Ultra Low Power Electronics in the Next Decade

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Texas Instruments Inc.
Dallas, USA
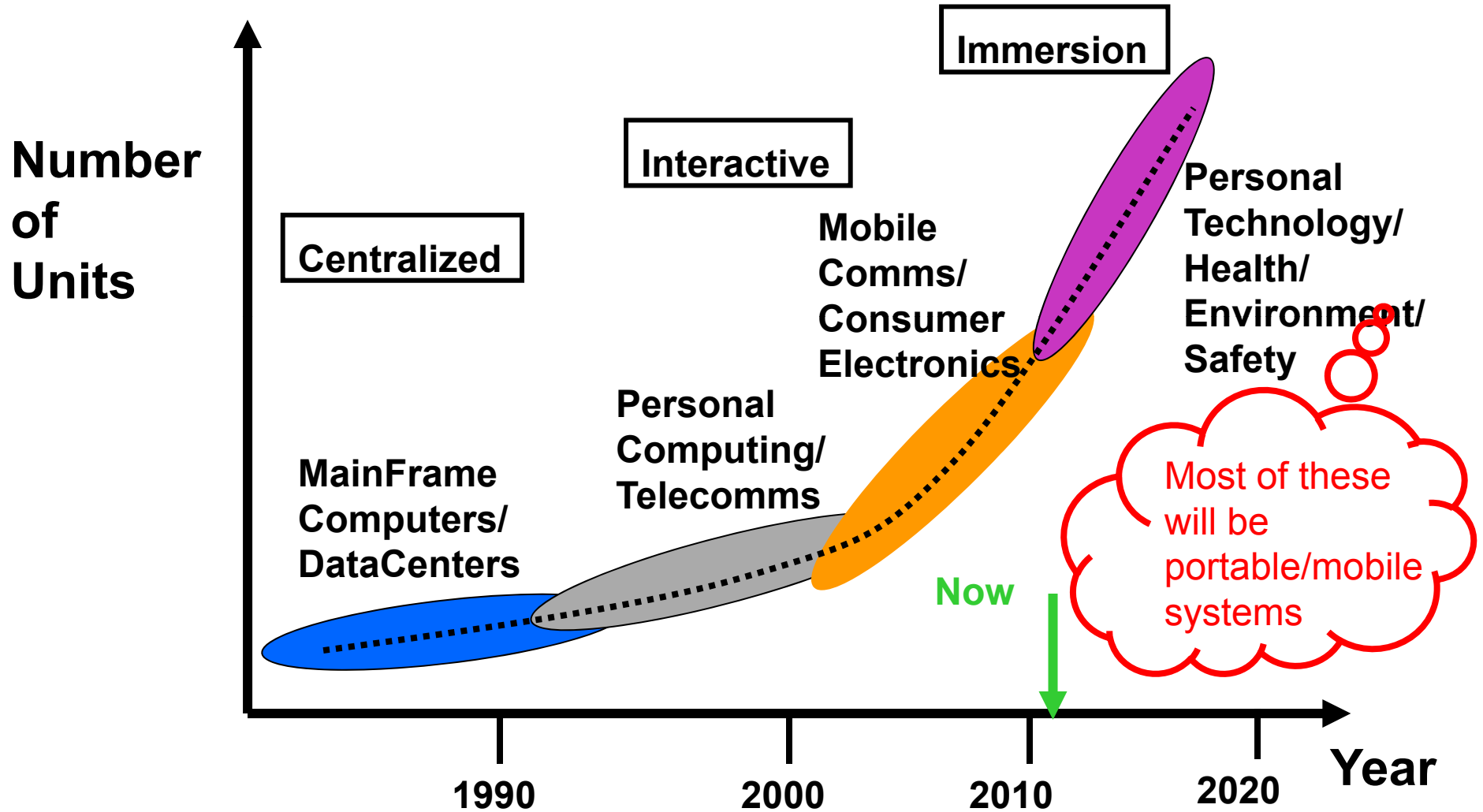**February 2012**
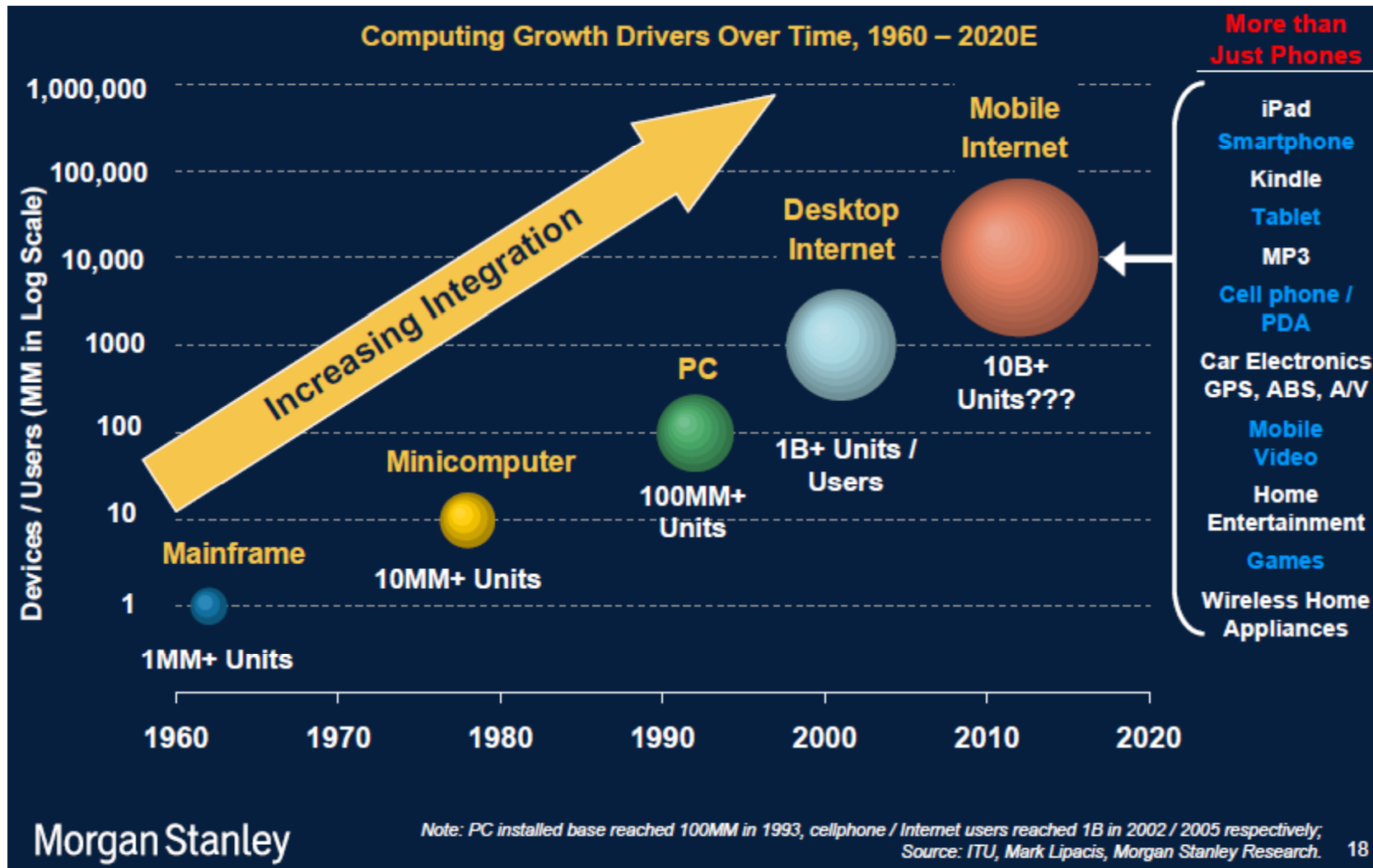
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SSCS Distinguished Lecture

