

Permanently Powered Deeply Embedded Systems

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Full Disclosure

- **Mark E. Buccini**
- **ULP Staff at TI**
- **20+ years strategy, applications, marketing, sales, and management experience**
- **Lead MSP430 worldwide introduction from 1995**
- **An MCU fan**
- **Promise to try and not oversell TI products**



Why a Permanently-Powered System?

- A deeply embedded system
- Convenient
- Battery or EH
- Costly to replace battery
- Greater reliability
- Reduced liability
- *How long is permanent?*



How Long is Permanent?

- Forever – toy - until it breaks
- 20 years – industrial - mechanical failure first
- 10 years – instrumentation - wears out
- 2 years – consumer medical - maintain quality

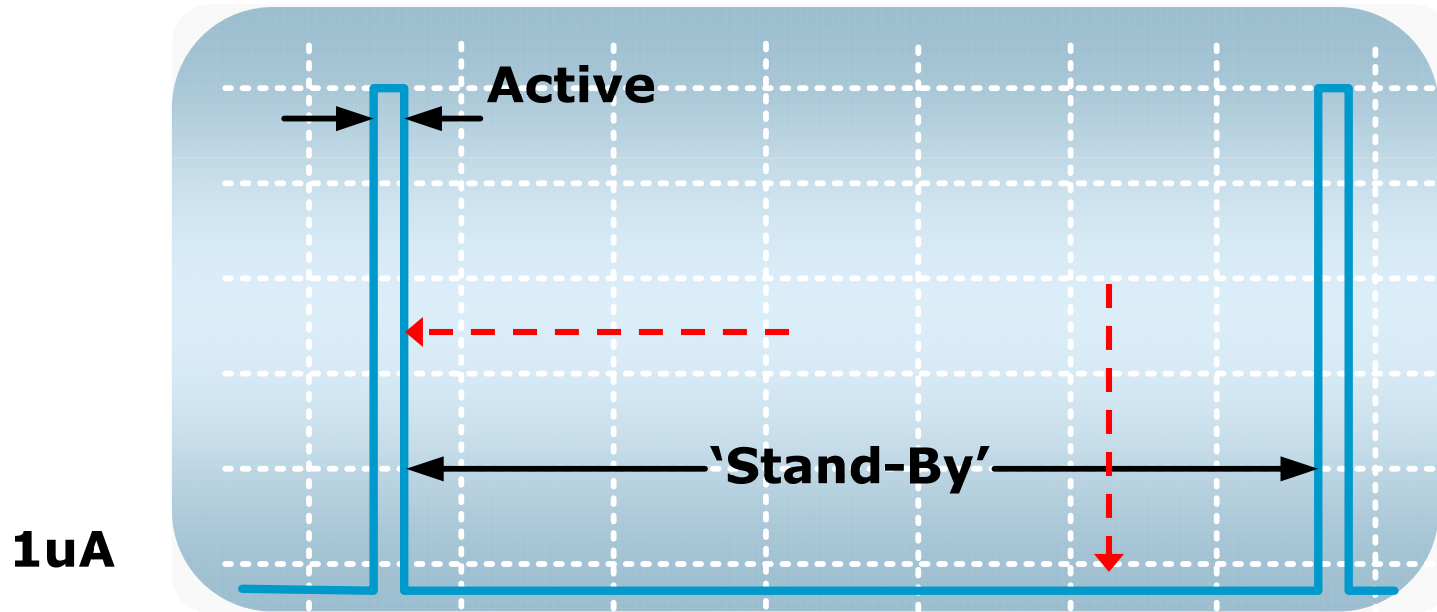


What is a Self-Powered System?

- An embedded systems
- A permanently-powered system
- No primary battery
- Uses Harvested Energy
- “Green”
- ***EH is naturally available***

