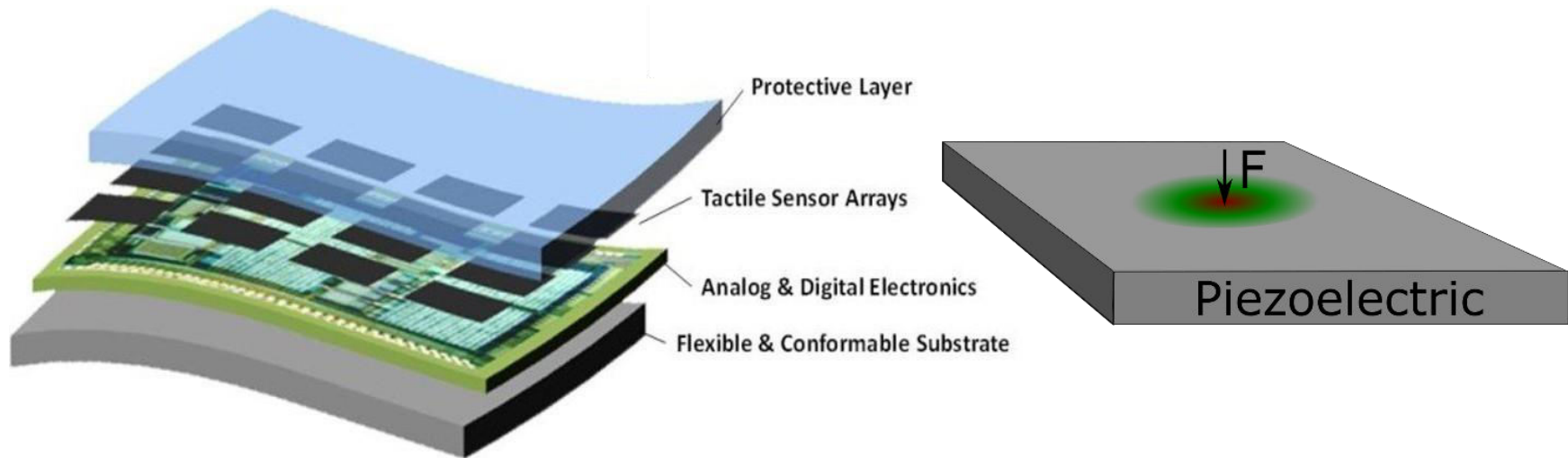
Energy storage/sources/consumption

Smart IoT Device Issues

- Battery life in many cases limited to few hours to couple of weeks of runtime
- Battery bulk dominates device size
- Limited computational resource to reduce power consumption

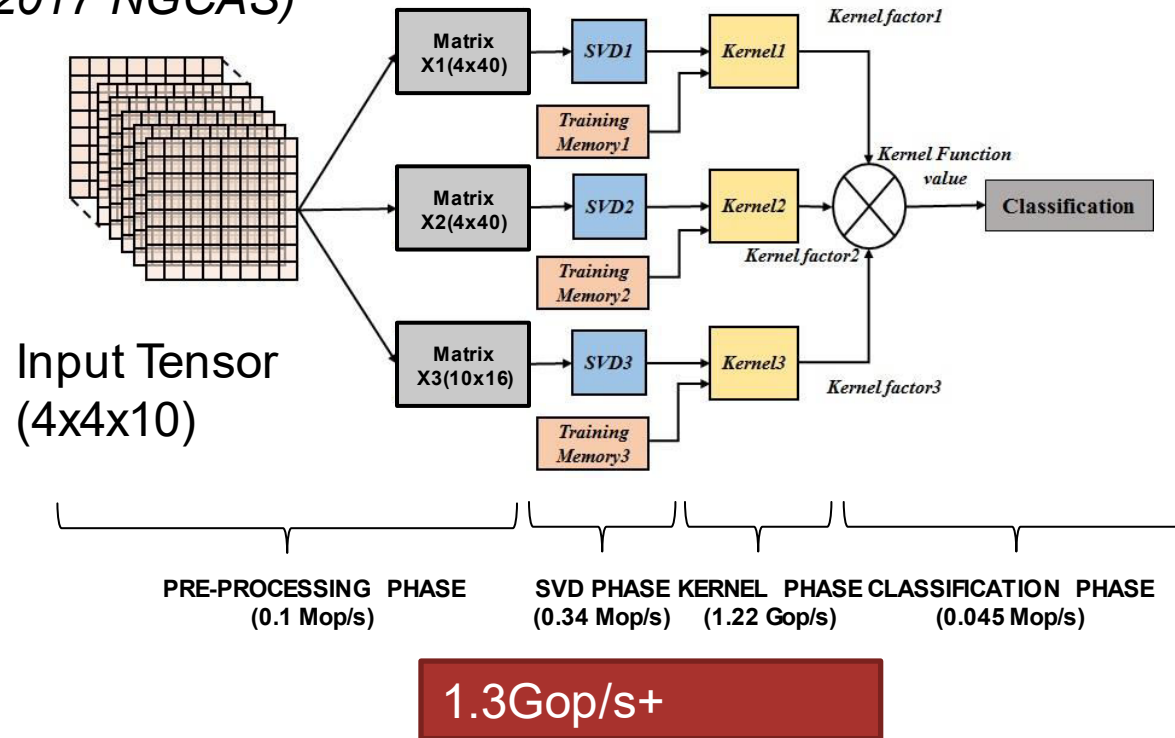


E-Skin



Bidirectional Interface for Prosthetics

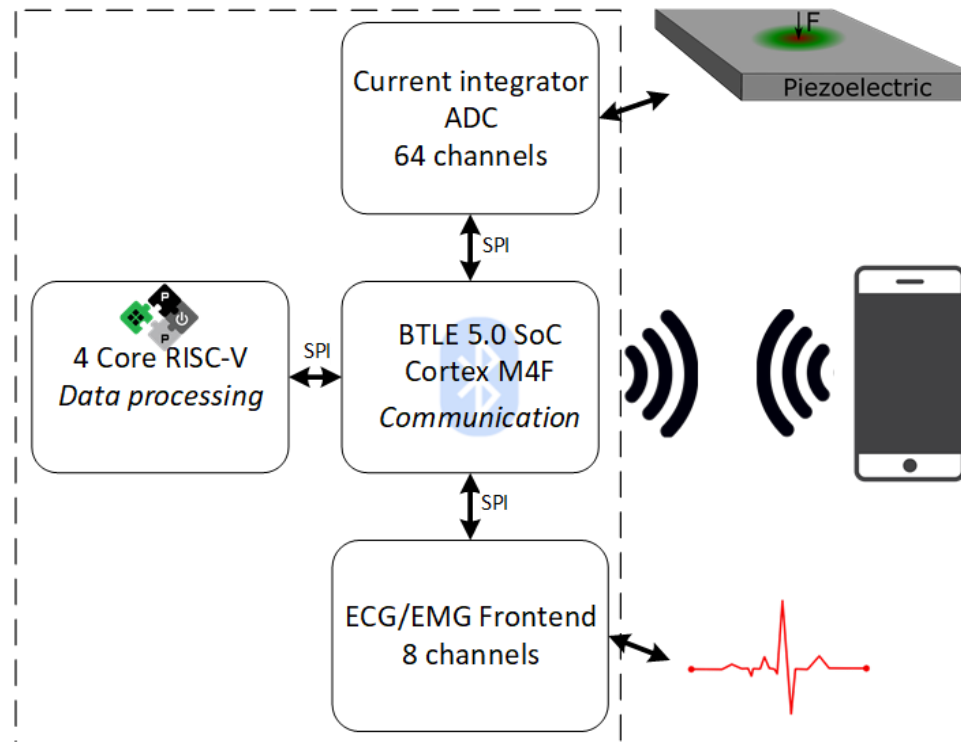
(Magno 2017 NGCAS)