OUTLINE

- Growth in Electronics

- What Do We Need?

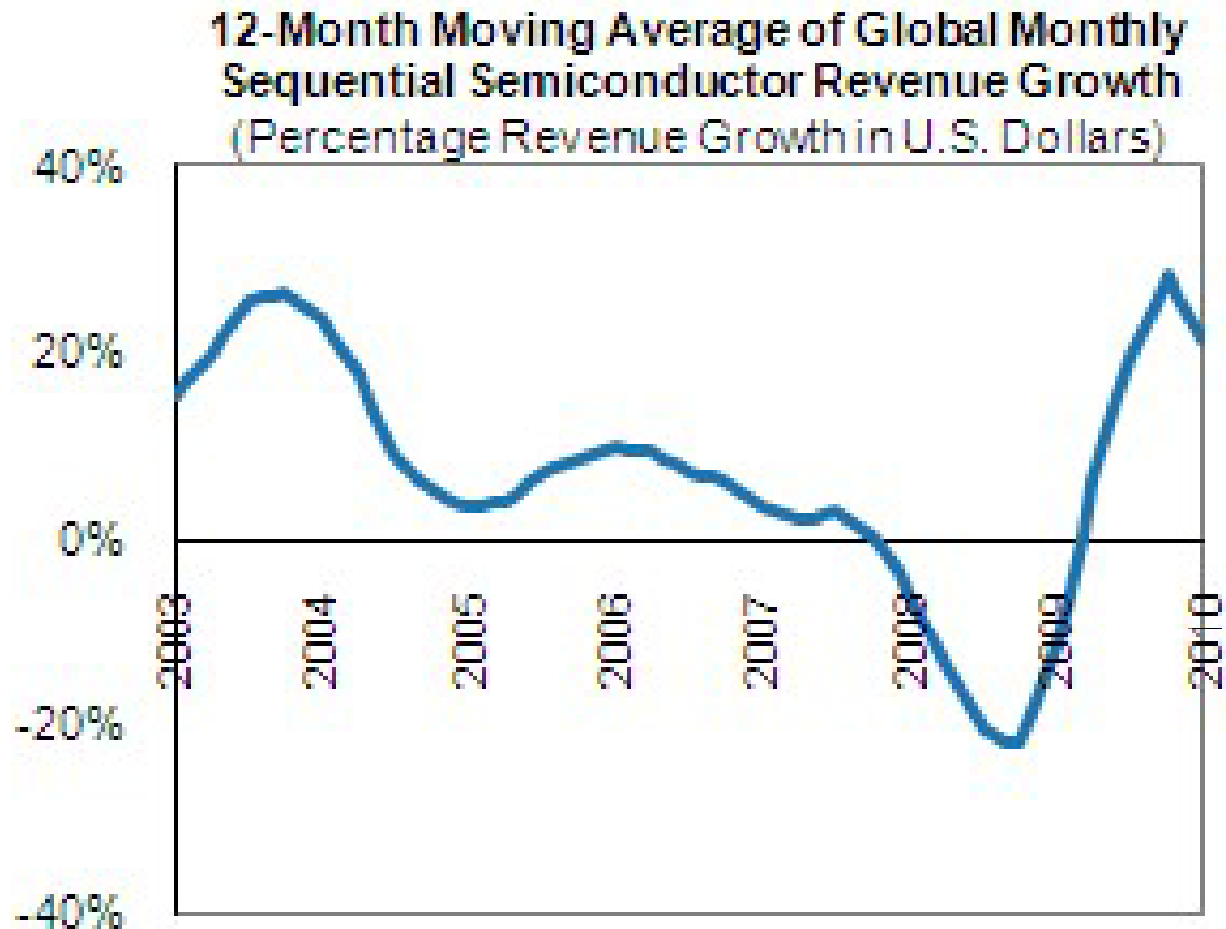- Next Steps in Low Power Electronics

- Key Challenges

- Conclusion

Growth in Electronics

Number of Units (y-axis)