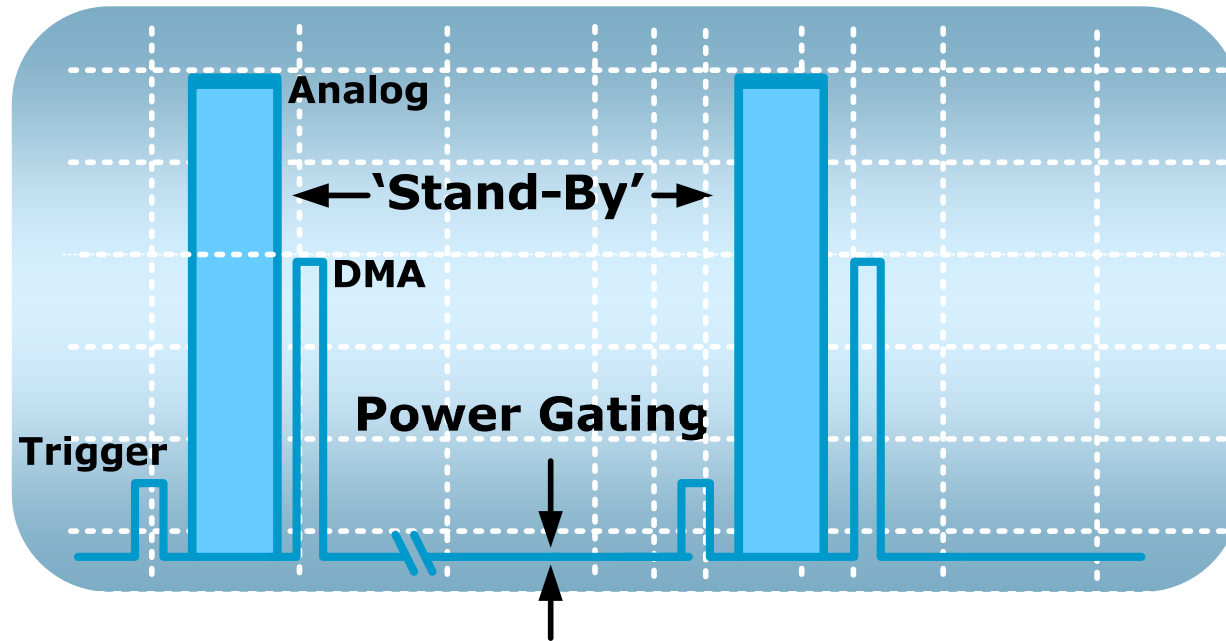


Ultra-low Power Profile



- *Extended **Ultra-Low Power** standby mode*
- *Minimum active duty cycle*
- *Interrupt driven performance on-demand*

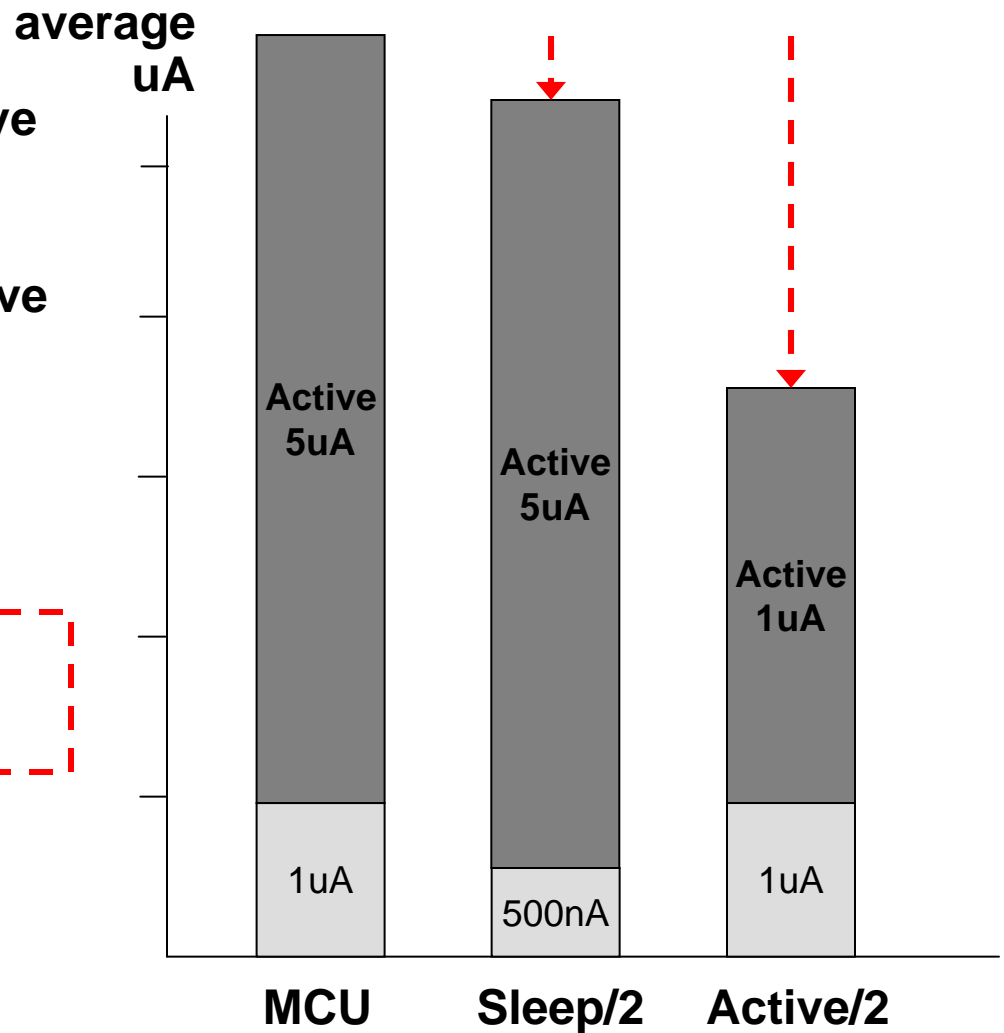
Real World: *Ultra-low Power Profile*



- *Fully autonomous intelligent peripherals*
- *Asynchronous triggers (not software) guarantee timing*
- *Background active mode using DMA*
- *Clocks on demand*
- *Automatic on/off of analog circuits*
- *Power wise firmware a must*

