Eta Compute
Self-timed ARM M3 Microcontroller for Energy Harvested Applications

Agenda

- Motivation
- A New Paradigm
- Dial Technology
- Chip Architecture
- Measured Results
- Sensor Reference Design

Deploying Billions of Sensors Require

- Low cost
- Small size
- Robust operation in unfriendly environments
- Standardized hardware and easy software development
- ARM processors with standard wireless
- NO BATTERIES….

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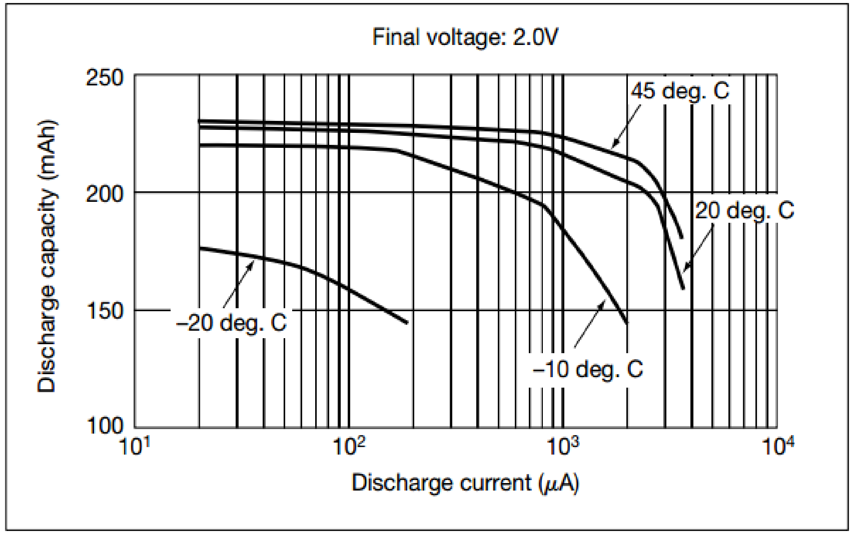
Issues with Batteries

● Relationship between Discharge Current and Discharge Capacity

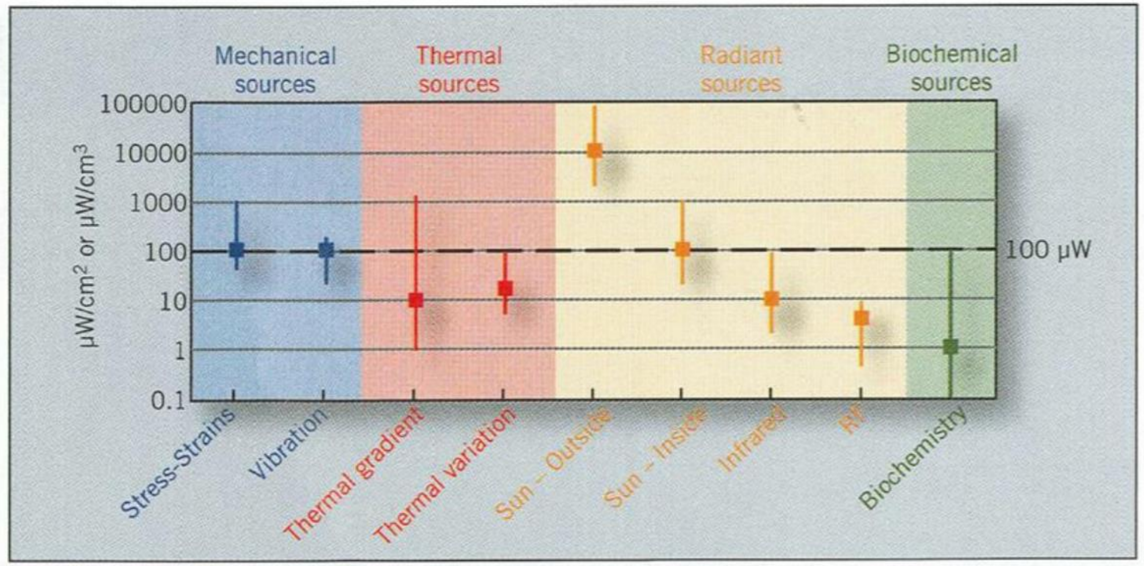


Limited temperature range
Limited capacity

Hazardous Waste / Disposal

Power Available from Energy Harvesting

- EH can supply 1uW to 100uW indoors (exclude PV outdoors)
- EH can support sensor fusion computations
- Storage from super-caps or rechargeable batteries for wireless connections



A comparison of ambient energy sources (before conversion). (Source: CEA-Leti).

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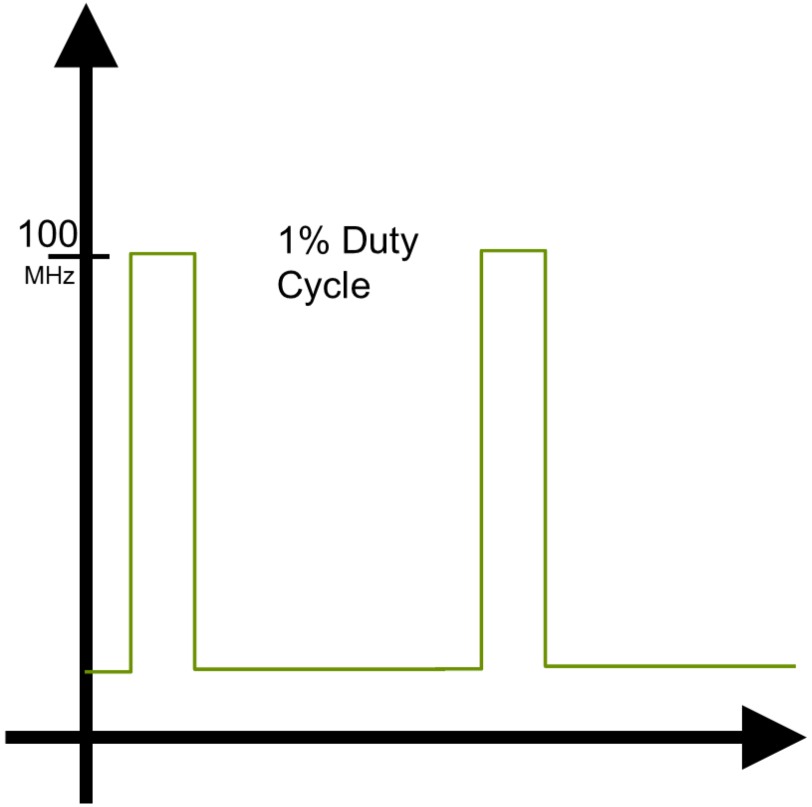
"Race to Idle" Paradigm

- Minimize energy use by running fast and switching to idle



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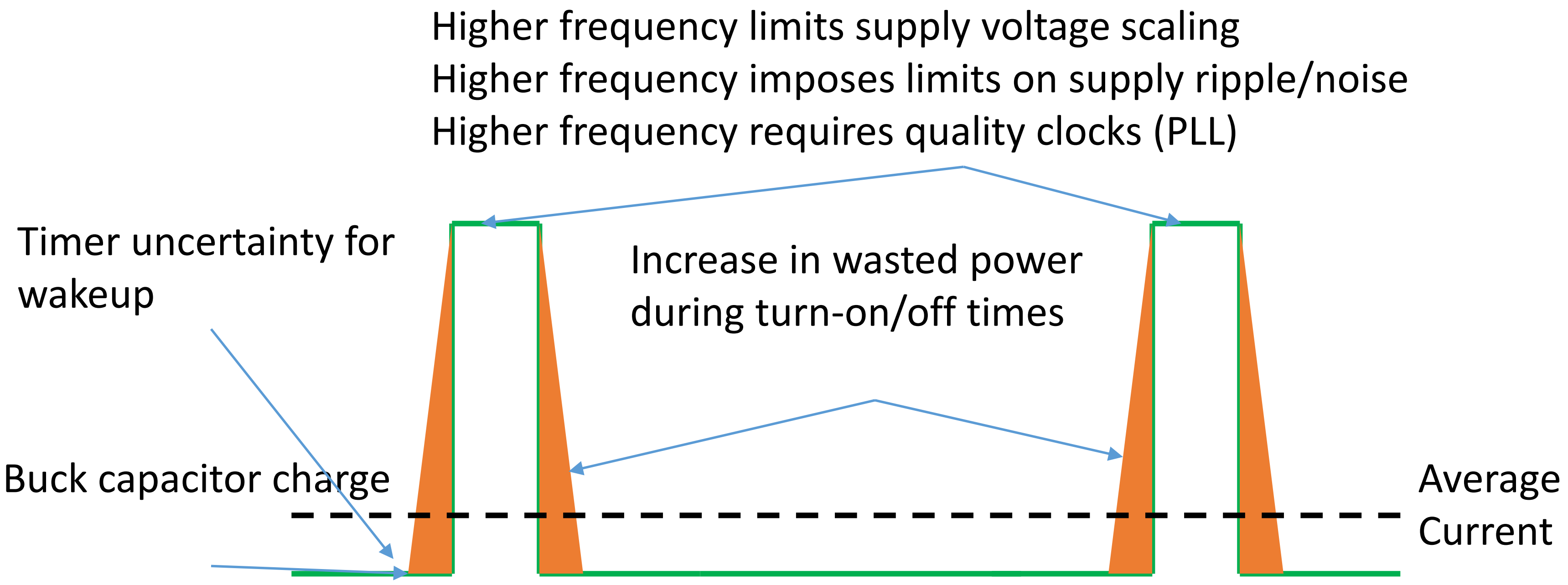
“Race to Idle” Wastes Energy