Year (x-axis): 1990, 2000, 2010, 2020

Centralized
MainFrame Computers/ DataCenters

Interactive
Personal Computing/ Telecomms

Mobile Comms/ Consumer Electronics

Immersion
Personal Technology/ Health/ Environment/ Safety

Now

Most of these will be portable/mobile systems

10x to 100x Increase in Units

Computing Growth Drivers Over Time, 1960 – 2020E

More than Just Phones

- iPad
- Smartphone
- Kindle
- Tablet
- MP3
- Cell phone / PDA
- Car Electronics GPS, ABS, A/V
- Mobile Video
- Home Entertainment
- Games
- Wireless Home Appliances

Devices / Users (MM in Log Scale)

y-axis: 1,000,000 / 100,000 / 10,000 / 1000 / 100 / 10 / 1

Increasing Integration

- Mainframe — 1MM+ Units
- Minicomputer — 10MM+ Units
- PC — 100MM+ Units
- Desktop Internet — 1B+ Units / Users
- Mobile Internet — 10B+ Units???

x-axis: 1960 1970 1980 1990 2000 2010 2020

Morgan Stanley

*Note: PC installed base reached 100MM in 1993, cellphone / Internet users reached 1B in 2002 / 2005 respectively;
Source: ITU, Mark Lipacis, Morgan Stanley Research.* 18

.........But Cost is Important

12-Month Moving Average of Global Monthly Sequential Semiconductor Revenue Growth (Percentage Revenue Growth in U.S. Dollars)

Source: iSuppli

- Semiconductor Revenue grows at <10%/year on average.
- Low cost solutions are critical to growth.

Reducing Chip Power Has Big Impact

ESTIMATED POWER

CO2 eliminated from the Atmosphere equivalent to taking the following number of cars off the road...

INITIAL POWER

100

12,500 Cars

Gen1
Gen2

Each 1 Watt power reduction per IC can reduce MW of power on the grid...

✓ Multi-Vt 25/75%
✓ Vectored Flops
✓ Strong-1Sigma
✓ 1.05V, 105°C
✓ Update RFQ

65

+2,500 Cars

✓ Clock Gating

59

+3,000 Cars

+6,700 Cars

✓ AVS

47

✓ Multi-Vt 25/75%
✓ Vectored Flops
✓ Strong-1Sigma
✓ 0.945V, 105°C

+2,700 Cars

Average Power Savings
Estimated Product Quantity
1M Units/year
For each 1W of power saved
Total Power Savings: *1 Mega-Watts*

✓ Clock Gating

39

34

Initial Design | Power Improved | +Clock Gating | +AVS Single Rail | Technology Migration | w/CG

Wireless?

EE Times: Latest News
Wireless is everywhere; ignore it at your peril

Bolaji Ojo
Page 1 of 2
EE Times
(01/07/2008 9:00 AM EST)

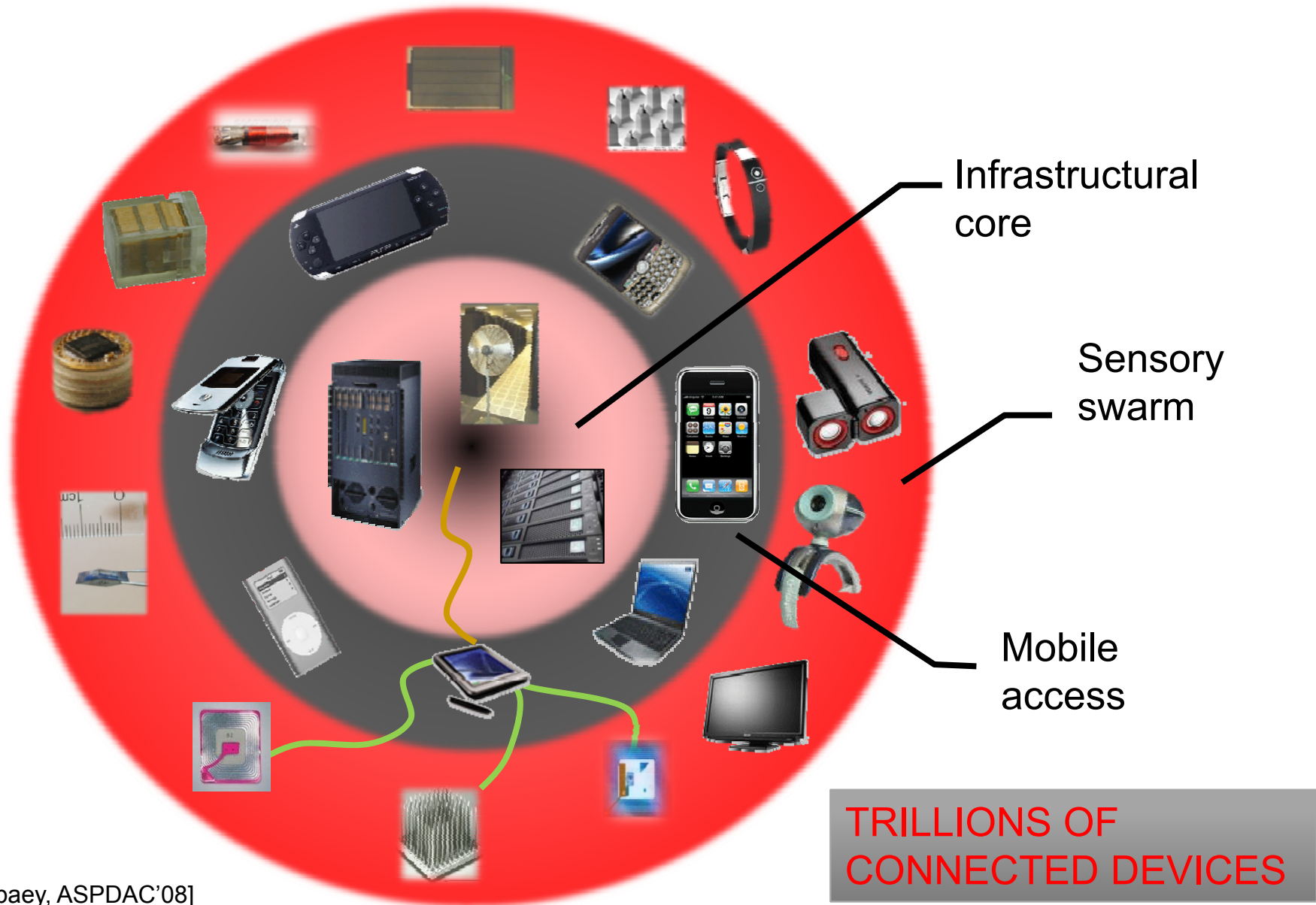PRINT THIS STORY
SEND AS EMAIL
REPRINTS

The search is over for the next killer app. It is wireless, it is all around you, and it will leave no sector of the global economy untouched.