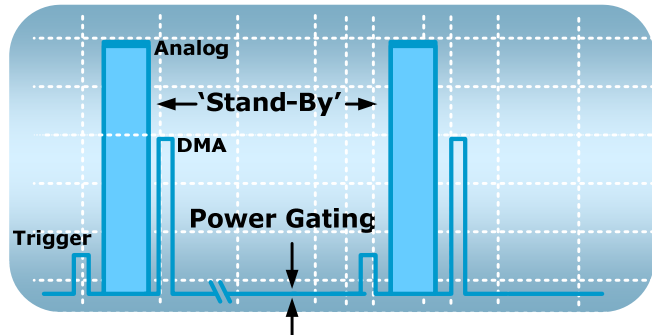
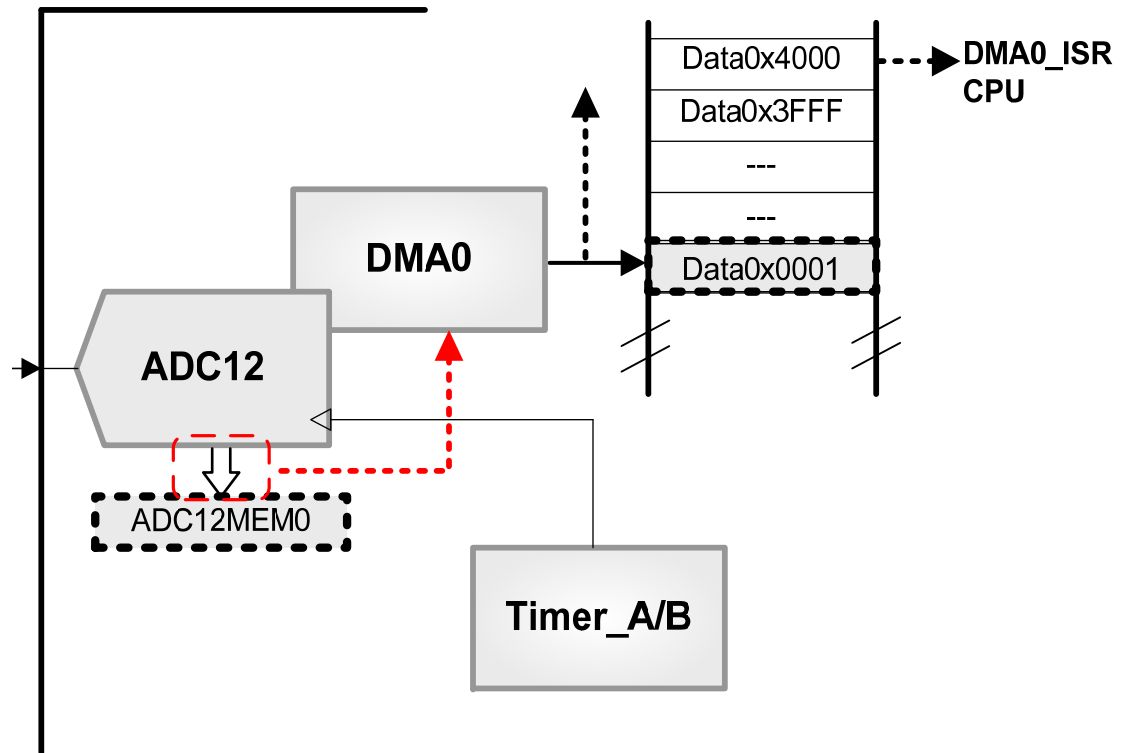
99.5% Sleep Calculation

- **Example: 99.5% Sleep**
Assume 1uA/1mA Sleep/Active
 - Reduce **Sleep/2?** ... or
 - Reduce **Active/2?**
- **Biggest impact reducing Active**
 - Intelligent peripherals reduce CPU load, improve response
 - Fast and agile clocking
 - Power-wise firmware a must!
- **No application sleeps forever**
- **At ~1uA reducing sleep has a diminishing return on total average power**