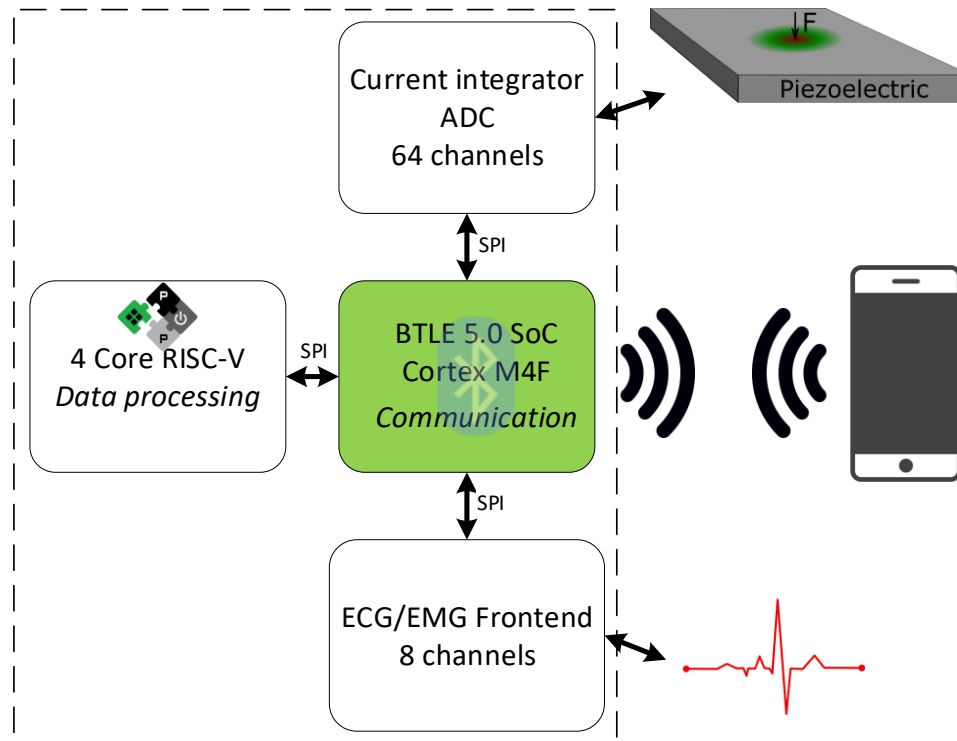
Contributions of this Work

- Design of a Wearable ExG/E-skin Sensor Interface with Wireless Connectivity
- Embedded Low Power Data Processing a RISC-V Multi-Core SoC
- Experimental Evaluation of Computational Resources and Power Consumption

