



Chip-Scale Energy and Power... and Heat

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Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE MAR 2009		2. REPORT TYPE		3. DATES COVERED 00-00-2009 to 00-00-2009	
4. TITLE AND SUBTITLE Flexibility for Ultra Low Power				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Virginia,Electrical and Computer Engineering Department,Charlottesville,VA,22904				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES MTO (DARPA Microsystems Technology Office) Symposium, 2009, Mar 2-5, San Jose, CA. U.S. Government or Federal Rights License					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 22	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Flexibility for Ultra Low Power

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Sub-threshold ($V_{DD} < V_T$) Survey

- Sub-threshold benefits
 - Leakage Power Decreases: 5X to 90X
 - Energy Consumption Decreases: 10X to 20X
 - E_{total} /operation minimized in sub- V_T
 - Aging Effects Improve: NBTI, EM, TDDB
- Challenges
 - Lower $I_{\text{on}} / I_{\text{off}}$
 - Variation
- State of art
 - Logic, SRAM, arithmetic units, processors, simple systems

Key Remaining Problems for Sub-threshold Operation in Systems

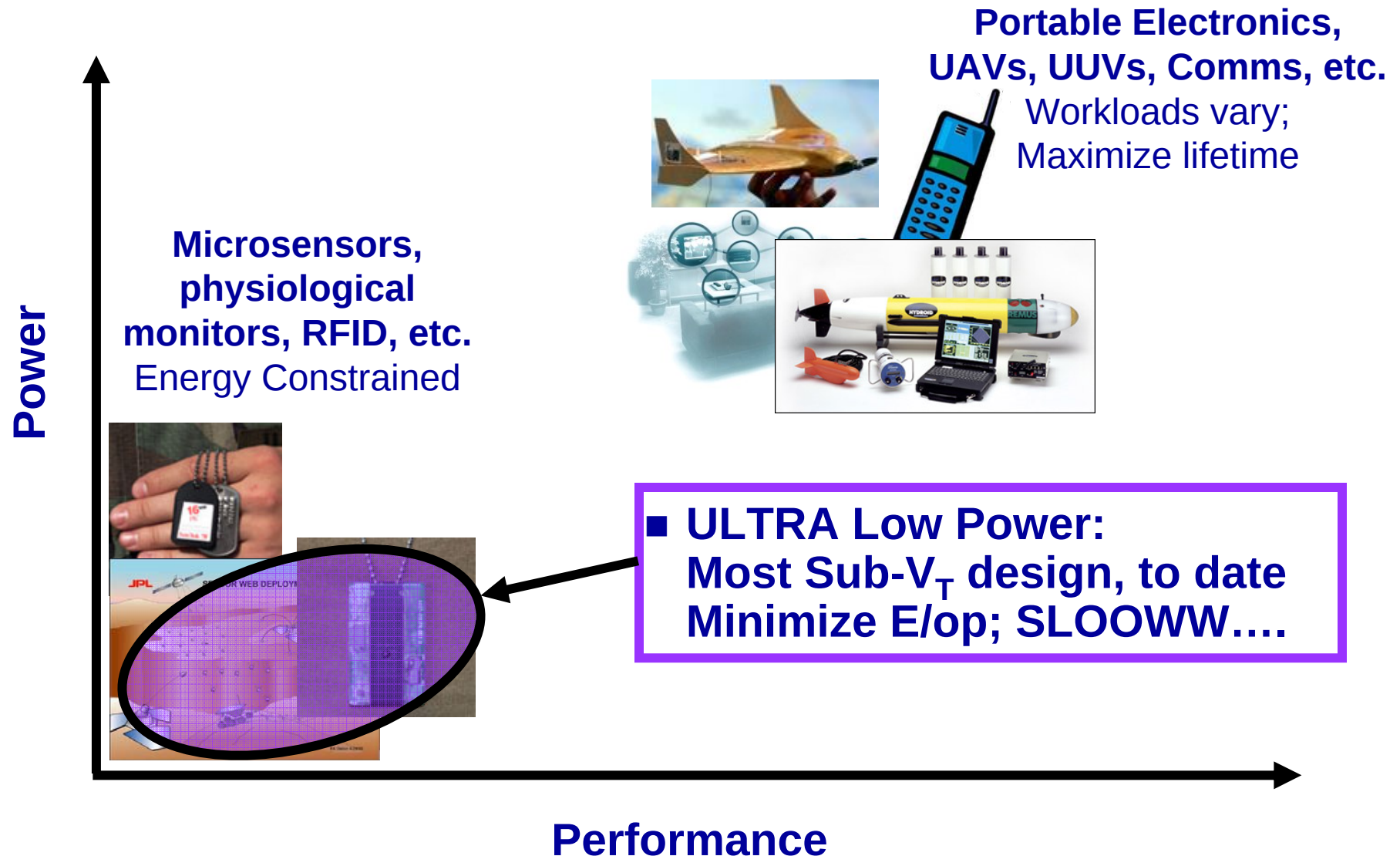
1. Very slow
2. Best efficiency comes from ASIC, but costly and slow for new applications
3. Digital power a small piece of pie in many ULP systems