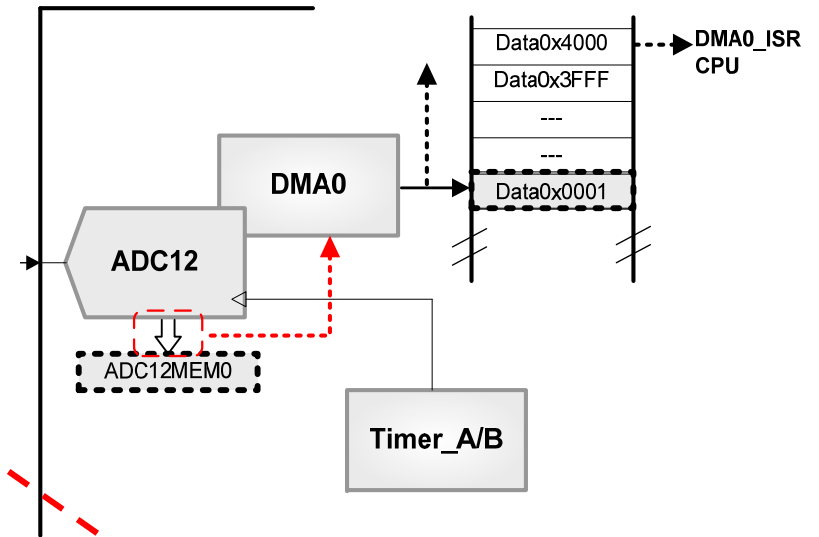
ULP 1ksp/s 12-bit ADC System

- **Standby normal mode**
All peripherals available
- **1kHz ADC timer trigger**
sample/convert
- **DMA automatic data transfer to RAM**
- **CPU process 1k sample on interrupt**



ULP 1kps 12-bit ADC System Results

```
// MSP430F2619
// -----
// LPM3 32kHz = 1.0uA
// Timer_A = 0.2uA
// ADC12 1kps = 4.2uA
// DMA 1kps = 2.0uA
// Mainloop = 0.2uA
// -----
// Total 7.6uA
```



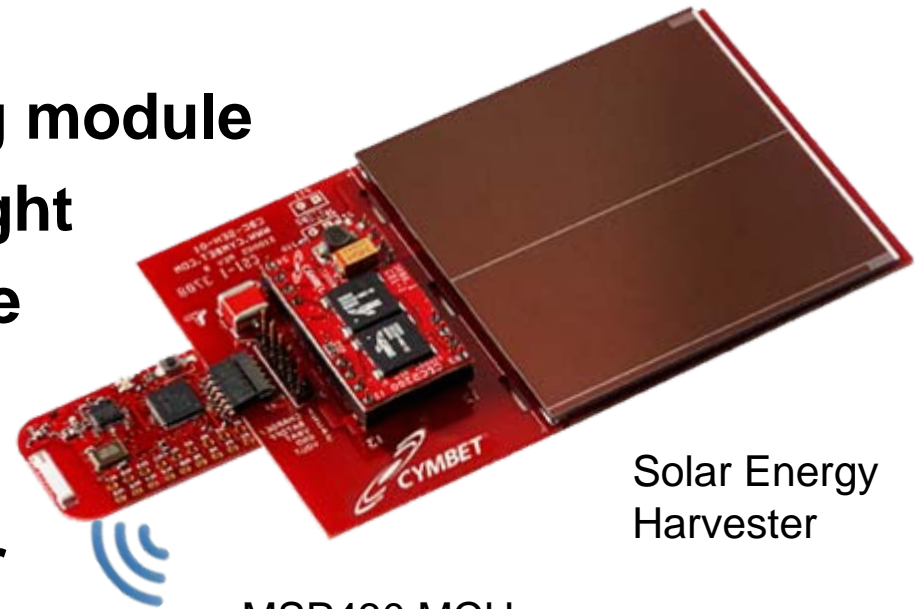
~Divide / 200

PARAMETER	TEST CONDITIONS	V _{CC}	MIN	TYP	MAX	UNIT
I _{ADC12} Operating supply current into AV _{CC} terminal (see Note 3)	f _{ADC12CLK} = 5 MHz, ADC12ON = 1, REFON = 0, SHT0 = 0, SHT1 = 0, ADC12DIV = 0	2.2 V		0.65	0.8	mA
		3 V		0.8	1.0	

Data Sheet = 200kps!

eZ430-RF2500-SEH

- **Solar Energy Harvesting module**
- **Works in low ambient light**
- **Negligible self-discharge**
- **400+ transmission with no light**
- **Adaptable to any sensor and RF network**