- Microcontrollers increasing frequency to reduce active time

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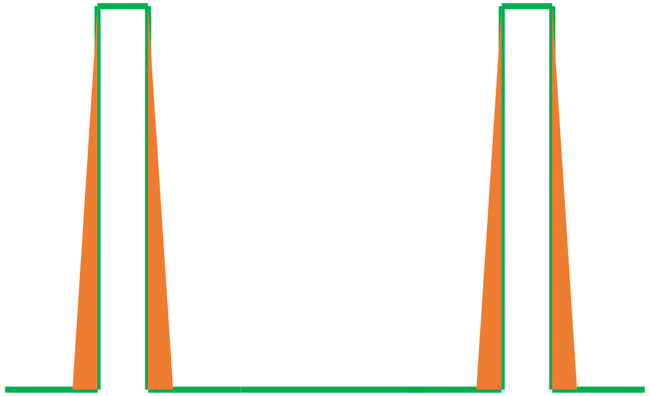
"Always-on" Paradigm

ADuCM4050
(Cortex M4)



Power = 0.01 * 4410 + 2.4 = 46.5 uW

EtaCore M3

Power (uW) = 8 uW

6x better without even accounting for wasted power !

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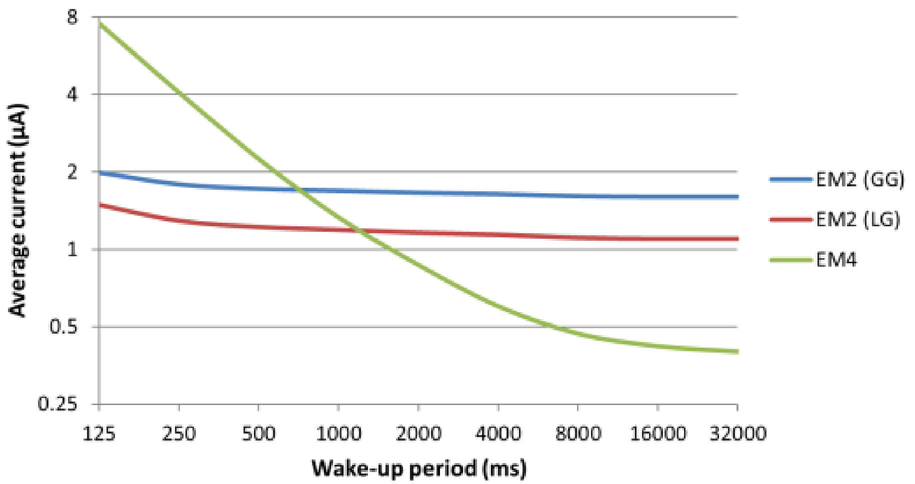
Software – “Race to Idle”

- Familiarize yourself with processor energy modes and transition times

Table 3.1. Energy Mode Description

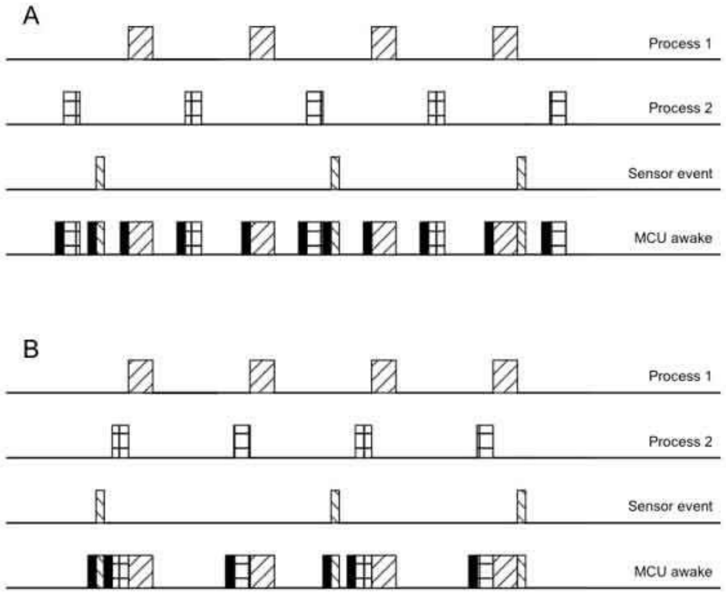
Energy Mode	Name	Description
	EM0 – Energy Mode 0 (Run mode)	In EM0, the CPU is running and consuming as little as 211 µA/MHz, when running code from flash. All peripherals can be active.
	EM1 – Energy Mode 1 (Sleep Mode)	In EM1, the CPU is sleeping and the power consumption is only 63 µA/MHz. All peripherals, including DMA, PRS and memory system, are still available.
	EM2 – Energy Mode 2 (Deep Sleep Mode)	In EM2 the high frequency oscillator is turned off, but with the 32.768 kHz oscillator running, selected low energy peripherals (LCD, RTC, LETIMER, PCNT, LEUART, I^2C, LESENSE, OPAMP, USB, WDOG and ACMP) are still available. This gives a high degree of autonomous operation with a current consumption as low as 0.95 µA with RTC enabled. Power-on Reset, Brown-out Detection and full RAM and CPU retention is also included.
	EM3 - Energy Mode 3 (Stop Mode)	In EM3, the low-frequency oscillator is disabled, but there is still full CPU and RAM retention, as well as Power-on Reset, Pin reset, EM4 wake-up and Brown-out Detection, with a consumption of only 0.65 µA. The low-power ACMP, asynchronous external interrupt, PCNT, and I^2C can wake-up the device. Even in this mode, the wake-up time is a few microseconds.
	EM4 – Energy Mode 4 (Shutoff Mode)	In EM4, the current is down to 20 nA and all chip functionality is turned off except the pin reset, GPIO pin wake-up, GPIO pin retention, Backup RTC (including retention RAM) and the Power-On Reset. All pins are put into their reset state.



Software – "Race to Idle"

- Familiarize yourself with different clocks
- Organize code to minimize wakeups

Oscillator	Type	Frequency	Typical consumption	Typical start-up time	Typical use
HFRCO	Internal RC	Run-time selectable: 1, 7, 11, 14, 21 or 28 MHz	22-106 µA	1 µs	Main HF clock
HFXO	External crystal/ceramic resonator or external clock	Fixed: 4 -32/48 MHz for resonators. Less than 32 or 48 MHz for external clock.	85-165 µA	400 µs	Main HF clock
AUXHFRCO	Internal RC	Run-time selectable: 1, 7, 11, 14, 21 or 28 MHz	22-106 µA	1 µs	Debug and flash write timing
LFRCO	Internal RC	Fixed: 32 kHz	190 nA	150 µs	LF peripheral clock
LFXO	External crystal/ceramic resonator or external clock	Fixed: 32.768 kHz for resonators. Less than 48 or 32 MHz for external clock	190 nA	400 ms	LF peripheral clock
ULFRCO	Internal RC	Fixed: 1 kHz	NA (always on)	NA (always on)	Watchdog clock



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Software – “Always on”