Growth of Wireless to Continue Unabatedly!

EE Times,
January 07, 2008

- 5 Billion people to be connected by 2015 (Source: NSN)

- 7 trillion wireless devices serving 7 billion people in 2017 (Source: WWRF)
  - 1000 wireless devices per person?

[Courtesy: Niko Kiukkonen, Nokia]

THE IT PLATFORM OF THE NEXT DECADE(S)

Infrastructural core

Sensory swarm

Mobile access

TRILLIONS OF CONNECTED DEVICES

[J. Rabaey, ASPDAC'08]

WHAT DO WE NEED?

Life in the Future

From back in the 60's!!

Techno-Optimism

- Man on the Moon
- Concorde and Jumbo Jets
- Electric Music, Video, Cassettes
- etc......

But......major limitations to the Jetson's World

- Power, Cost, size

What does it take?
- Wireless Networks
- Low Power Circuits
- Sensors
- Human Machine Interfaces
- Energy Harvesting
- RF/Analog
- High speed Data Communication
- Data Analysis

Energy Generation and Management

- **Major limitation for expansion of the application space for semiconductors**

  - Intelligent environment requires wireless and autonomous systems that can operate for approximately 10 years.

  - Two types of portable electronics:

    - Performance "hub" devices such as computers, multi-media devices, wireless hubs and PDAs which have 1W to 5W needs today.

    - Distributed systems with micro and nano watt needs.

- **Typical autonomous system would be:**

  - 10 years life.

  - Battery size/cost point is ~1mAh.

  - Average power available from battery < 1nW.

Battery Technology Is Trailing Demand

- Battery technology scaling at about 2x every 10 years compared to semiconductor technology at 2x every 18 months.
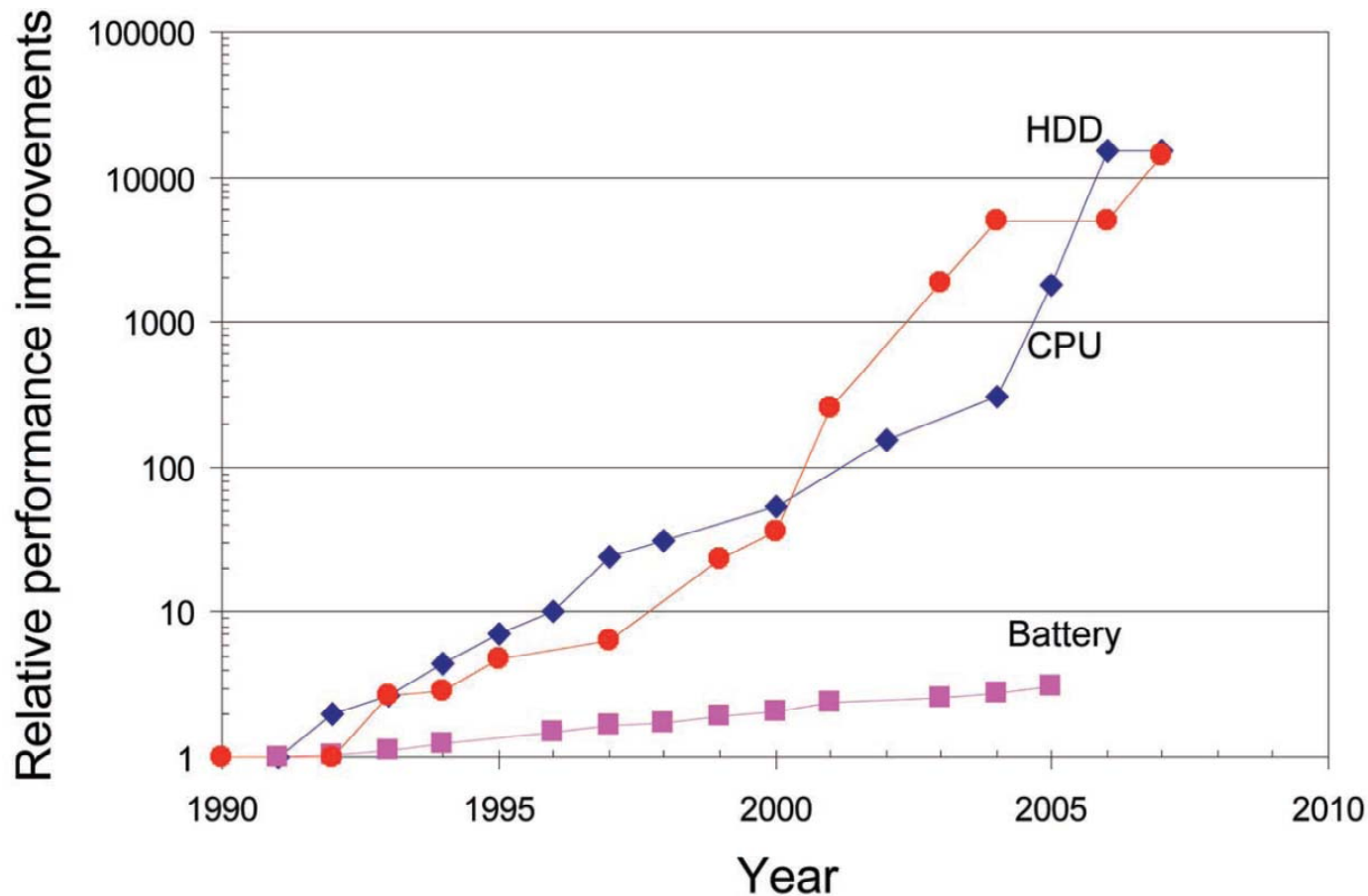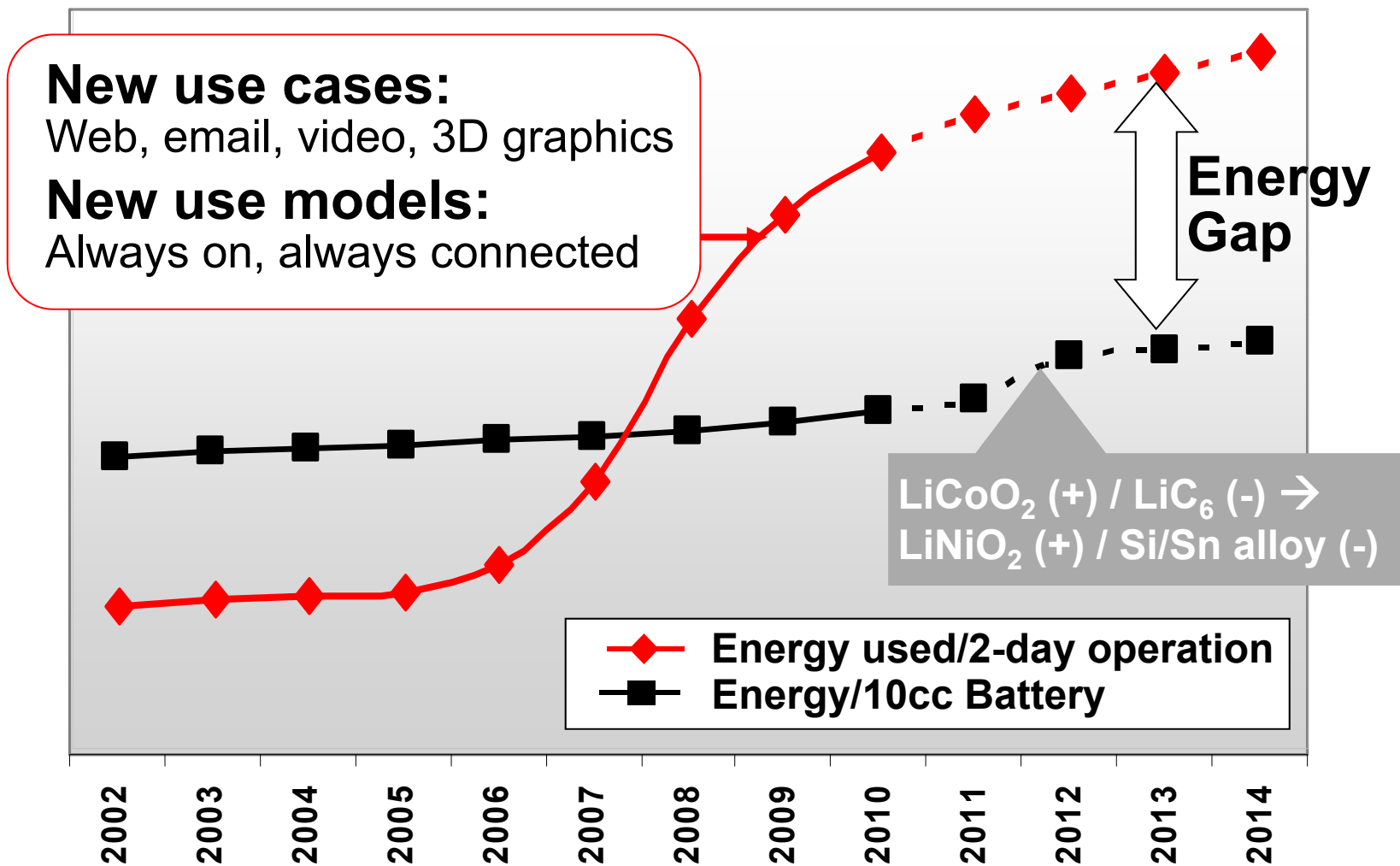