Outline

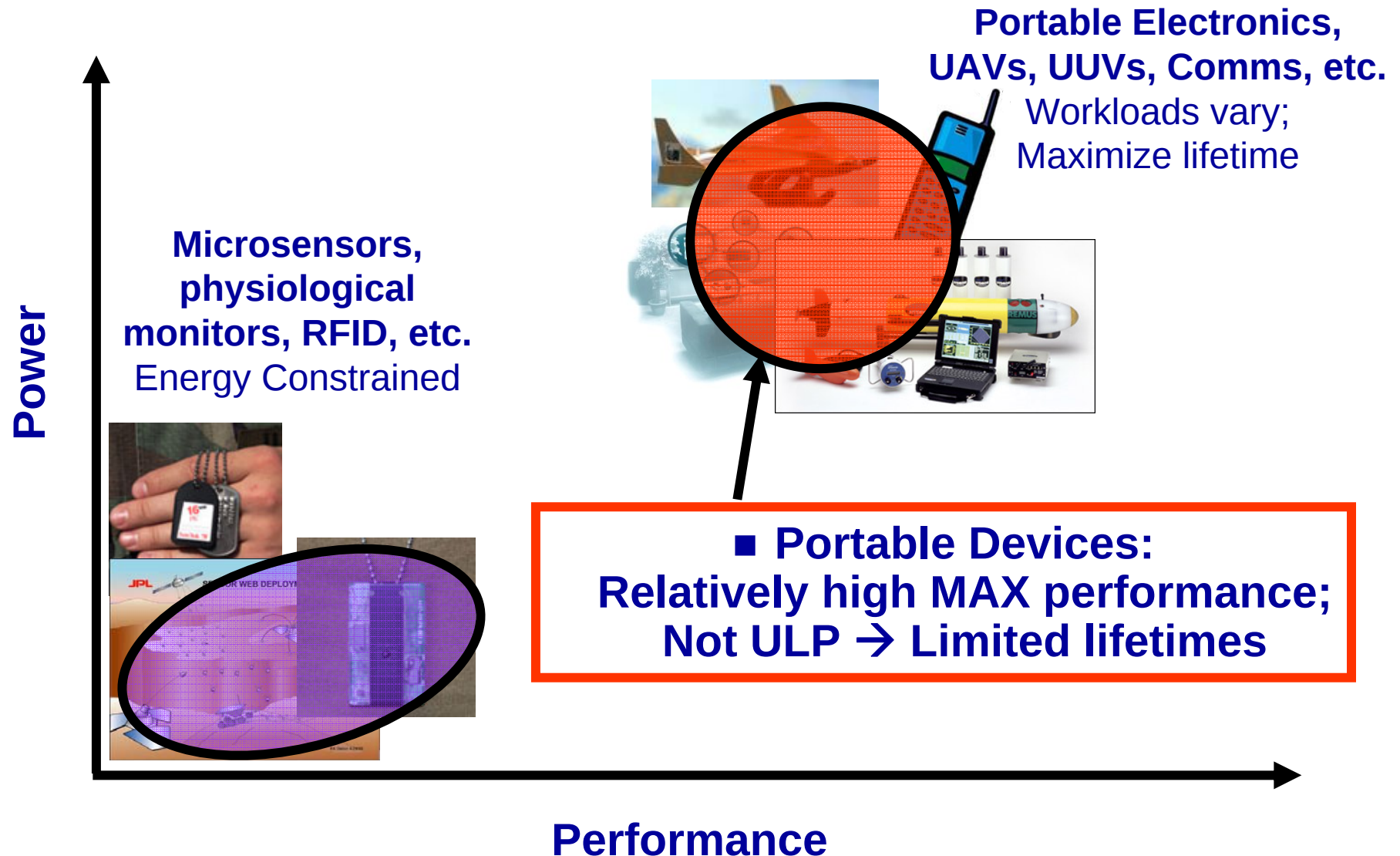
THESIS: Flexibility can help solve the key problems facing sub-threshold systems

- Energy / Performance Flexibility
- Hardware Flexibility
- System-Level Flexibility