- Power constrained : Determine available power and set voltage

OR

- Performance constrained : Determine MIPS needed and set voltage

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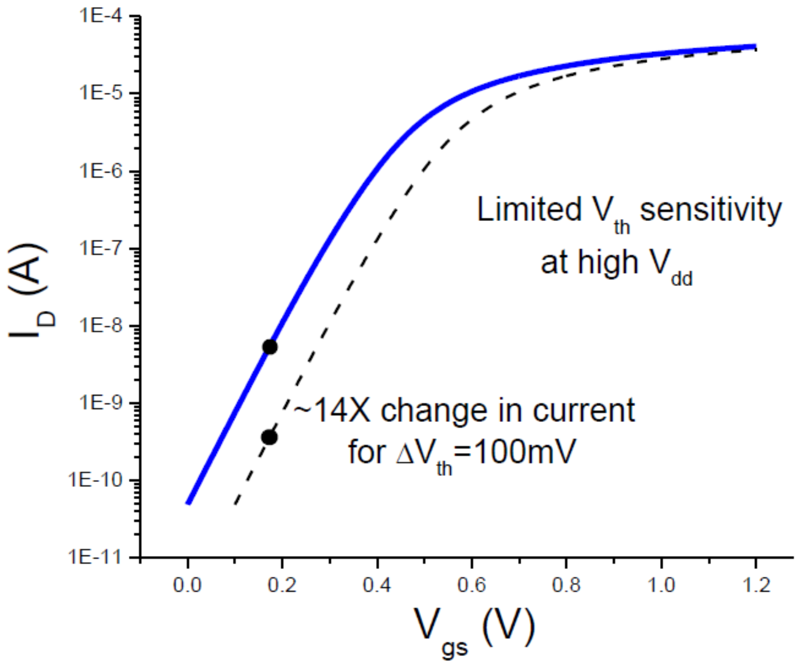
Challenges in Deep Subthreshold Operation

- Model quality
- Large delay variation over PVT
- Lognormal delay distribution – timing closure tools ?
- 3x mismatch between adjacent gates



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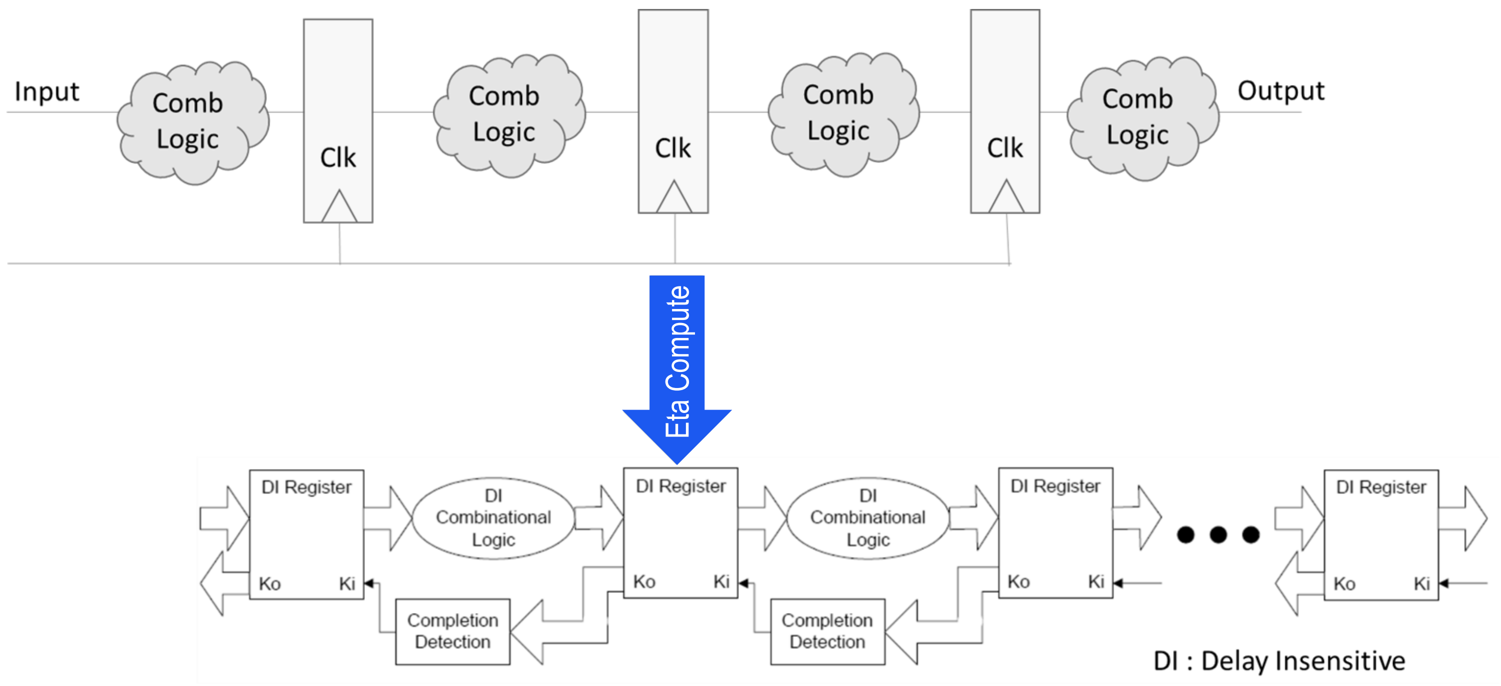
DIAL Architecture



- Circuit operates from 0.25 – 1.2V continuously with no resets required

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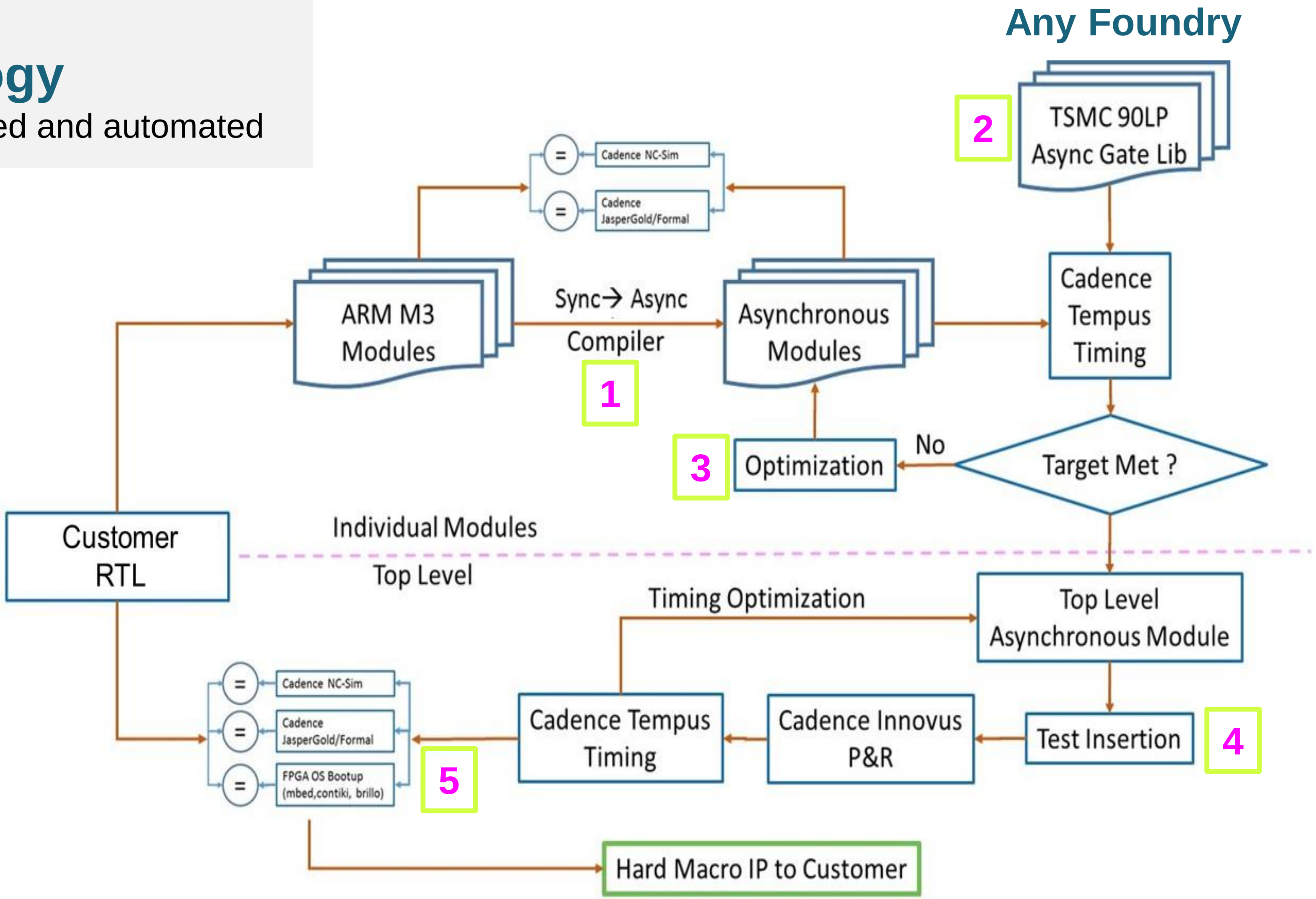
DIAL™ Methodology