Ref: Chalamal, Proc. IEEE, 2007

Power Management Techniques

	Dynamic Power Reduction[1]	Leakage Power Reduction[1]
Multi-VT and Multi-L	Varies	34%/~7x
Clock Gating	~12% - 30%	Varies
Memory PM Modes	~2x	3-30x
Voltage Islands	CV^2F	~1.5x
Adaptive Voltage Scaling Static (Open Loop)	~9-15%	~10% -27%
Adaptive Voltage Scaling Dynamic (Closed Loop)	~10-19%	~15%-50%
Optimized IP	Varies	Varies
Power Islands	NA	~20-100x
Dynamic Voltage and Frequency Scaling (DVFS)	Varies	Varies

1 Figure of Merit, Impact is design dependent

Energy gap of a mobile device

New use cases:
Web, email, video, 3D graphics

New use models:
Always on, always connected

Energy Gap

$LiCoO_2$ (+) / LiC_6 (-) →
$LiNiO_2$ (+) / Si/Sn alloy (-)

◆ Energy used/2-day operation
■ Energy/10cc Battery

2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

Delagi, ISSCC10

Source: Öfversten [IWPC'08], Samms [IWPC'08]

Silicon performance advances require power management

Delagi, ISSCC10
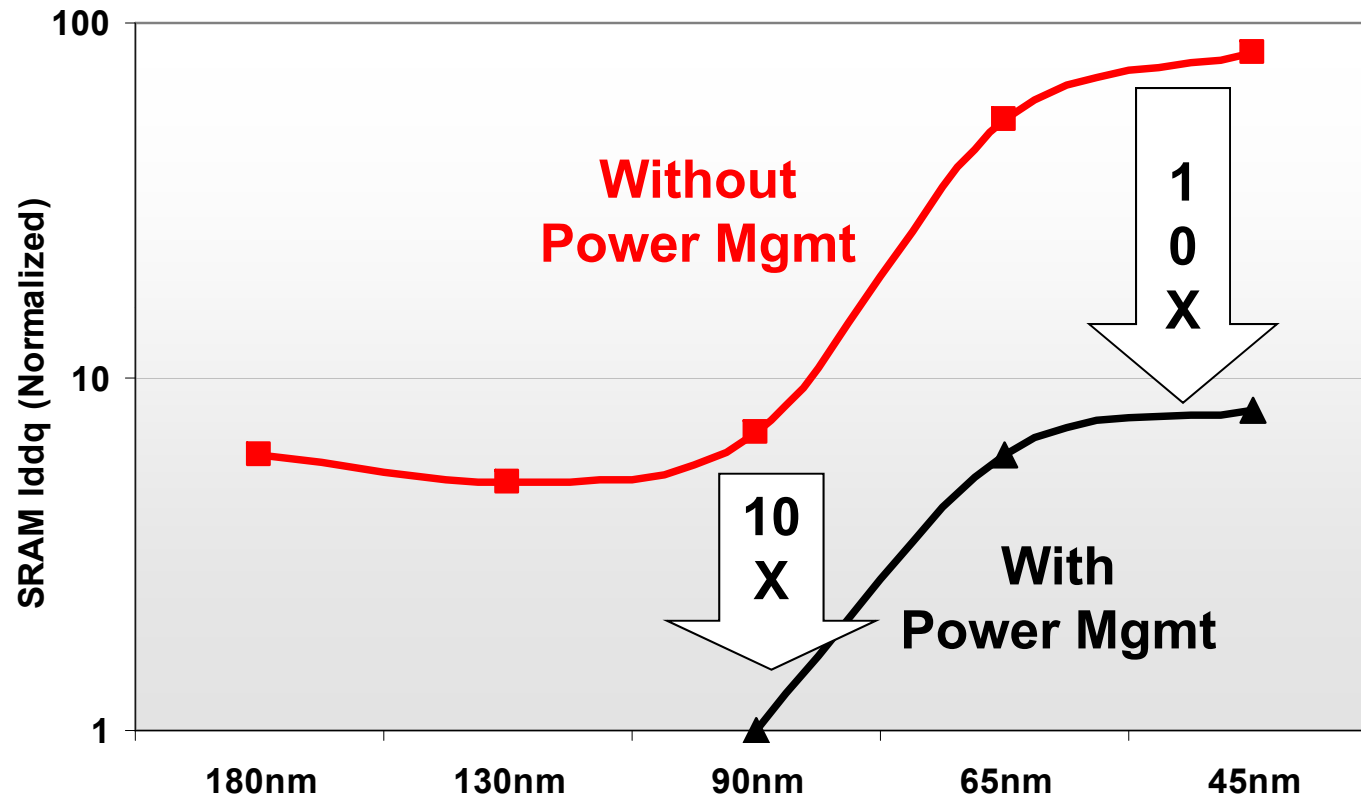
- **Performance: +20~30% node-to-node**
- **Leakage: a concern in 90nm, required fundamental change in 65nm**
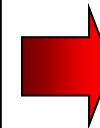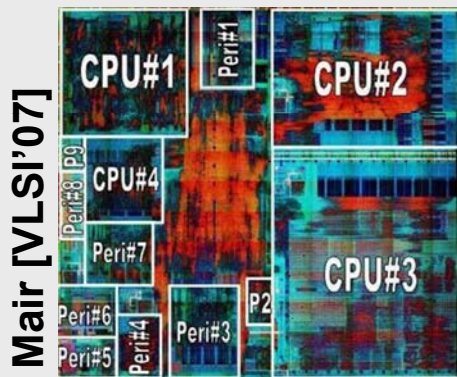
Circuit-level power mgmt

Industry breakthrough examples (published)

- **Power** & **performance** management technology
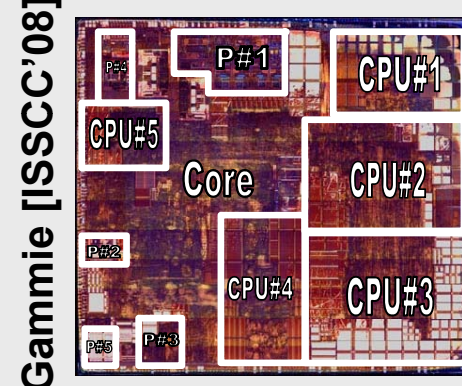- Reduces both leakage <u>and</u> active power, increases performance

65nm leakage power reduction: 300X
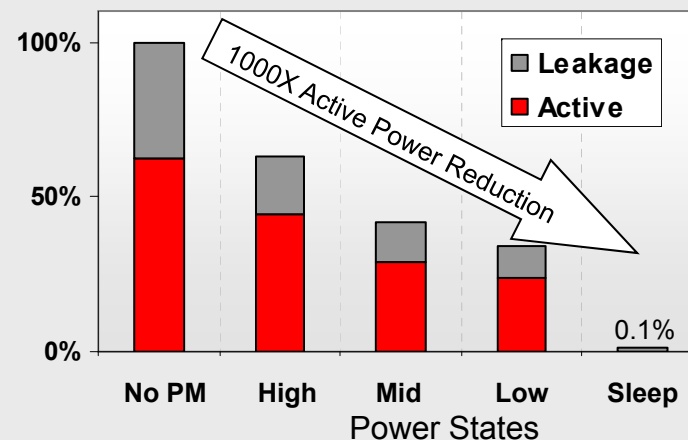
Mair [VLSI'07]

- SRAM retention
- Logic power gate
- Channel length
- Logic retention
- Process/temp AVS
- DVFS

300X Leakage Power Reduction

No PM
AVS, All-On
Deep-Sleep

Cumulative %

Normalized Leakage Current
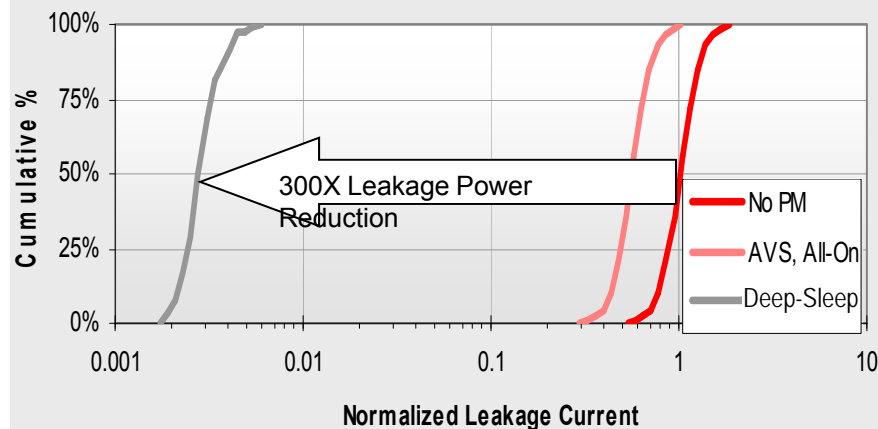
45nm active power reduction: 1000X