“Low Power” Application Space



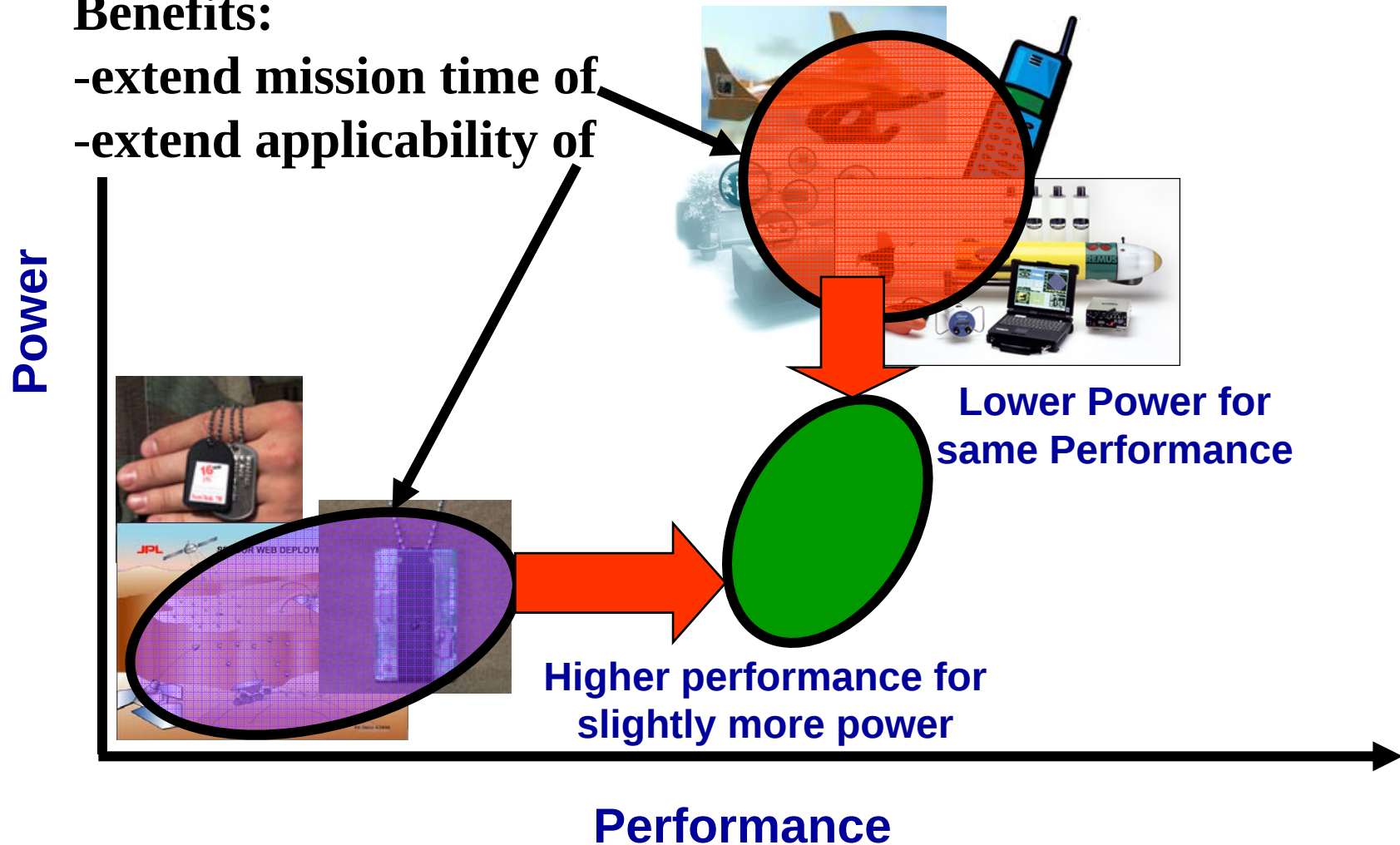
“Low Power” Application Space



Proposed Energy/Performance Flexibility

Benefits:

- extend mission time of
- extend applicability of



How will we do this?

- Key insight: Definition of Performance

Old definition: Fixed speed or throughput

**Accurate definition: Speed or throughput
required to get “the job” done**

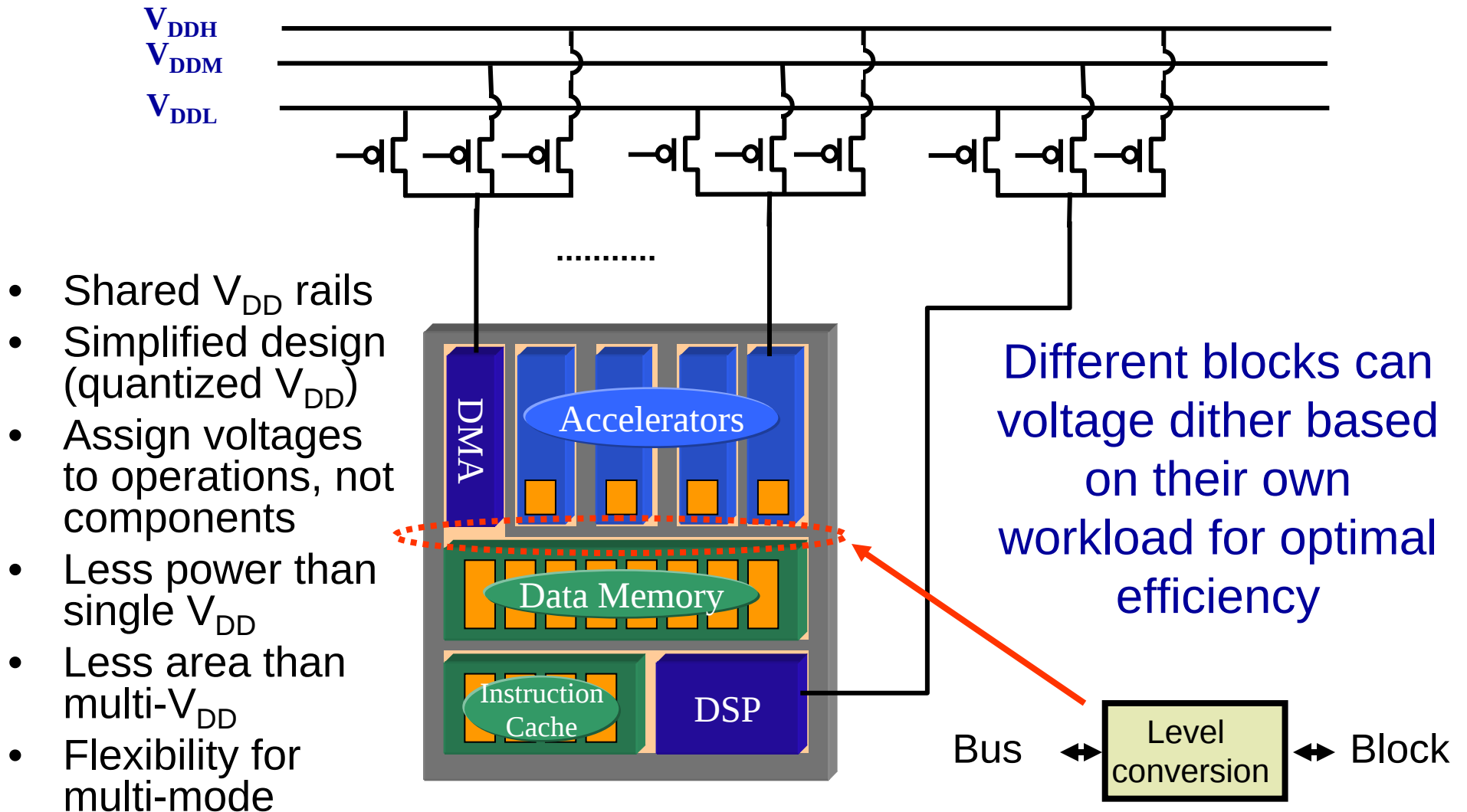
“The job” changes:

**→ a range of performance requirements
for a single app, depending on what
is going on**

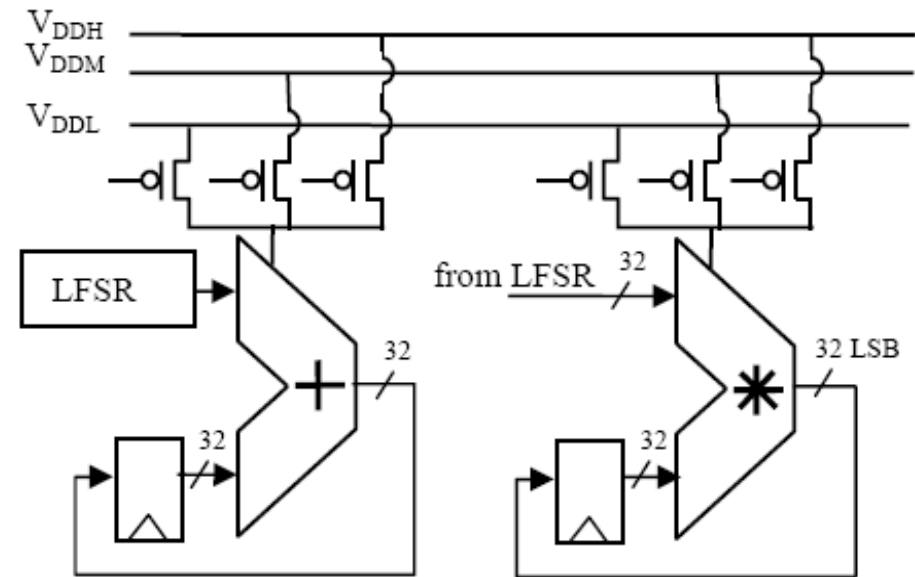
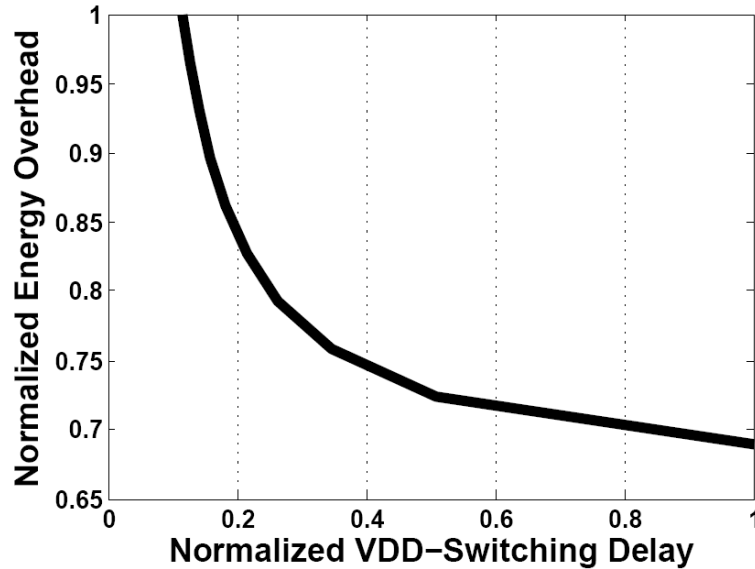
Proposed Approach

- Maximize efficiency of multi- V_{DD} design
 - Voltage is most effective knob
- Panoptic Dynamic Voltage Scaling (PDVS)
 - Multi- V_{DD} s (~ 2 -4 voltage rails), local headers
 - Fully enables classical DVS
 - UDVS possible (hop to sub-threshold)
 - Finer *spatial* and *temporal* granularity
 - Multiple inherent power modes
 - Simple, low overhead implementation
 - LOTS of flexibility

Example System: Apply PDVS to ASIC



V_{DD} -switching energy



90nm Test Chip

Measured E overhead
to find number of
cycles at V_L to break even:
 $< 1!!$

$$N_{BE} = \frac{(E_{High} - E_{Low})}{E_{switch}}$$

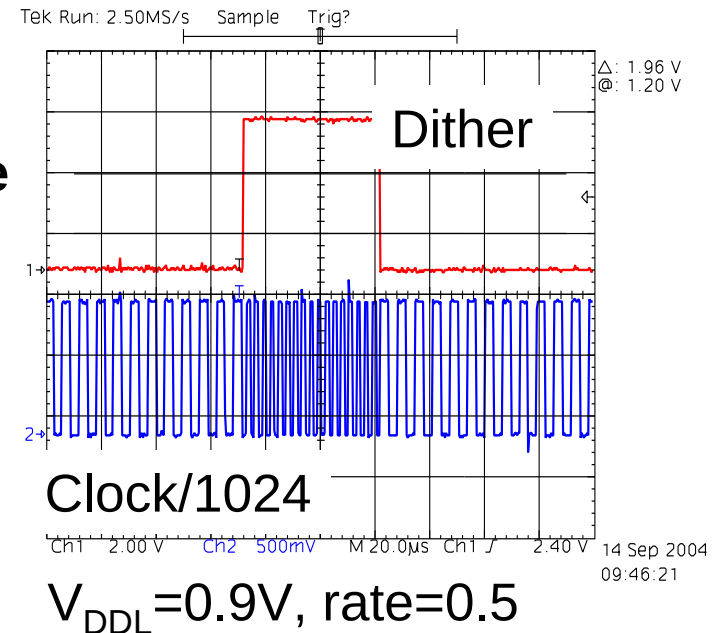
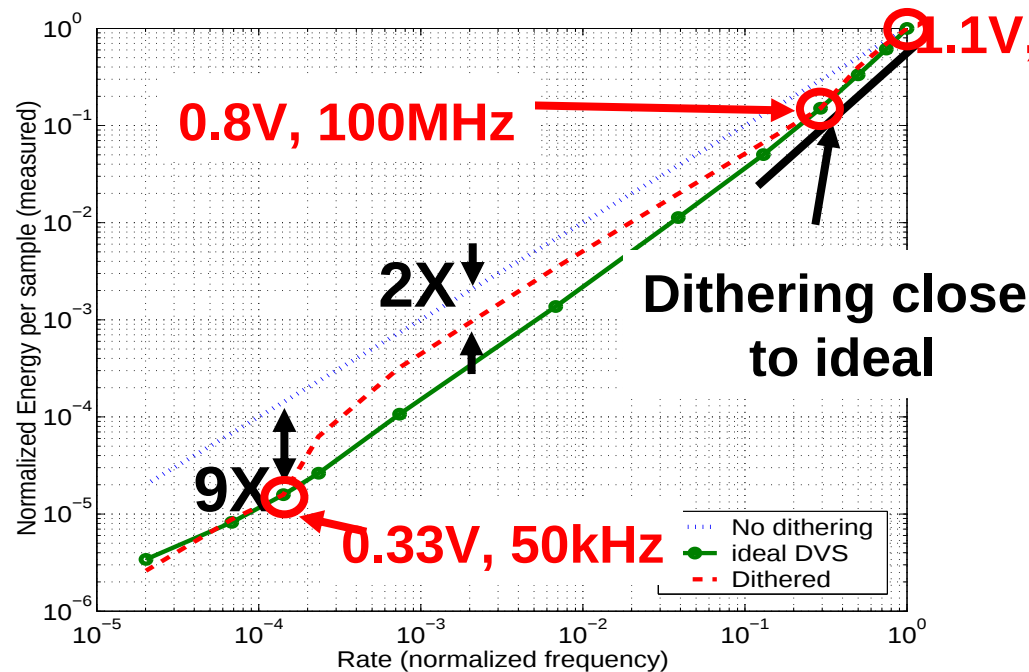
[ICCD, 2008]