All aspects of the design flow are addressed and automated

Design Methodology

1. Sync to Async low voltage conversion
2. Delay insensitive cell library development
3. Optimization for PPA
4. Async DFT Scan Insertion at operational voltage
5. Sync to Async Formal Verification



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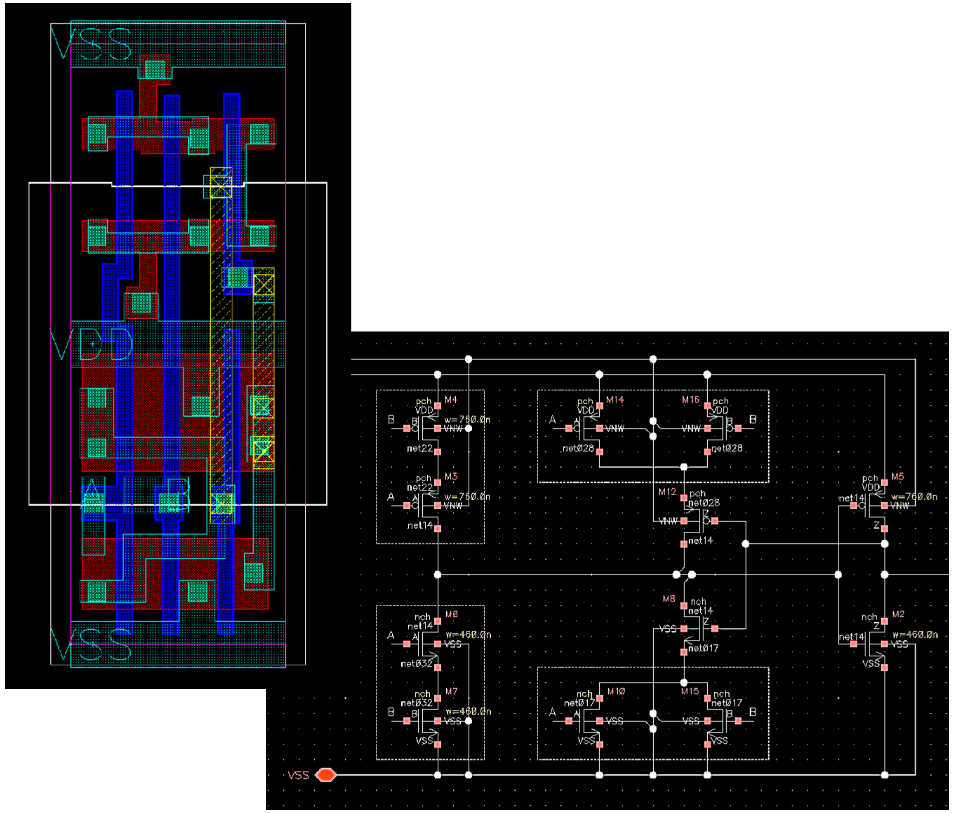
Foundry Library



- We've done 180nm, 130nm, 90nm and 55nm
- Deep sub-threshold operation
- 5X MIPS/Watts of any competing processor
- Used this logic to develop low power SoC
- Allows processor operation down to 0.25V
- Robust across and temperature

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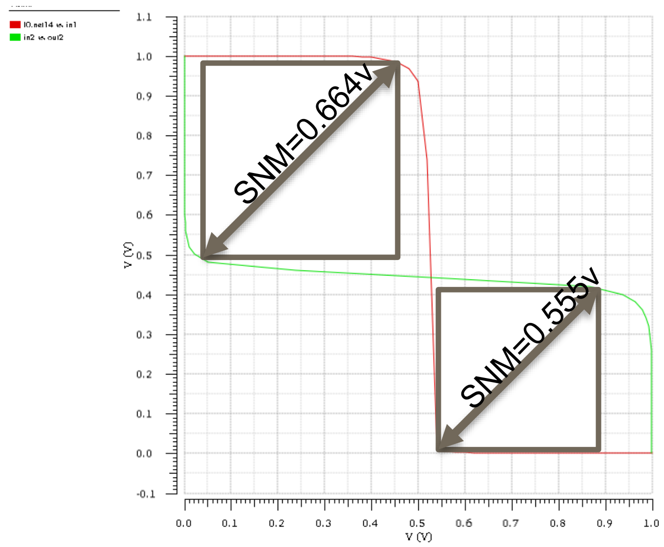
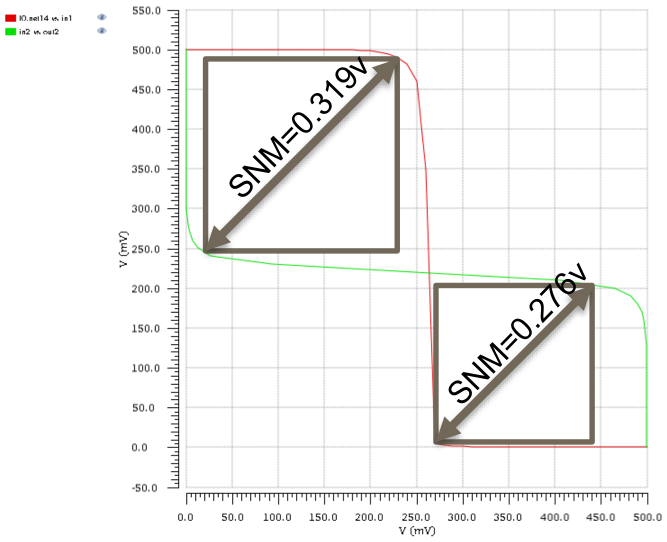
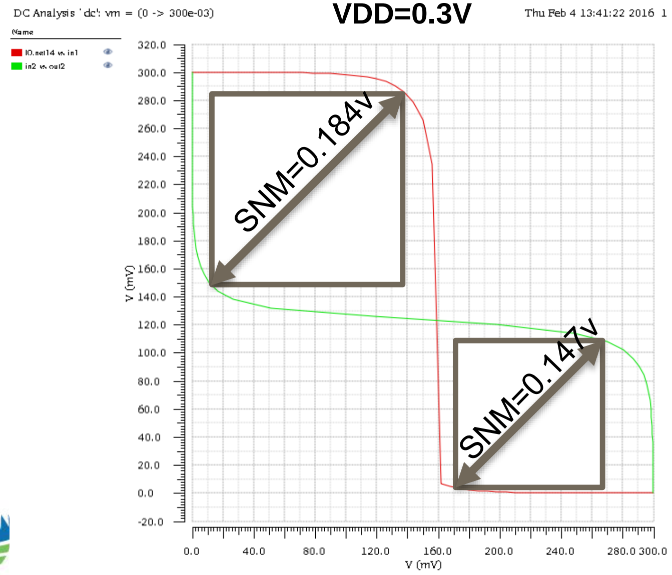
Design for Low-Voltage Operation over Corners