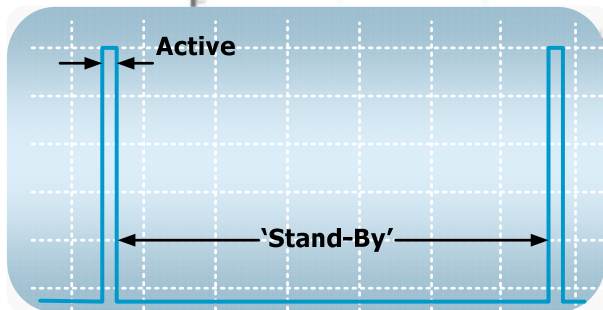
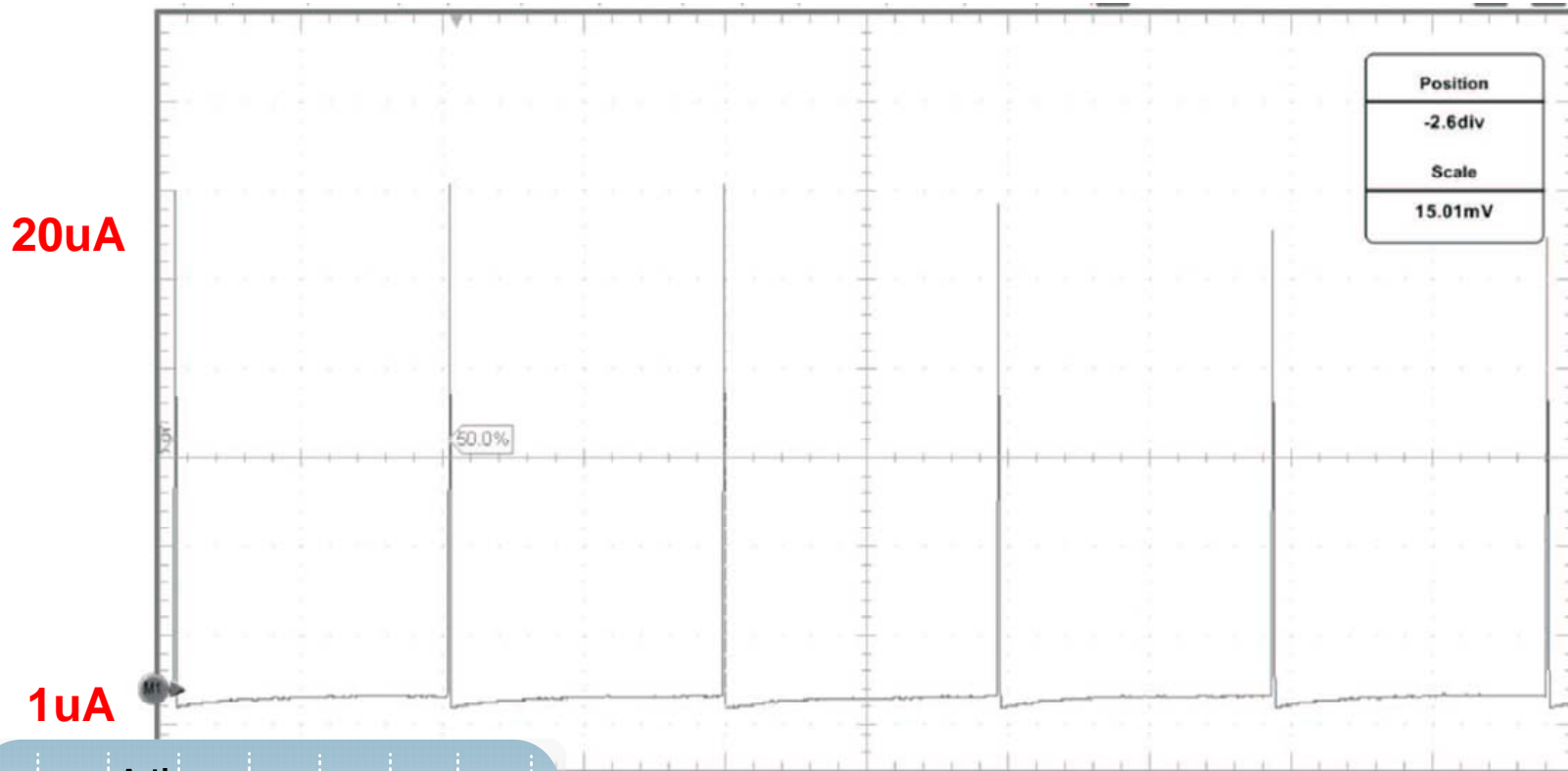