Low Supply Voltage	Adder Break Even Cycles	Multiplier Break Even Cycles
0.9	0.689	0.436
0.8	0.579	0.408
0.7	0.607	0.263
0.6	0.721	0.328

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UDVS: ULP (Sub- V_T) Option

Dither during high performance operation and switch to sub-threshold minimum energy operation when speed is not important



Calhoun & Chandrakasan, "Ultra-Dynamic Voltage Scaling Using Sub-threshold Operation and Local Voltage Dithering in 90nm CMOS," ISSCC, 2005.

Outline

- Energy / Performance Flexibility
- Hardware Flexibility
- System-Level Flexibility

The Problem: Many ULP Applications

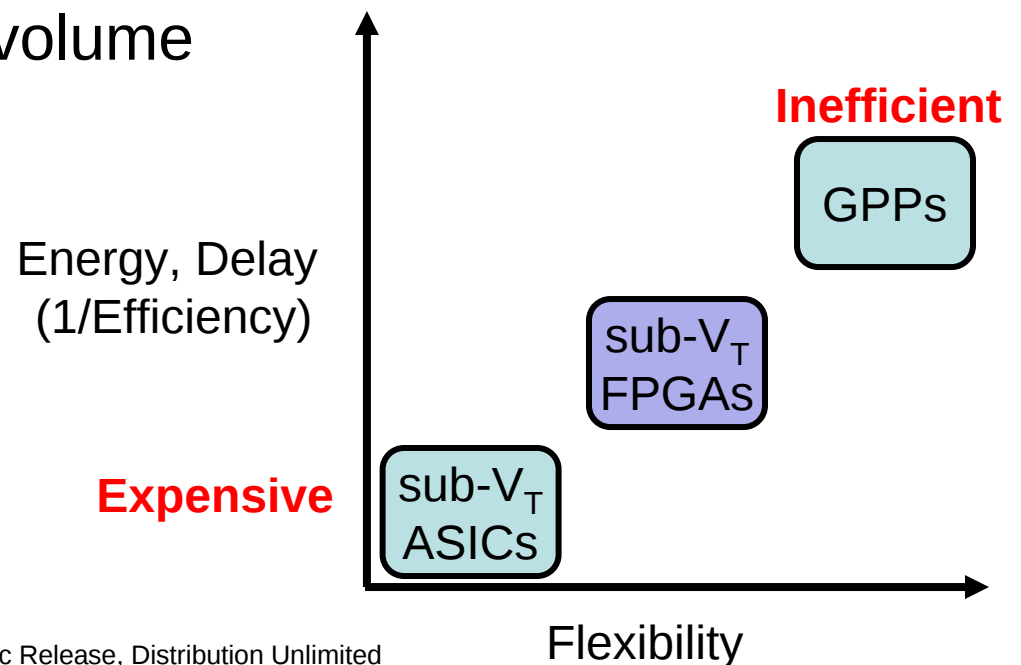
- Lots of apps (microsensors, RFID, tracking nodes, biotelemetry, micro-UAVs, hybrid insects, etc.)