Gammie [ISSCC'08]

- Adaptive Body Bias (ABB) for performance & power
- Retention 'Til Access (RTA)

1000X Active Power Reduction

Leakage
Active

100%

50%

0%

No PM   High   Mid   Low   Sleep
Power States

0.1%

Delagi, ISSCC10

Directions in ultra-low power

Ultra-low power video codec

Source: JSSC Nov 2009

CACHES

CORE DOMAIN

MEMORY CONTROLLER DOMAIN
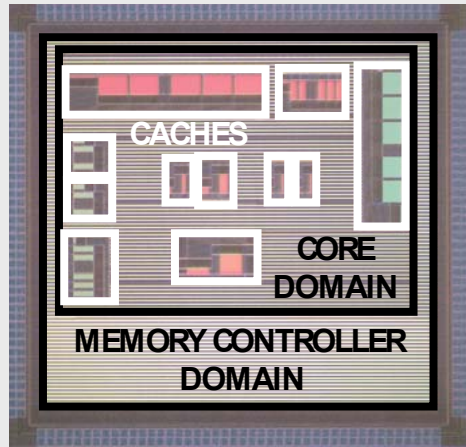
Video decoding for <2 mW at Vdd = 0.7V

Ultra-low power medical processor

Source: ISSCC 2008

DC-DC converter

Core logic

128Kb SRAM array
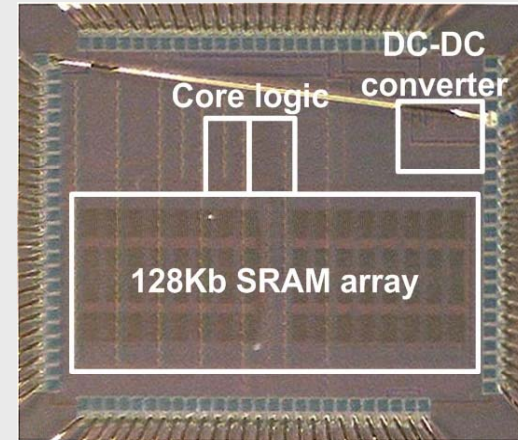
MSP430 uC with SRAM at Vdd = 0.3V

Ultra-low power DC-DC converter

Source: MIT research

Efficiency (%)

Load Current (µA)
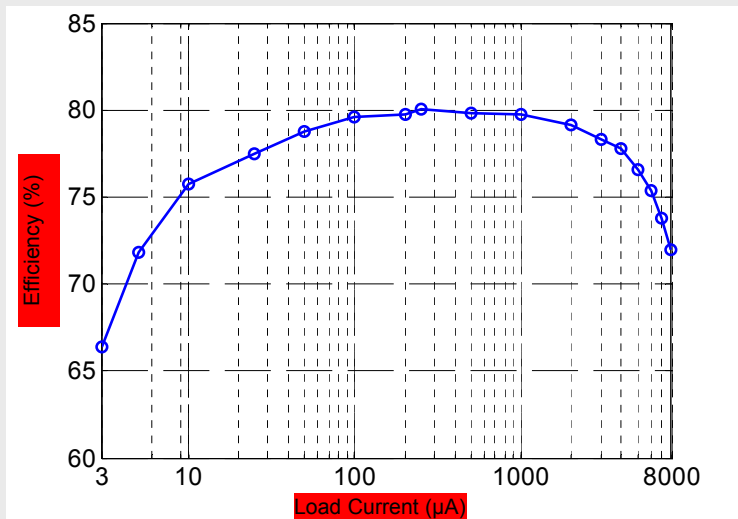
DC-DC with 75% efficiency down to 10 uA

Energy scavenging

Power (W)