Solar Energy Harvester

MSP430 MCU
Sensors
CC2500 2.4GHz RF

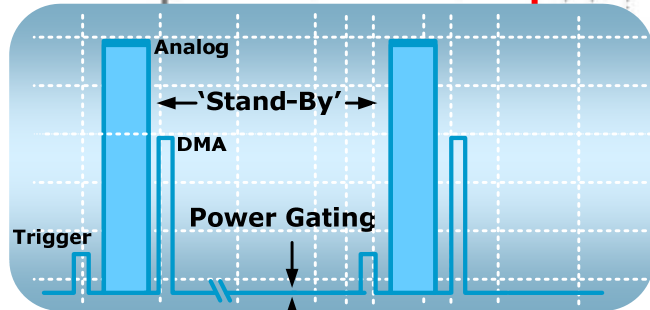
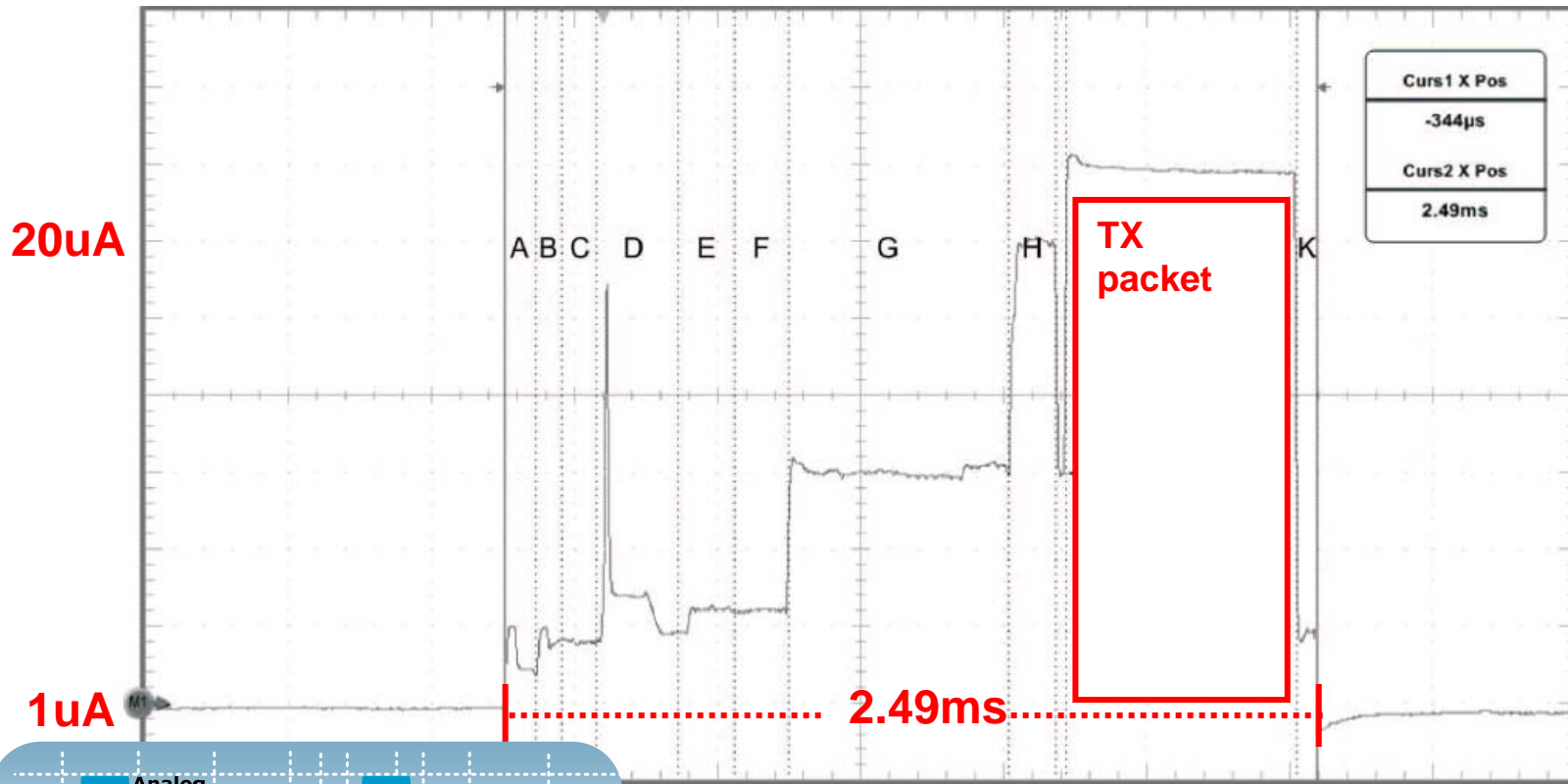