VDD=0.3V

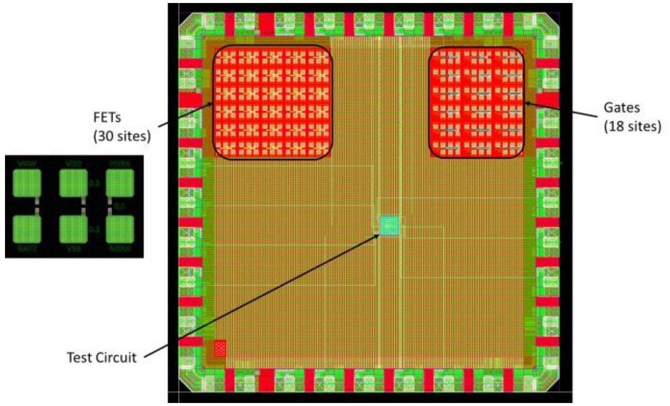


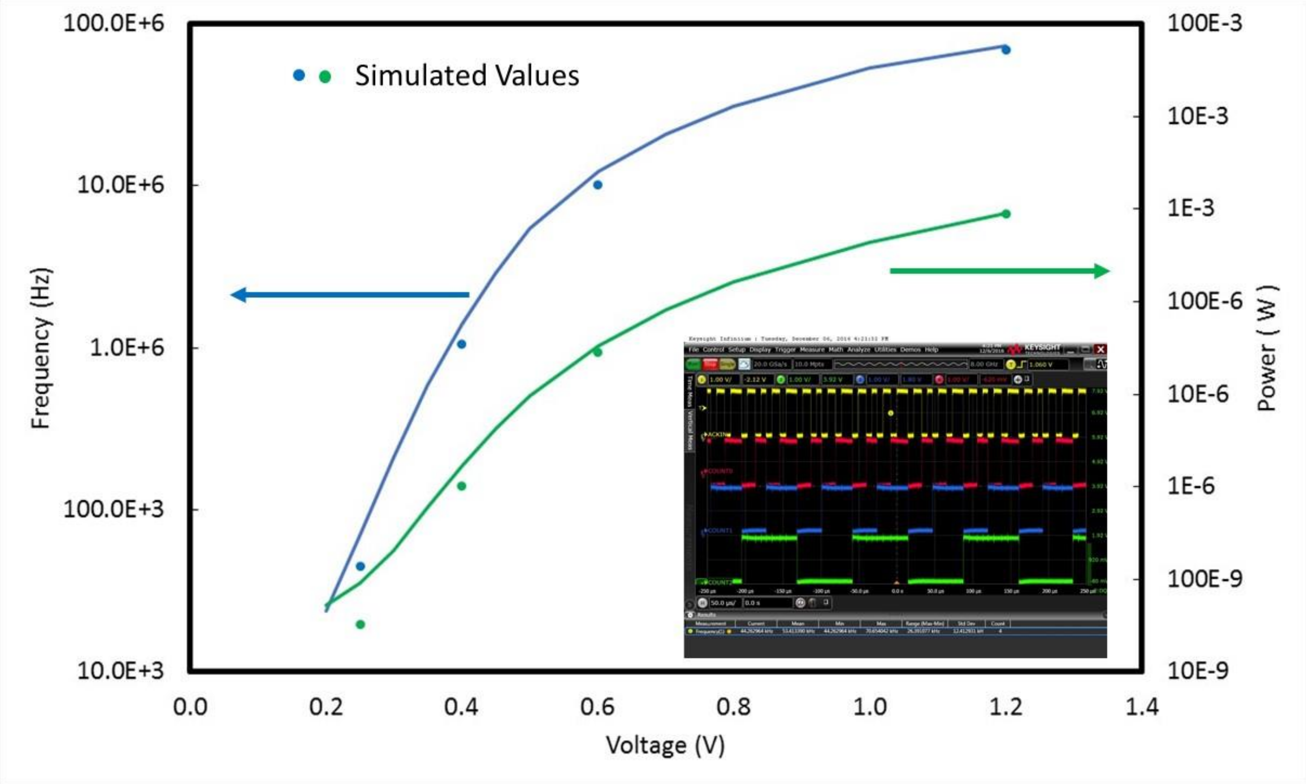
VDD=0.25V

Over 5% NM

Silicon Measurements of Test Circuits and Cell Library

- Transistor chains and gates for standard cell characterization – in progress
- Example of TSMC90LP
- 32 bit counter test chip shows good match between measurements and simulations
  - 25 kHz / 50 nW
- Today we also have a fully functional fully self timed Cortex M3 SOC in DIAL technology.





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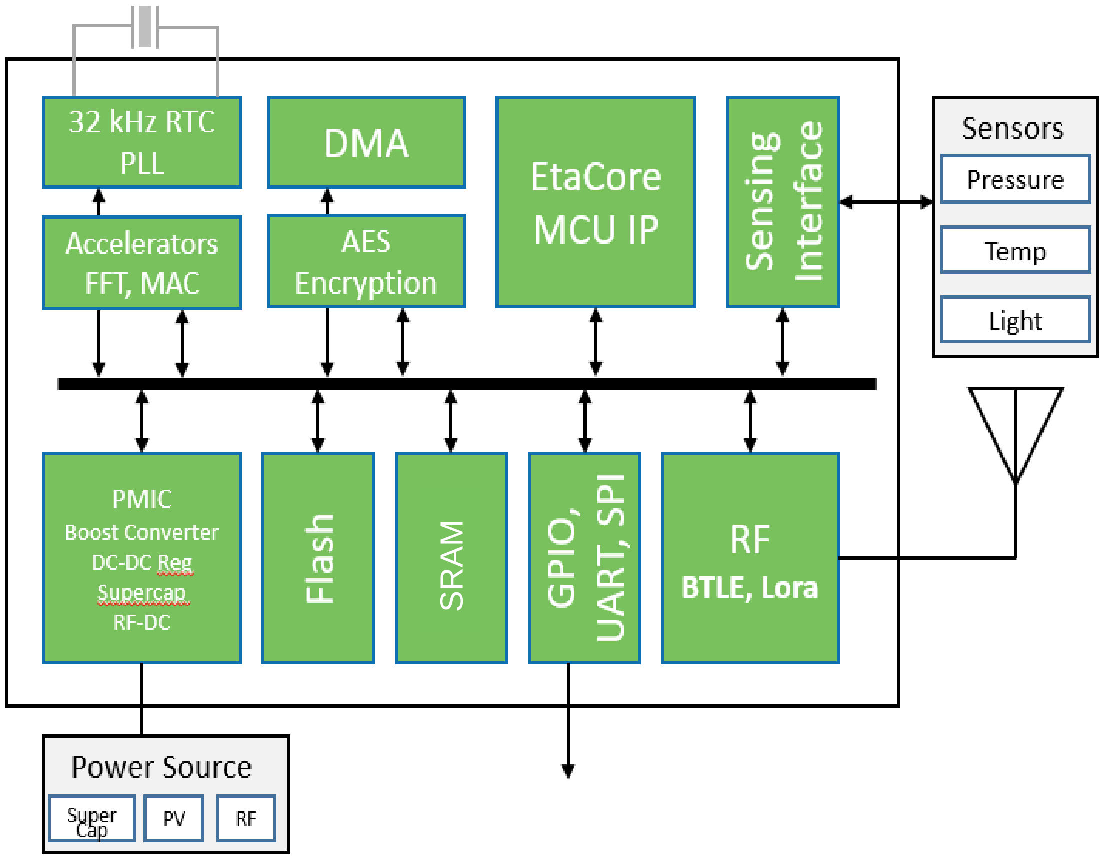
Build Into a Holistic Low Power Platform

"Eta Compute can safely claim without contradiction that they have developed the world's lowest power microcontroller IP"
Bernard Murphy: SemiWiki, ex-CTO Atrenta

- Low-voltage, delay insensitive logic
  - 1 patent granted, 15 pending
- Digital circuits
  - Coolflux DSP
  - Real Time Clocks
  - AES
- Asynchronous SAR ADC
- High efficiency power management
- Unique interfaces to SRAM, UART…



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Benefits of an Always On Processor