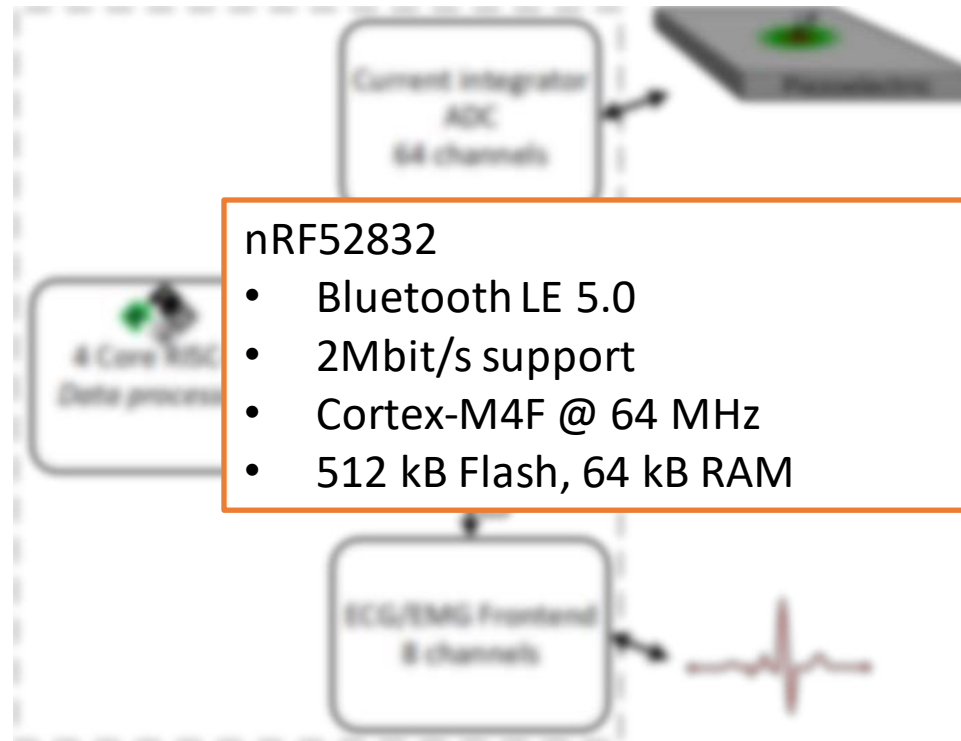
System Overview



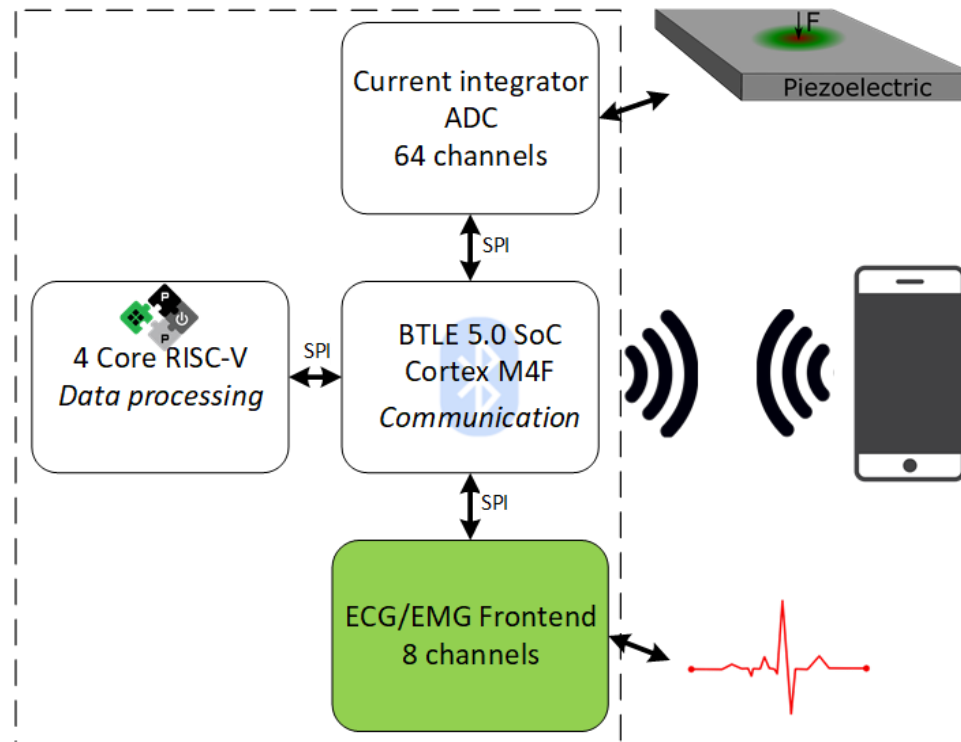
System Overview



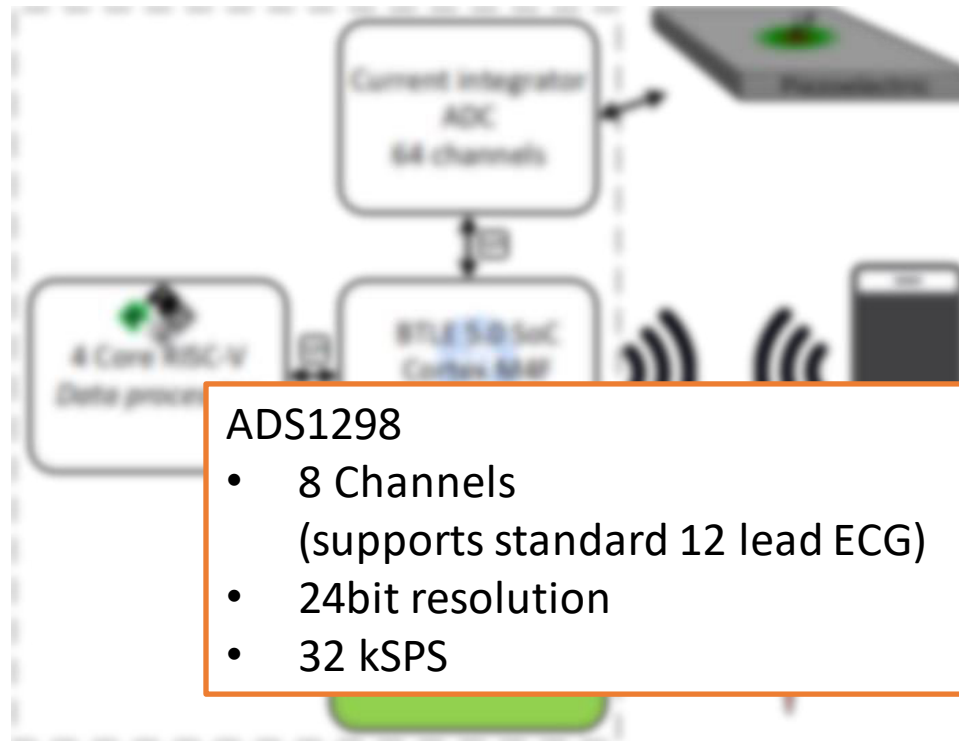
System Overview



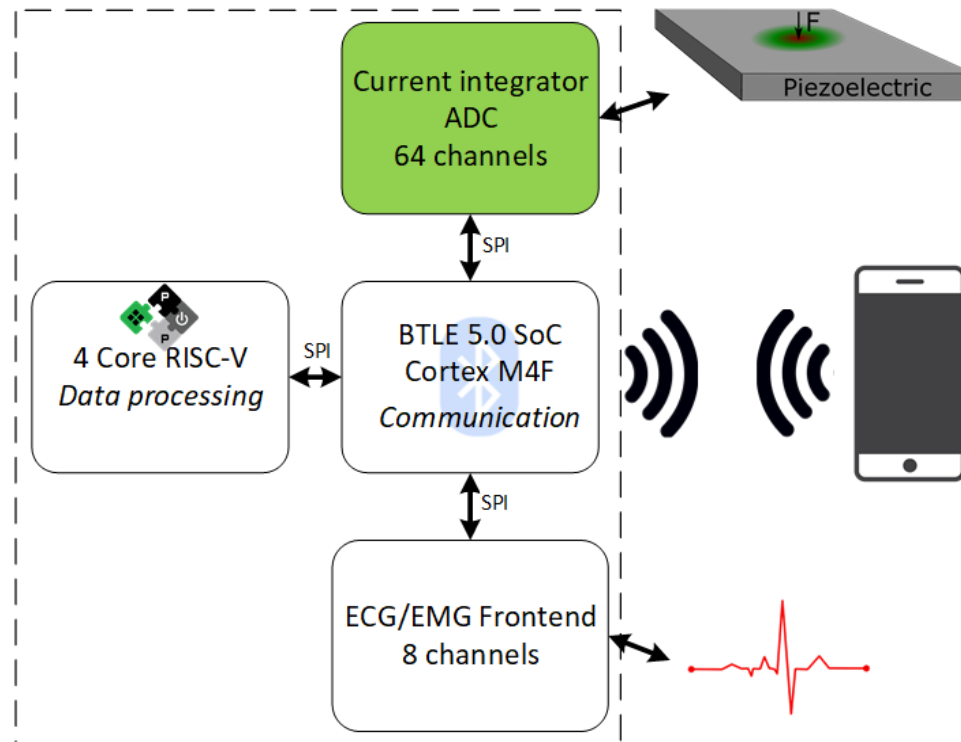