WSN Activity Profile



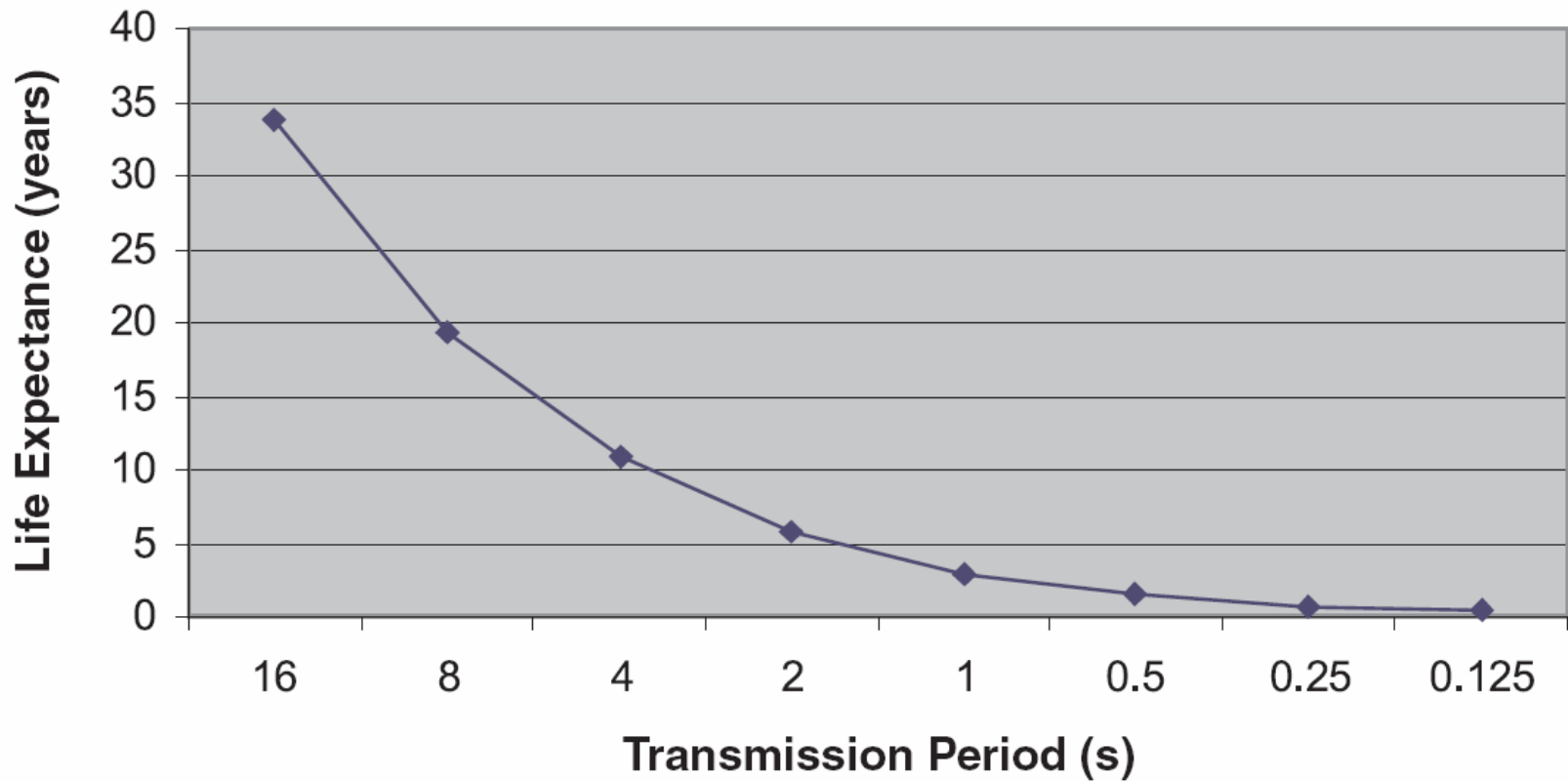
- *Sample MCU temp sensor and VCC*
- *Prepare and transmit RF 2.4 GHz packet*
- *Very low active duty cycle*