- Fast interrupt response
- Regular monitoring of sensor to alter node behavior
  - Optimize transducer energy conversion (MPPT)
  - Schedule RF during high source energy periods
- Vary performance depending on load ("paddle-shift")
  - Sensor data collection / processing at low frequency
  - RF transmission at high frequency
- "Pay as you go" on energy

oscillator only when communicating

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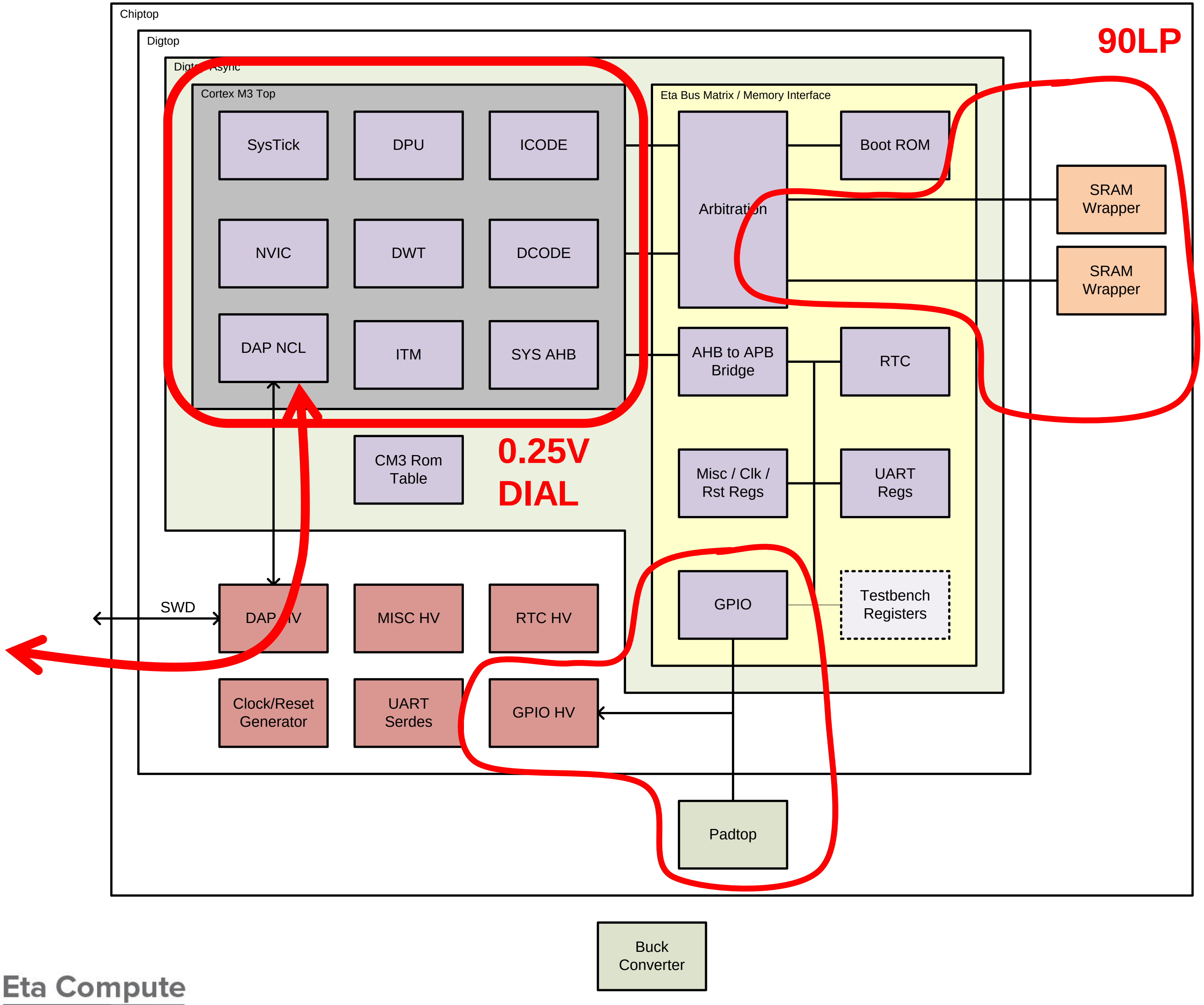

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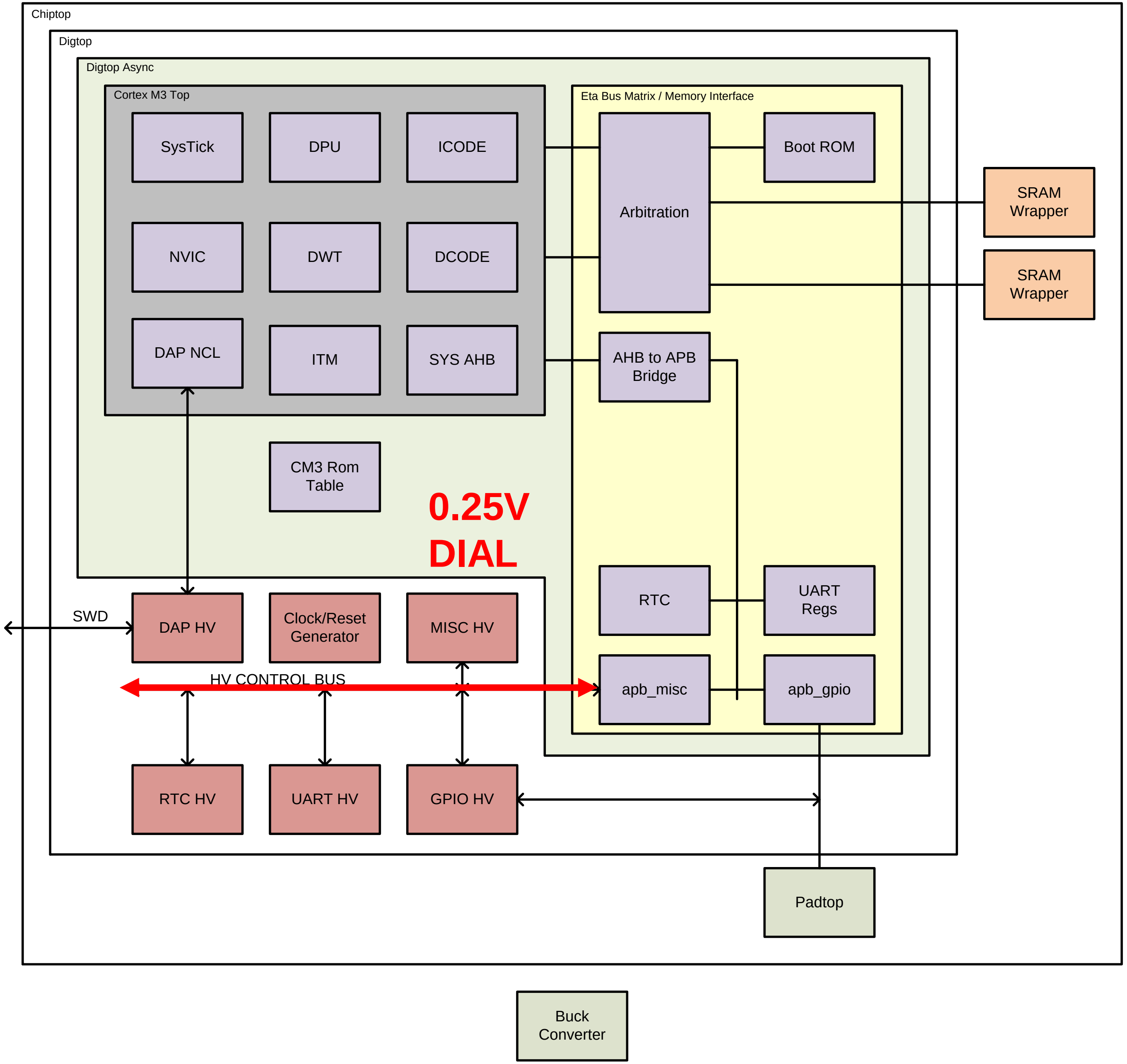