System Overview



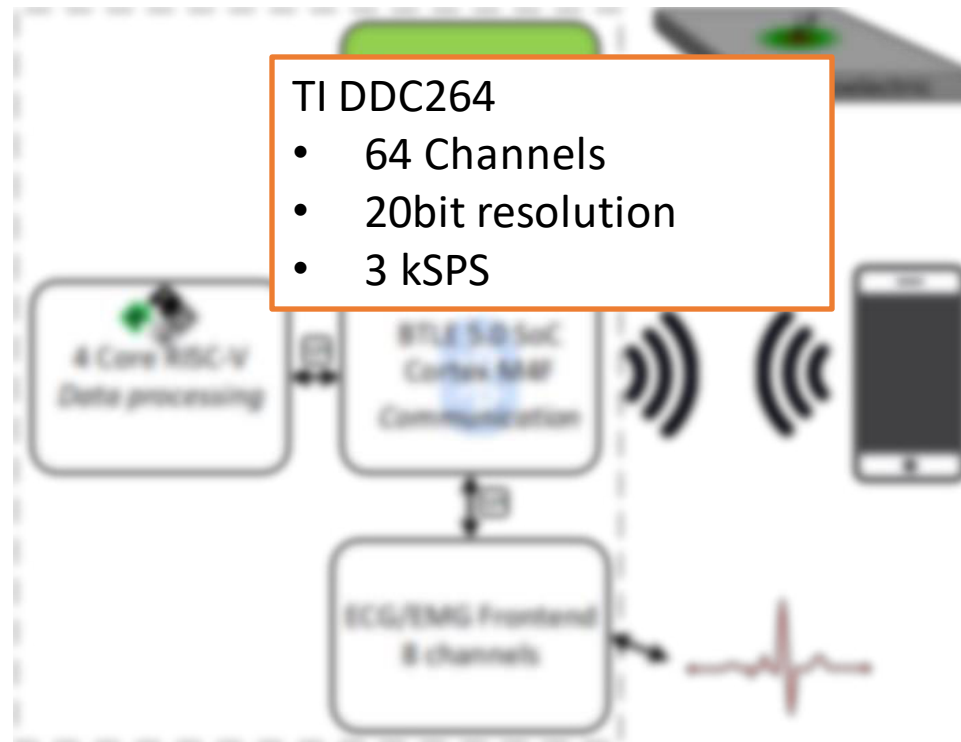
System Overview



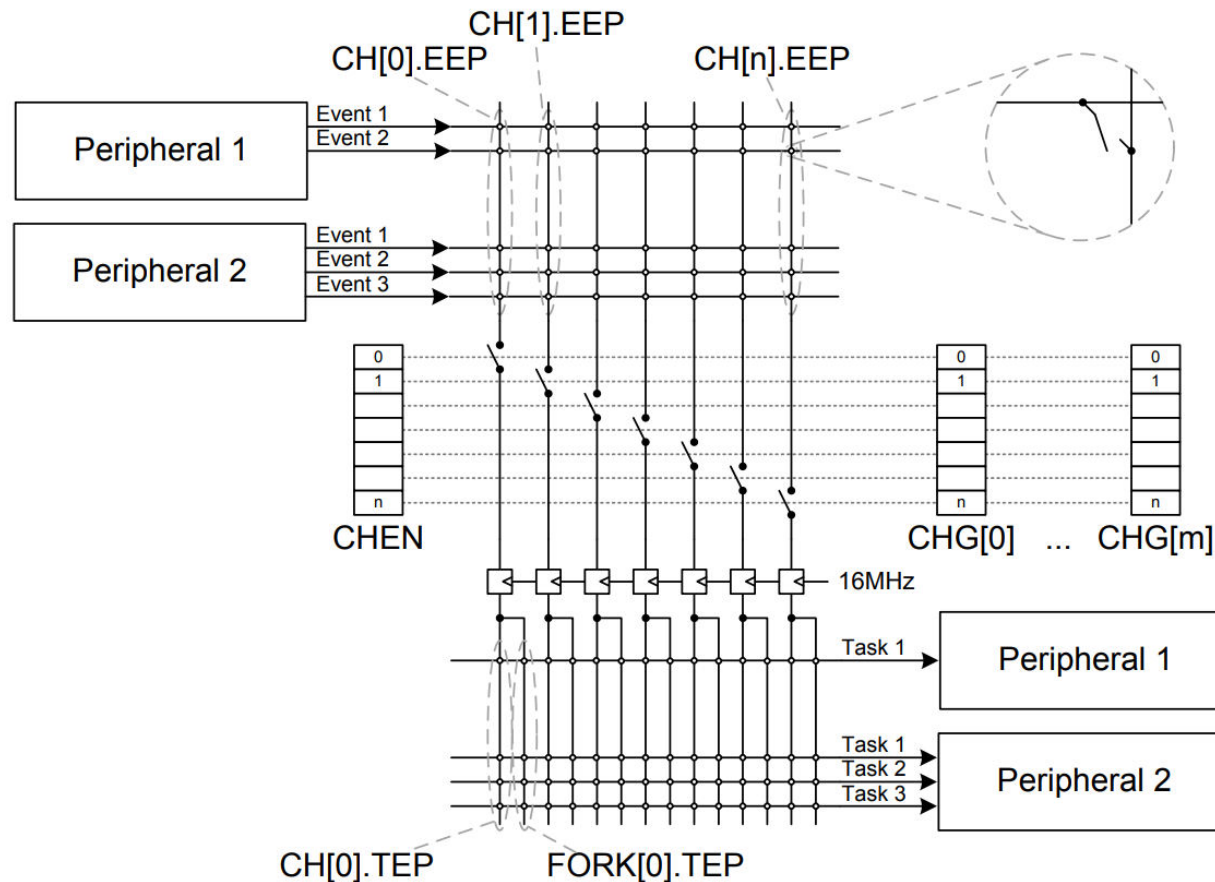
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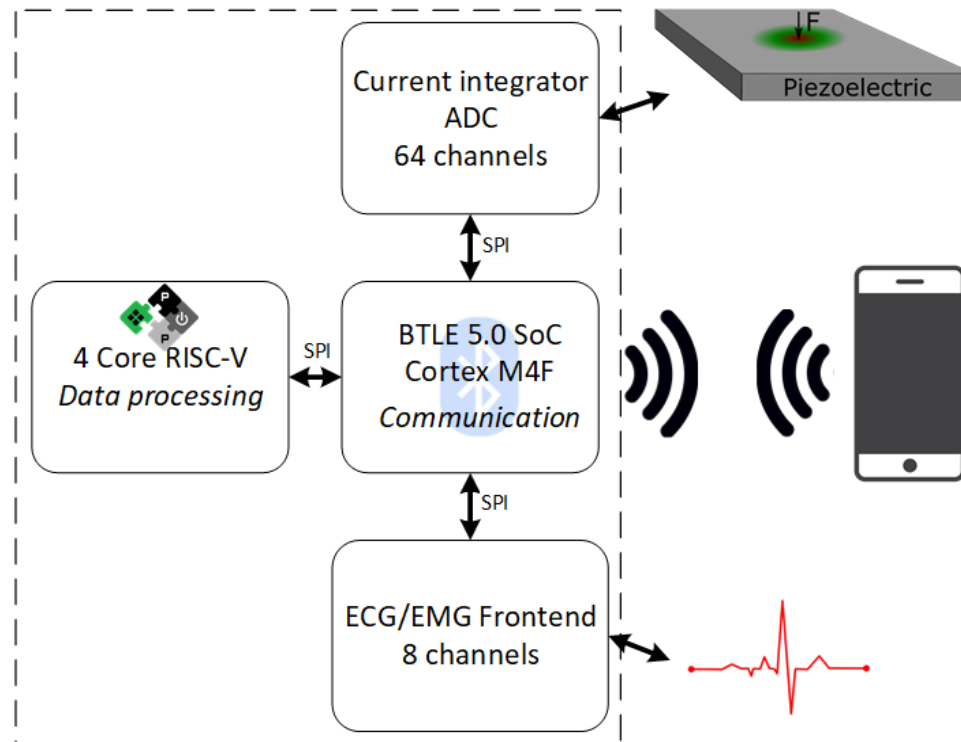
System Overview