- Need ULP (sub- V_T) for feasibility
- Economics: Often low volume

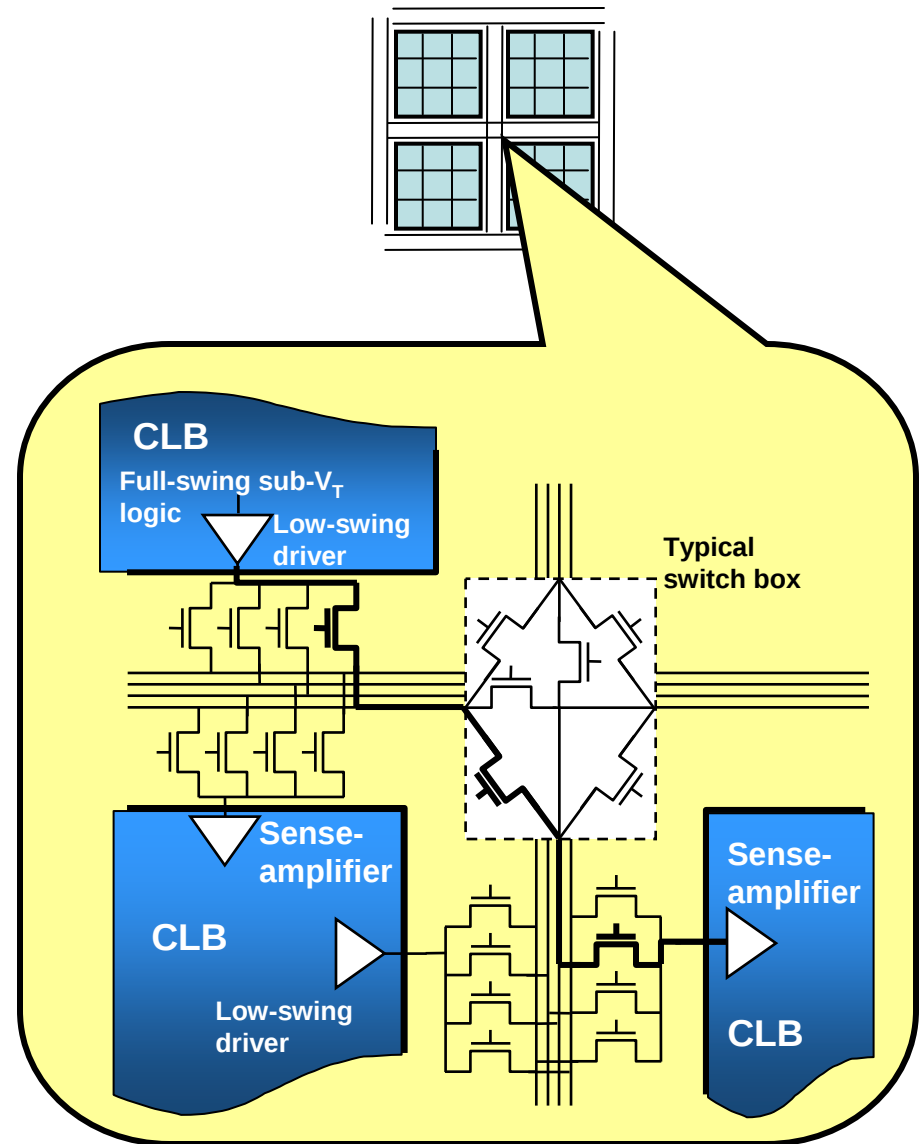
Sub- V_T FPGA:

- Flexible, portable
- Low time-to-deployment
- Mission-specific efficiency
- Low unit cost



Ultra Low Power FPGA

- **Challenges to sub- V_T FPGA**
- **Variation, low I_{on}/I_{off}**
- **Interconnect dominates delay and power**
- **Approach**
 - Low swing interconnect w/ sub-threshold sense amplifier
 - Regularity to reduce variation sources
 - Modified SRAM for config bits
- **Anticipated Result**
 - > 20X energy reduction
 - Tapeout spring 2009



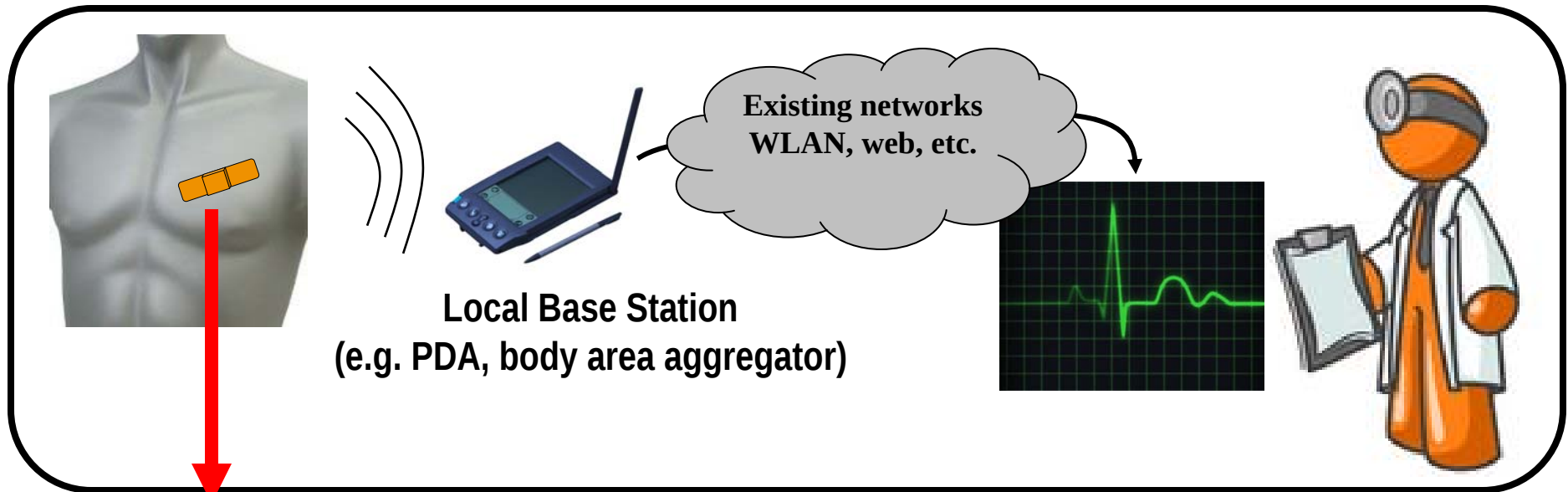
Outline

- Energy / Performance Flexibility
- Hardware Flexibility
- **System-Level Flexibility**