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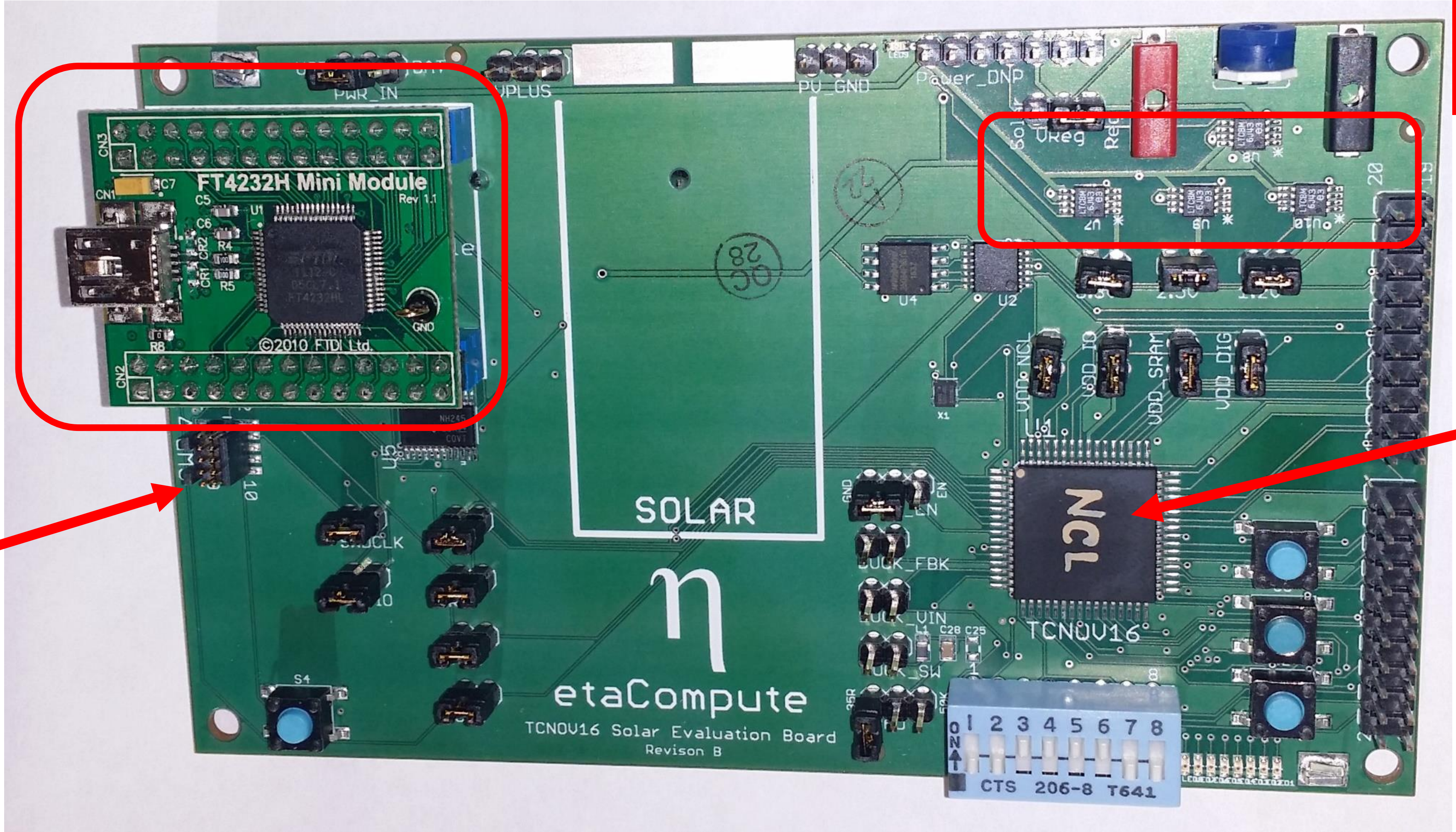
USB Connection
- 5V
- UART/com:
- Front Panel
- SWD/openocd

Regulators
- 3.3V USB
- 2.5V I/O
- 1.2V DIG
- 0.25 DIAL



TEST CHIP

10 PIN Coresight

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Silicon Measurements of ARM Cortex®-M3 based SoC

- TSMC90LP M3 Operation at 5 uW
- Optimizations yielded 30% reduction- more coming
- Standard Eclipse, Keil and Linux debug and development
- Runs >200 kHz directly off solar cell with fluorescent lighting
- Working on 55LP ARM Cortex-M3
  - Further power reductions
  - DSP, ADC, PMIC, RTC

Etacore EH - Performance

EH- enhanced DI
Gen 2 in design now

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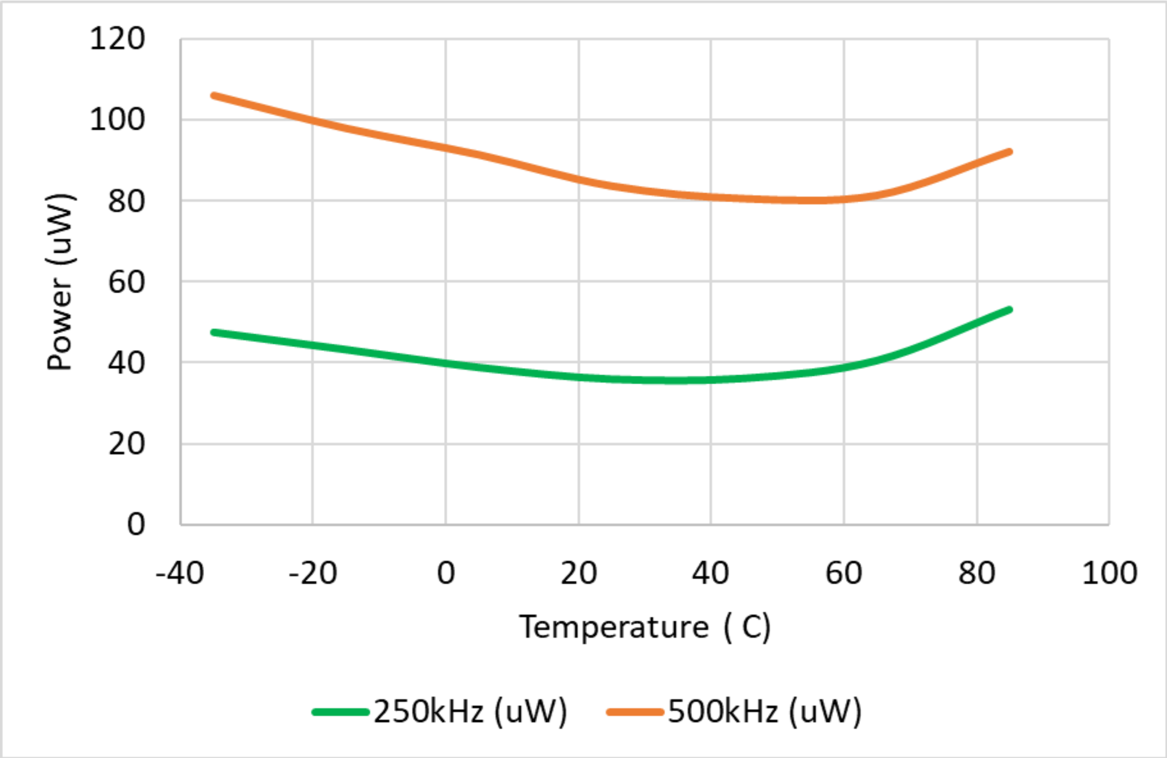
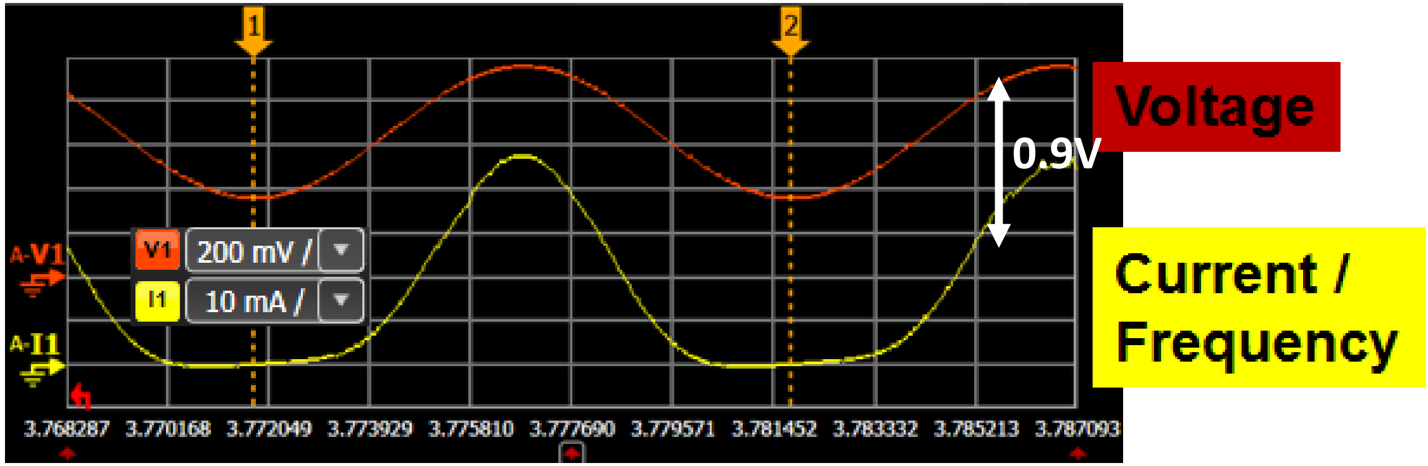
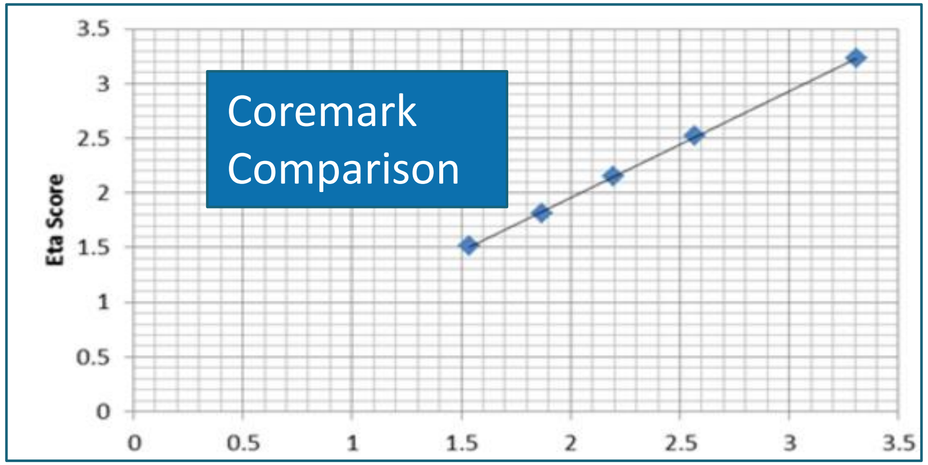
Minimal Power Variation across Temperature