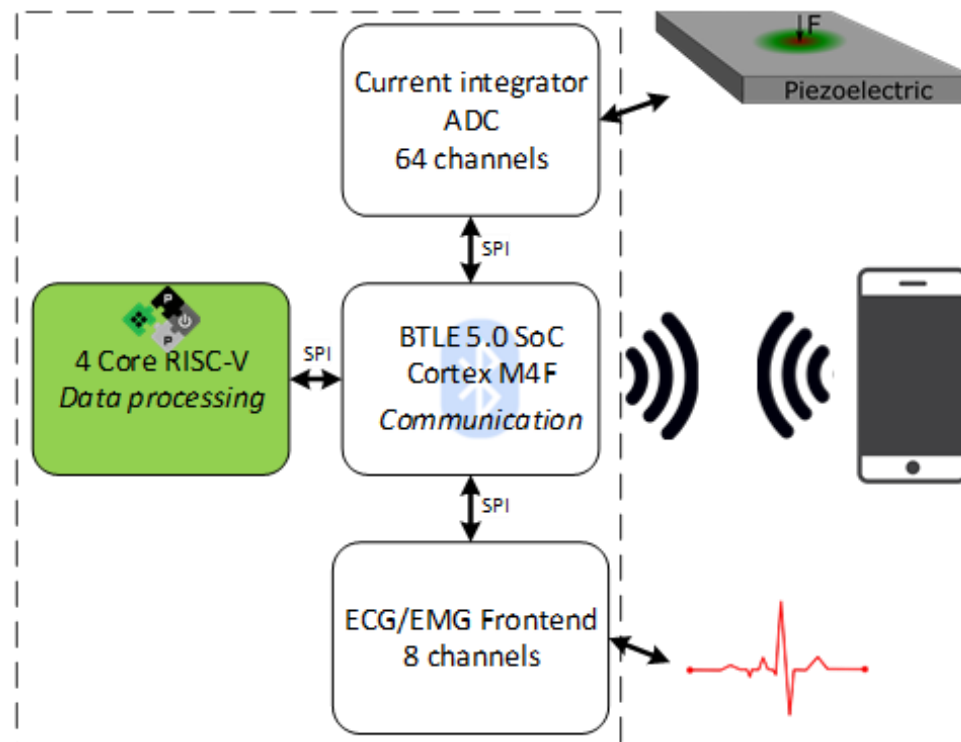
Interfacing the Current-Input ADC



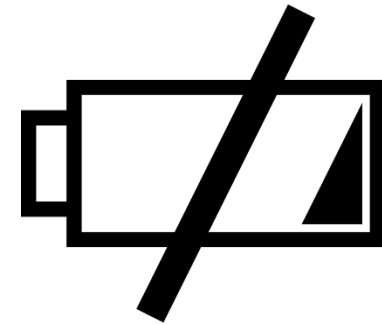
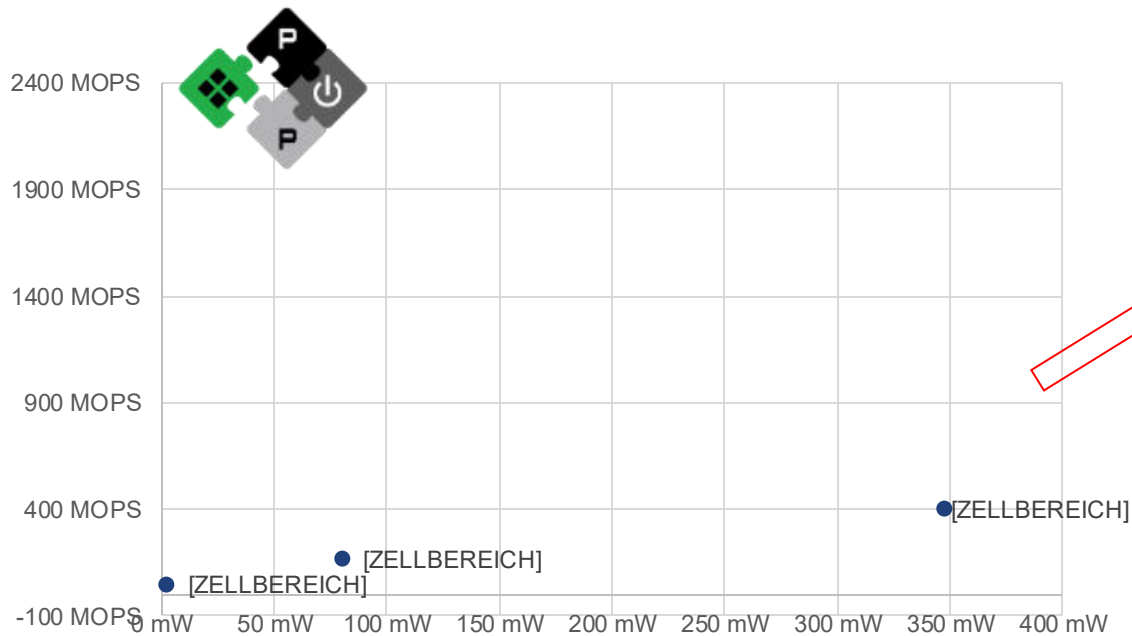
System Overview