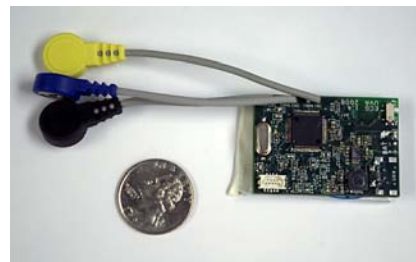
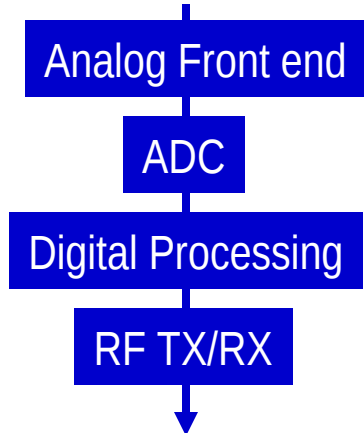
System Level Flexibility

- Must consider system power breakdown
- Radio often dominates
- Leverage ULP digital (e.g. pre-process to reduce wireless data rate)
- Example system: ECG on a band-aid

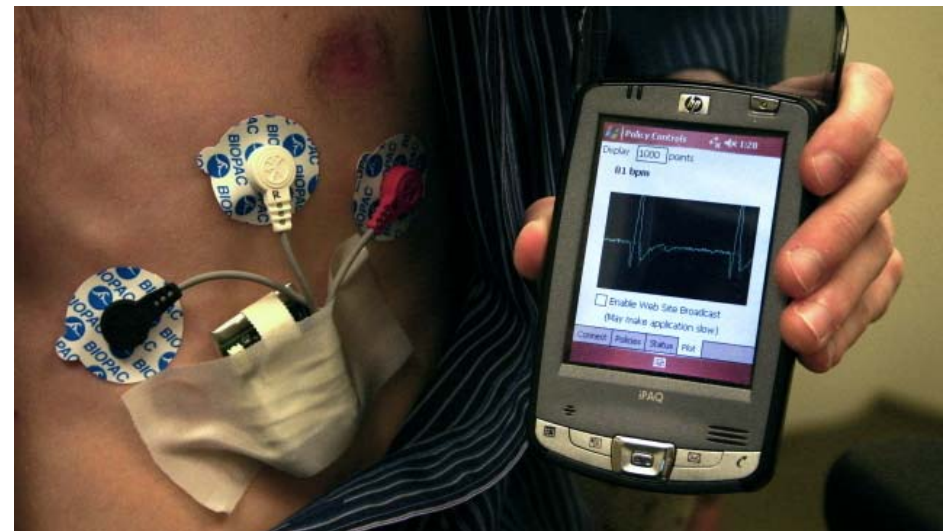
Example: ECG Monitoring System



ECG sensing "patch"



Discrete prototype

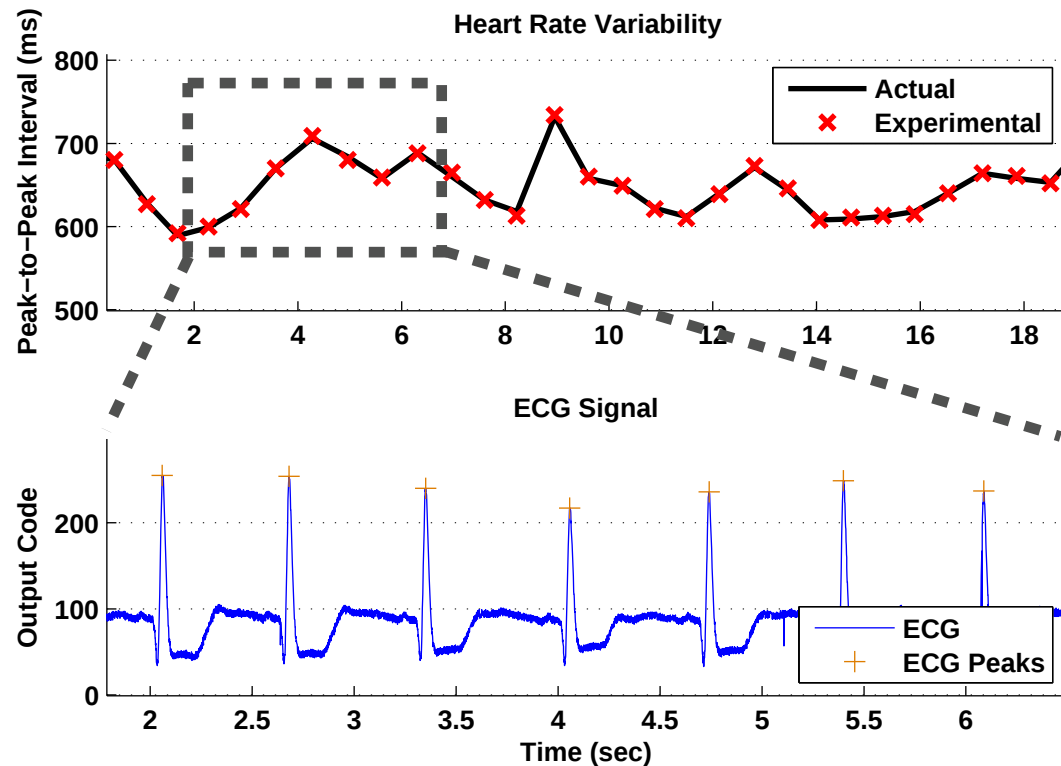
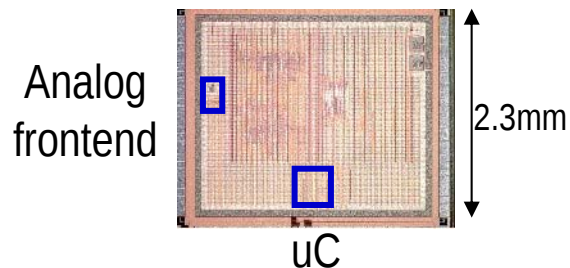
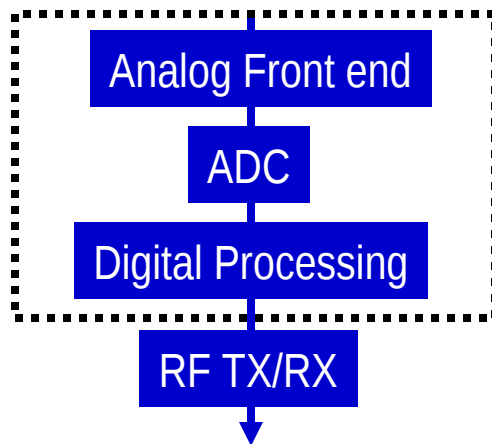