WSN Details



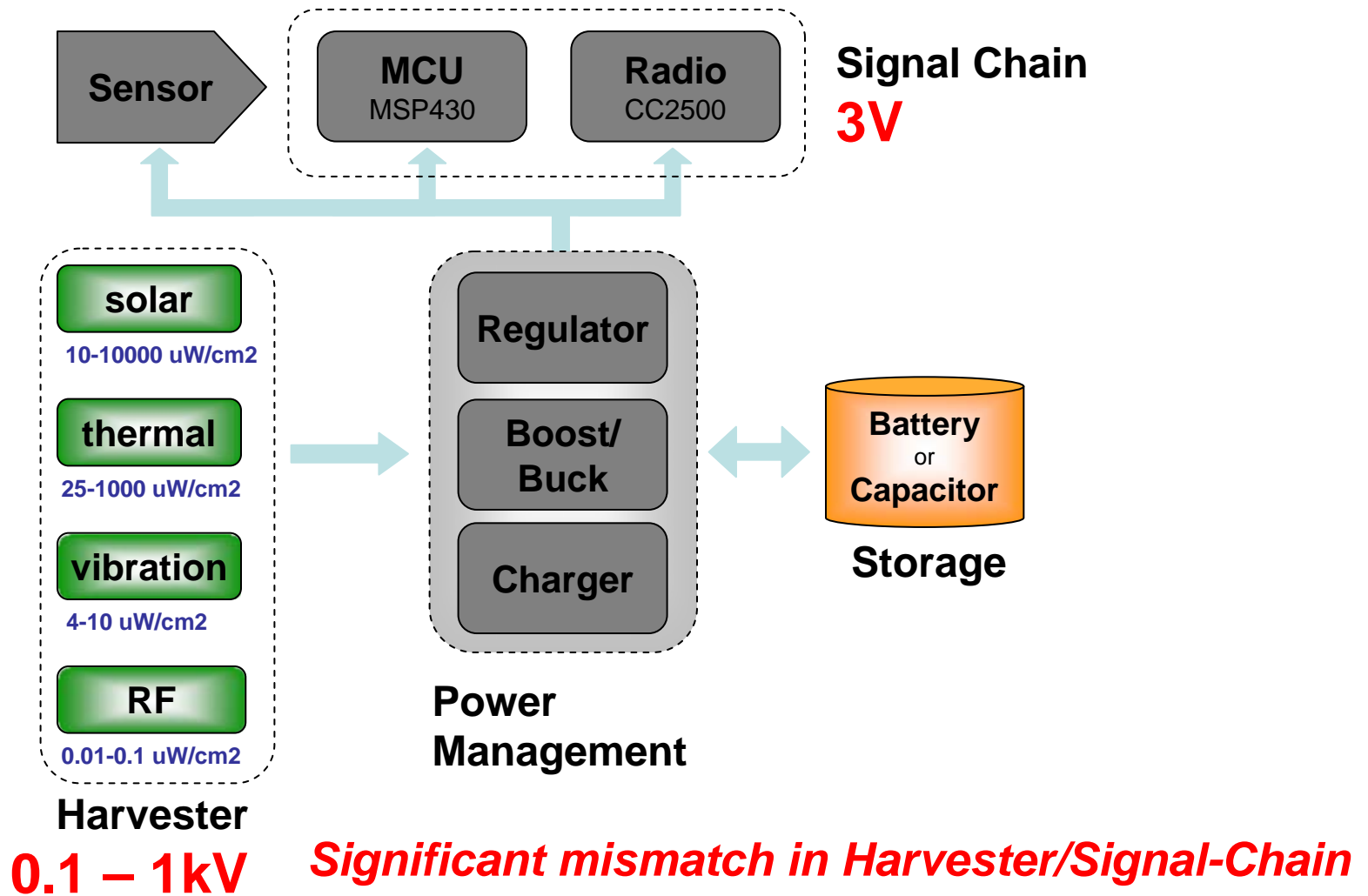
- **2.49ms TX packet**
- **1uA baseline sleep**
- **9uA on average @ TX packet 5s interval**

WSN Duty Cycle



Duty Cycle Drives Battery Life

Self-powered Embedded System



Batteries?



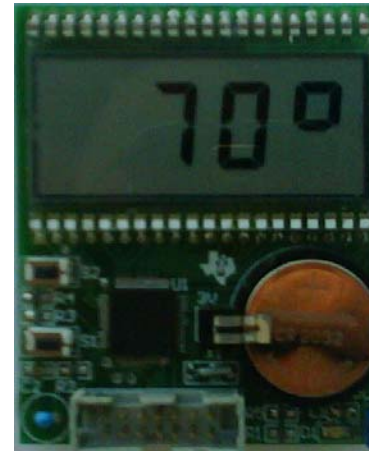
	AA x2	CR2032	CR123A
Voltage	1.5V x2	3V	3V
Discharge	Sloping	Flat	Flat
Capacity	2500mAh	220mAh	1500mAh
Capacity to 2.55V	1250mAh	220mAh	1500mAh
Impedance	0.14ohm	30ohm	0.5ohm
Leakage (21C)	3%	1%	1%
10-year Op Current	9.8uA (??)	2.2uA	15.4uA
Cost	\$0.50	\$0.20	\$2.00

~ **7uW** /10-years ~ **46uW** /10-years

Permanently Powered Embedded System



- *~9 μ A average*
- *1500mAh CR123A capacity*
- *12-year+ battery life (5s sample)*



- *~2 μ A average*
- *220mAh CR2032 capacity*
- *10-year+ battery life*

Permanently Powered Systems

- **How long is “permanent” – what is good enough?**
- **Real world is not a demo ... is not *while(1)***
- **1uA standby/sleep is starting point**
- **Reducing active power has a significant impact**
 - Intelligent peripherals reduce load, improve performance
 - Duty cycle to minimum practical
 - More data, fewer TX intervals, mitigate fixed overhead
 - Power wise firmware an absolute must
- **Active power is application-specific and a complex system interaction**

Thank You