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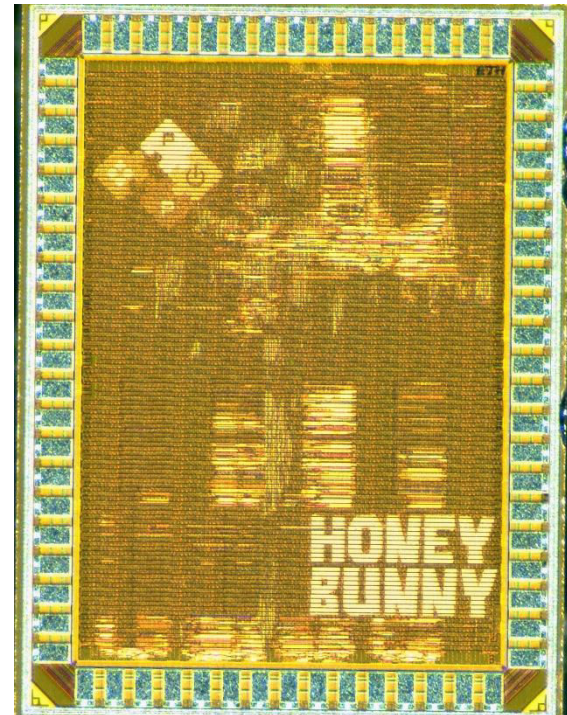


Performance of Current Low Power Microcontrollers

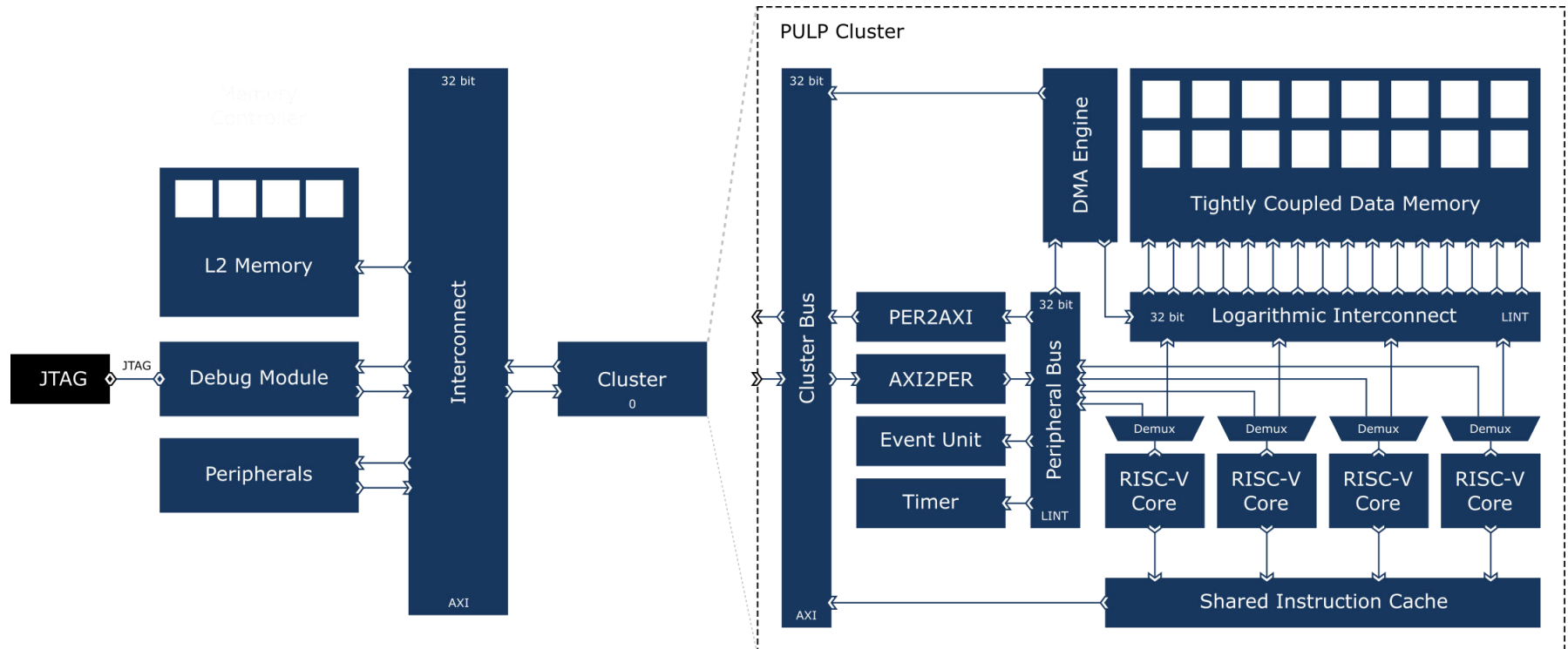


Honey Bunny

- Globalfoundries 28nm 2 MGE
- 4 RV32-ICM (RI5CY) Cores
- 625 MHz (2.5 GOPS)
- 256 kB of L2 memory
- 64 kB of SRAM-TCDM
- Peripherals:
 - QSPI (1x master, 1x slave)
 - I2C
 - I2S
 - JTAG
 - UART