[with T. Blalock (UVA, ECE)]

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Mixed Signal ECG System on Chip

ECG sensing “patch”



Leverage Sub- V_T processing by re-partitioning tasks at system level

Heart rate computation cuts wireless data rate by 500X

[with T. Blalock (UVA, ECE)]

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Conclusions

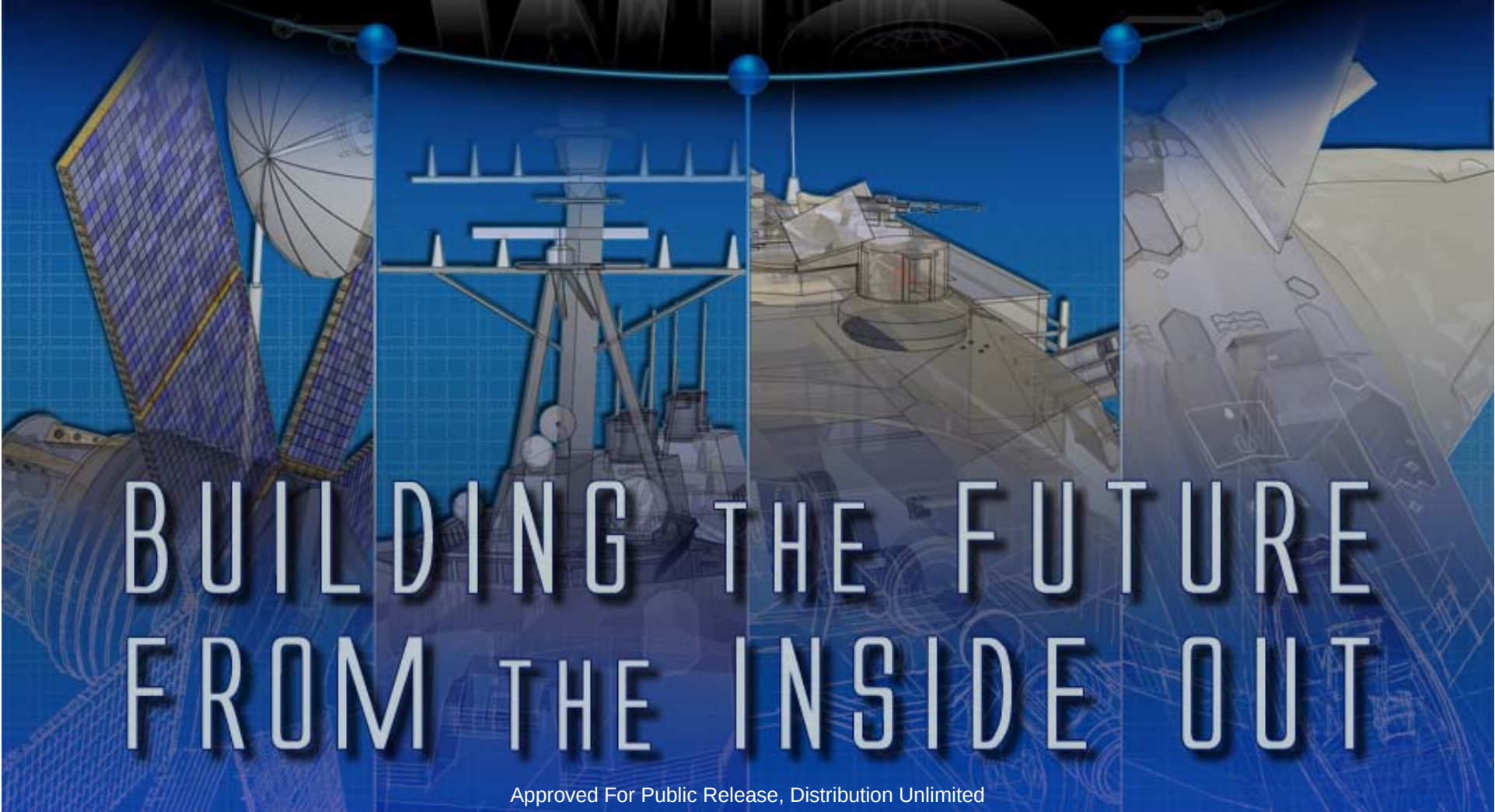
- Flexibility solves key problems for sub- V_T systems
 - Energy/performance flexibility
 - Hardware flexibility
 - System flexibility
- Thank you! Any questions?

MICROSYSTEMS TECHNOLOGY OFFICE

MTO SYMPOSIUM

The logo for the Microsystems Technology Office (MTO) Symposium. It features the letters 'MTO' in a large, bold, metallic font. The 'O' is a circle containing a globe with the word 'DARPA' on it. Circuit traces extend from the 'M' and 'O'. Below 'MTO' is the word 'SYMPOSIUM' in a smaller, white, sans-serif font. The entire logo is set against a dark background with a reflection effect below it.

BUILDING THE FUTURE
FROM THE INSIDE OUT

The background of the poster is a collage of various technological and infrastructure elements. On the left, there's a large satellite dish and a solar panel array. In the center, a complex antenna structure is visible. On the right, there's a large, modern building with a glass facade. The entire background is in shades of blue and white, with a grid pattern overlaid. A thin blue line with three blue spheres runs horizontally across the middle of the image.

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