- Constant current- PMIC varies voltage for temp & process compensation

Robust to Power Supply Variation





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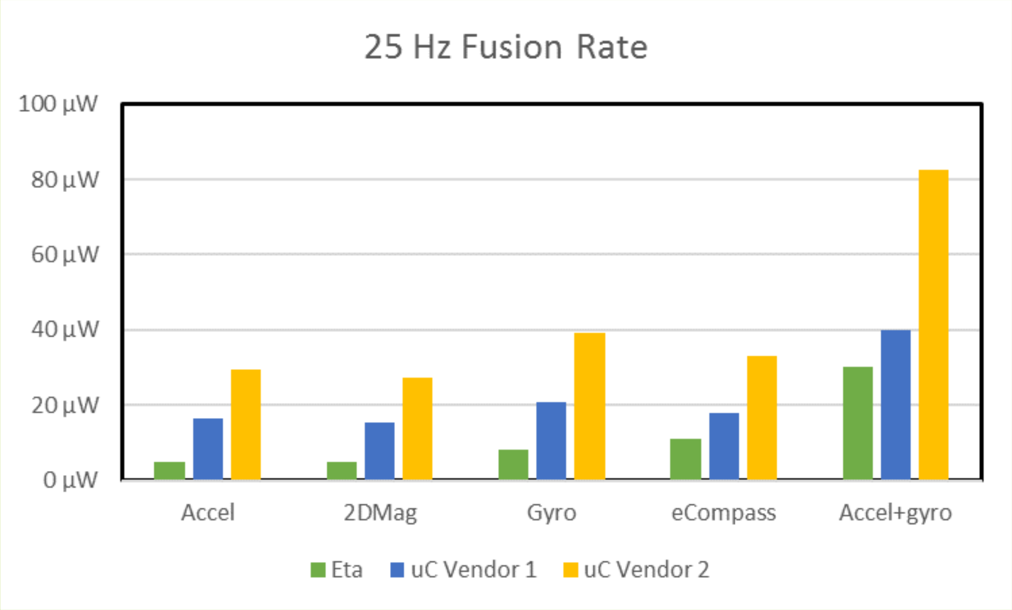
Sensor Fusion Applications

- Sensor hub processing using M4 instruction set
  - A possible next step on our roadmap.
  - Optimized design flow with EtaCore DSP is estimated to reduce power by over 2x compared to these numbers
  - Estimated instruction count from Freescale app note
- Advantage grows exponentially with lower fusion rate
  - eg. Bluetooth Beacon



	State	Time (us)	Current (mA)	Comments
1	Pre-processing	1160	3.26	Radio setup
2	Radio Prep	101	4.3	Radio on / Transition to RX
3	TX	280	6.1	0 dBm, Channel 37, 20 bytes
4	TX to RX Transition	112	4.66	Tx to Rx transition
5	RX	184	6.47	Receive Time
6	RX to TX Transition	370	3.43	Rx to Tx transition
7	TX	280	6.1	0 dBm, Channel 37, 20 bytes
8	TX to RX Transition	112	4.66	Tx to Rx transition
9	RX	184	6.47	Receive Time
10	RX to TX Transition	370	3.43	Rx to Tx transition
11	TX	280	6.1	0 dBm, Channel 37, Aruba - 20 bytes
12	TX to RX Transition	112	4.66	Tx to Rx transition
13	RX	184	6.47	Receive Time
14	Post Processing	685	2.45	Process received packets and go to sleep
	Total On Time	4.414	msec	
	Transmit dutycycle	0.5	sec	

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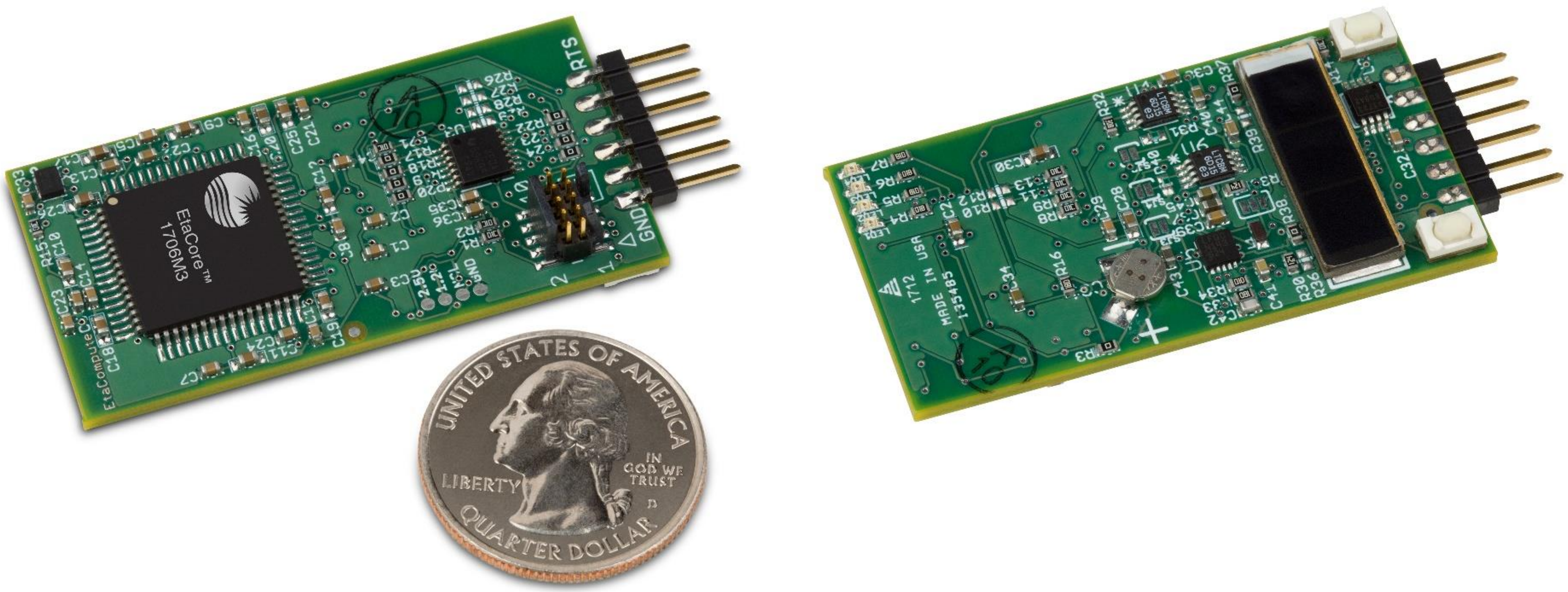
Energy Harvested Edge Node

Based on our fully self timed Cortex M3.



Demonstration

Summary

Where can this technology go, all the way to neuromorphic machine learning at the edge with unsupervised learning

- Unique digital technology that enables always-on sensor nodes
- Enable more processor MIPS at much lower power consumption
- Longer battery life, small size sensor nodes
- We deliver SoC, turnkey sensor boards

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THANK YOU!

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