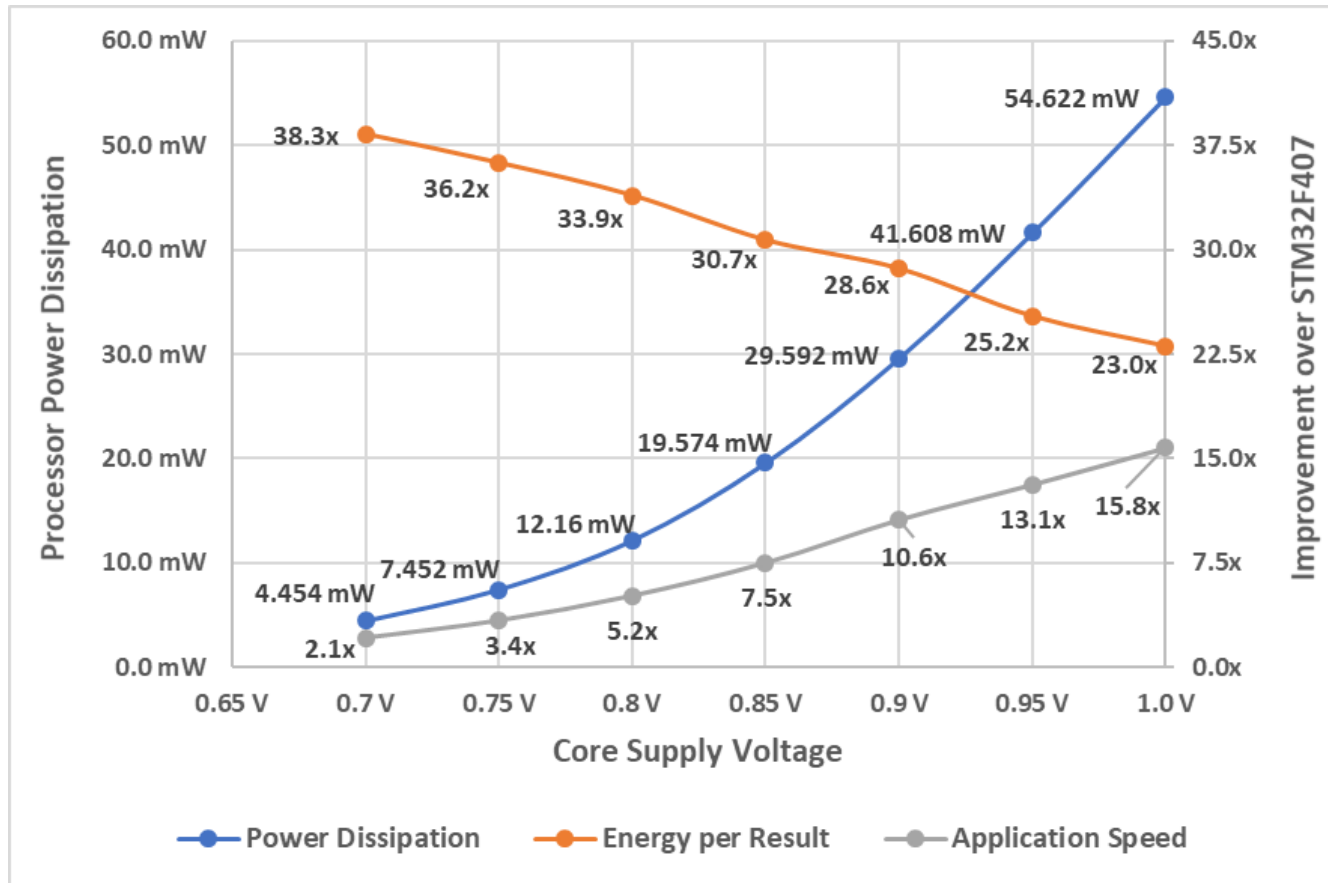


Honey Bunny



Performance Comparison

Honey Bunny – STM32F407

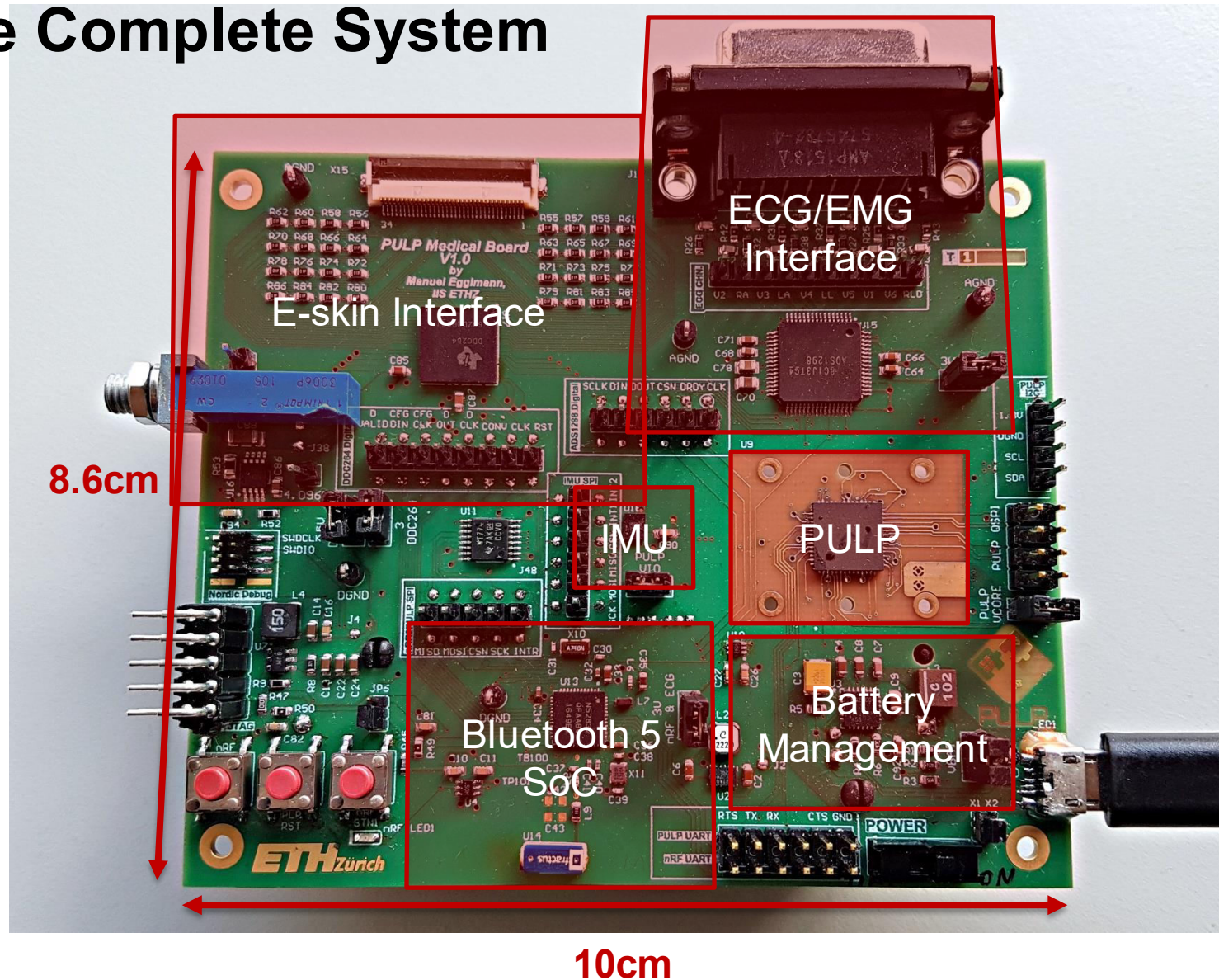


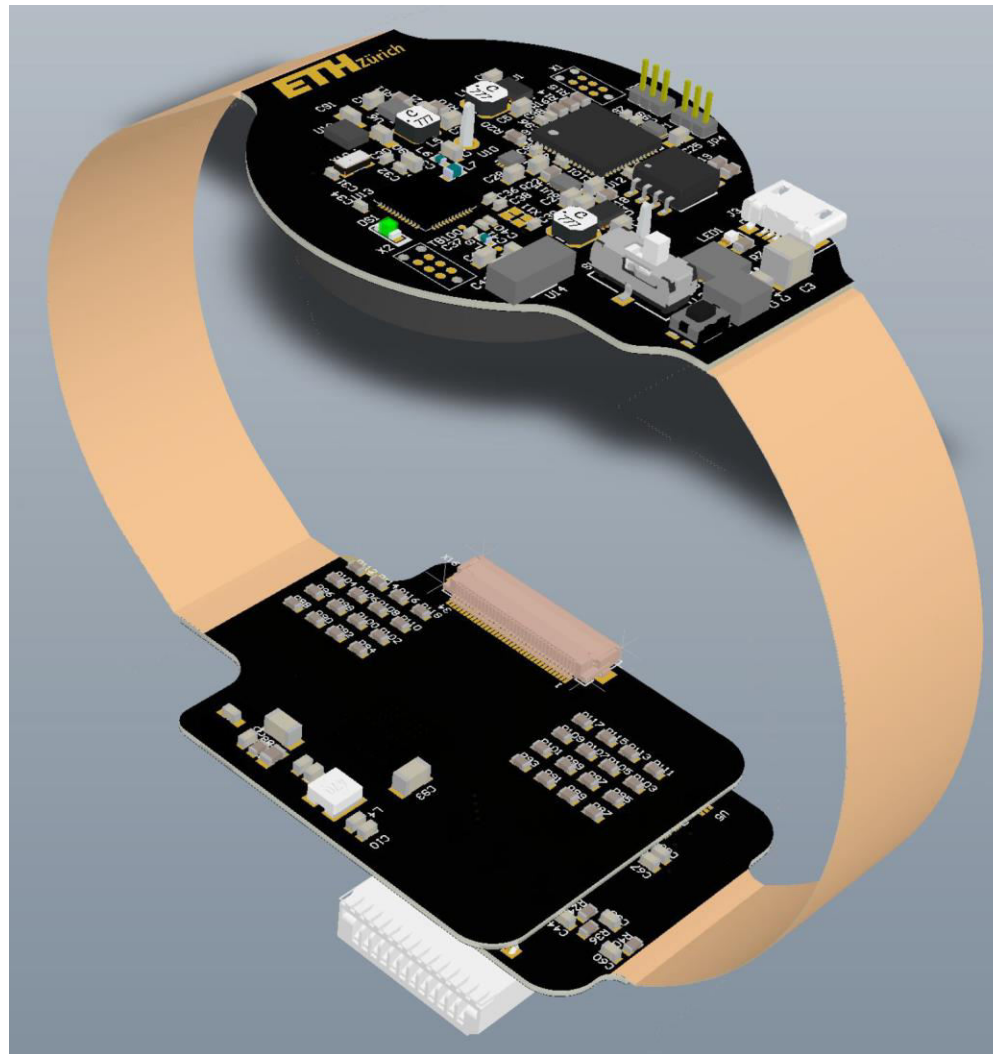
Performance Comparison

Honey Bunny – STM32F407

	STM32F407 $V_{\text{core}} 1.2\text{V}$	Honey Bunny $V_{\text{core}} 1\text{V}$	Honey Bunny $V_{\text{core}} 0.69\text{V}$
	168 MHz	625 MHz	40 MHz
Power	79.7 mW	54.6 mW	4.54 mW
Speed (normalized)	1.00	15.8	2.1
Energy Efficiency (normalized)	1.00	23.0	38.3

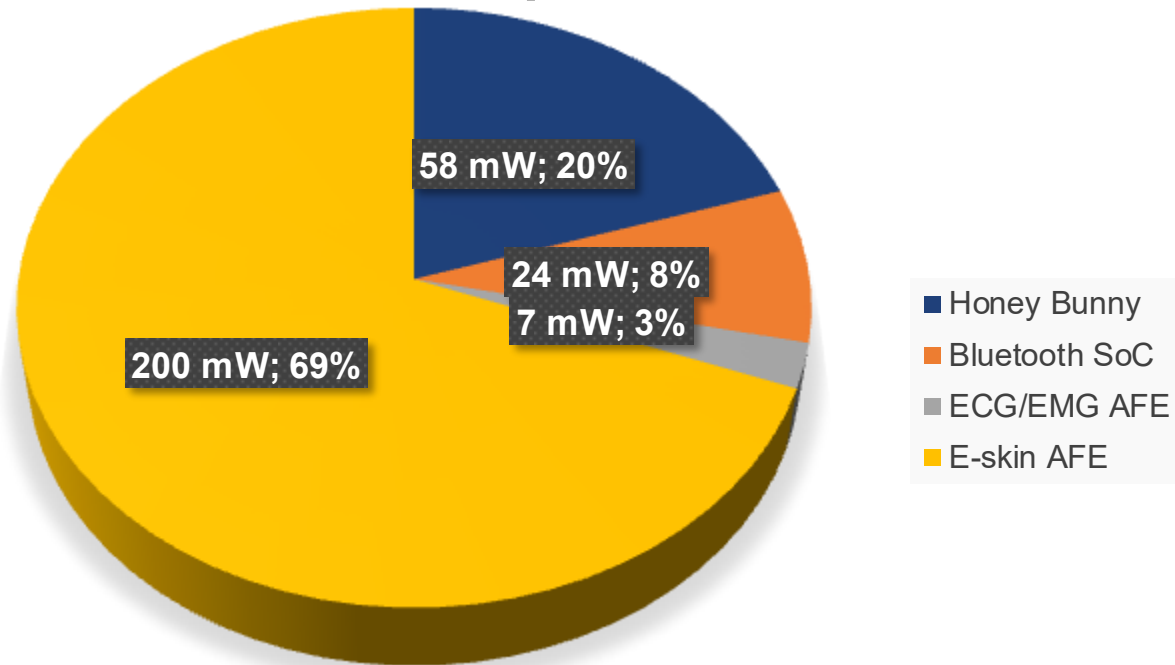
The Complete System





Power Budget

Peak Energy Consumption by Component



Power Scenarios

Scenario	Power	Estimated Runtime*
ECG filtering (250 SPS), PULP filtering a 50 MHz (1 core), Bluetooth SoC TX (72 kBit/s)	21 mW	20 days
ADCs turned off, PULP processing at 600 MHz (4 cores), Bluetooth SoC idle	58 mW	7 days
ECG filtering (250 SPS), E-skin filtering (2.5 kSPS), PULP processing at 600 MHz (4 cores), Bluetooth SoC TX (72 kBit/s)	280 mW	36 hours

*Using on-board battery with a capacity of 3500 mAh

Conclusion

- We presented Honey Bunny a new RISC-V multi-core SoC with a peak performance of 2.5 GOPS and a 38 times higher energy efficiency than the STM32F407
- We designed a wearable, battery powered ExG/E-Skin interface device for biomedical applications with Honey Bunny for realtime processing of the sensor data