Thermal

Electromagnetic

Electrostatic

Piezoelectric

Photovoltaic

µW-mW energy scavenging devices
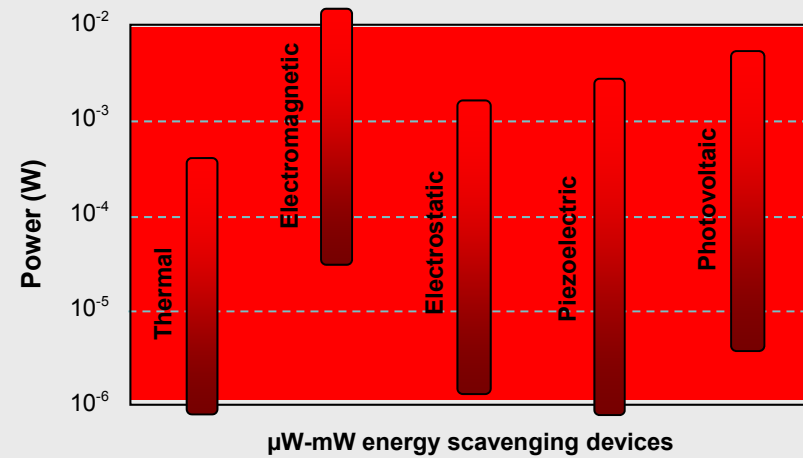
Scavenging energy from the environment
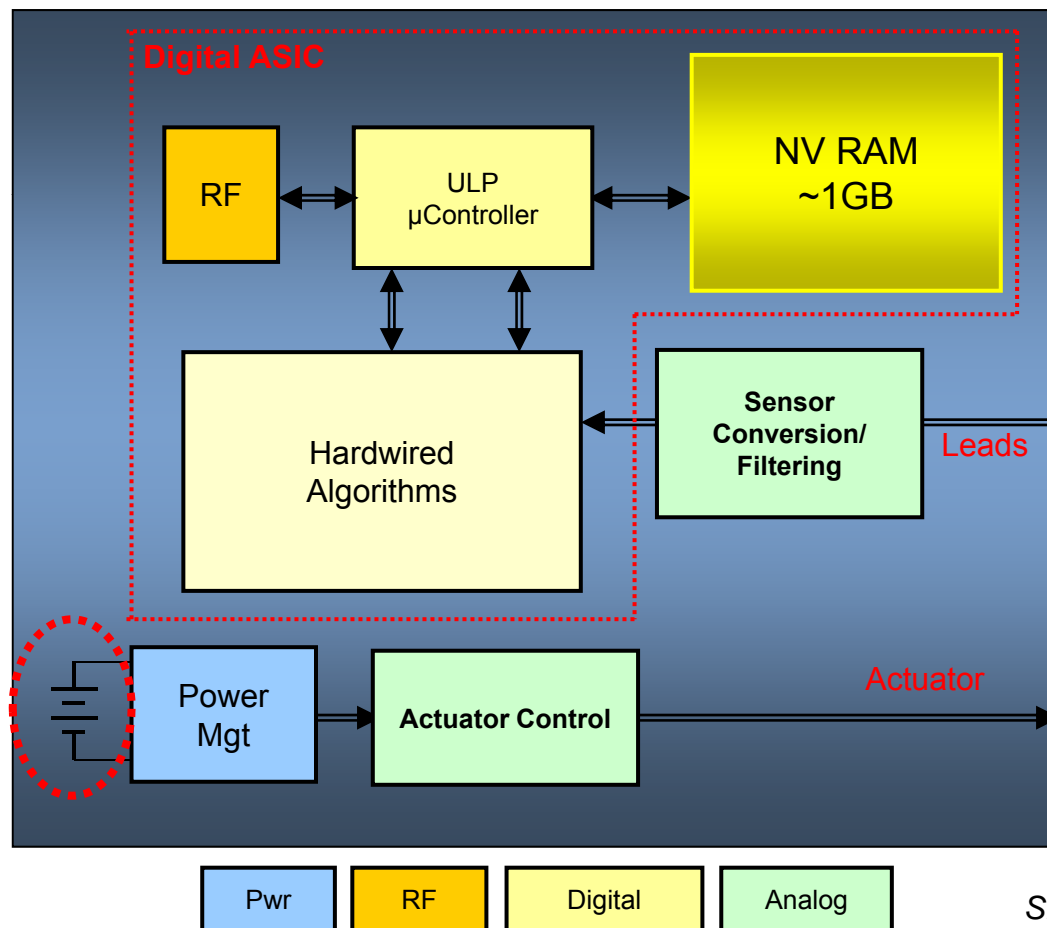
Next Steps in Low Power Electronics

Ultra Low Power Chip Design

Typical Design for Intelligent Ambient Applications

1mA-Hr Battery for 10 years
1uA average power budget
<1uA <u>average</u> for digital system

- Use circuit design techniques for optimizing energy-performance

- Then apply system design and software management to reduce power by another order of magnitude

Digital ASIC

RF

ULP µController

NV RAM ~1GB

Hardwired Algorithms

Sensor Conversion/ Filtering

Leads

Power Mgt

Actuator Control

Actuator

| Pwr | RF | Digital | Analog |

Sridhara, VLSI Symp. 2010

Battery Technology is Critical

- **Li-Ion was the game-changer for the 2000's.**

    - In 1990s nickel cadmium and nickel metalhydride rechargeable batteries were the preferred energy technology
    - In last 10 years, lithium batteries have taken over with a current market share of over 70%.
    - lithium cell is its high energy density, => small size, lightweight, longer lifespan than comparable battery technologies.
    - Also, high power, high-energy efficiency, low self-discharge, and good cycle life. Specific energy densities greater than 190 Wh/kg.
    - But now approaching its limit with small incremental gains

- *We need the next breakthrough in energy delivery for the 2020s!!*

    - Capacity, Cycles, Rate, are critical parameters.

Renewable Energy

- Renewable Energy Has Tremendous Potential

- Solar energy products
  - Photovoltaic systems
  - DC/AC power inverters

- Wind energy products
  - Wind turbines

- Hydro energy products

- Heating systems
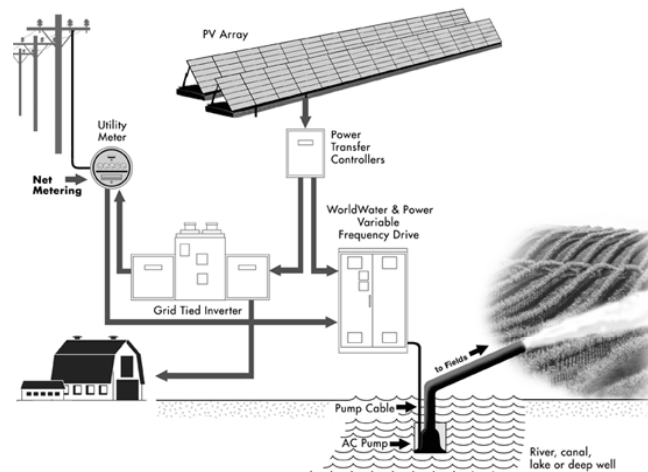
Energy Harvesting

- Vibrational, thermal, photovoltaic, RF power have been proposed.
  - Harvest energy from motion, heat, light and RF.
  - Great for triggering imagination.

- But micro and nano ampere power levels are very inefficient.

- Laws of conservation usually apply
  - Inserting a harvester can increase the energy usage by the generating system.

Need a lot more understanding to appreciate trade-offs and practical solutions.

20 Heat scavenging   The Economist Technology Quarterly March 6th 2010

Stealing the heat

Energy: The idea of recycling paper, glass, metal and plastics has become commonplace. New technologies allow heat to be recycled, too

"WATER, water everywhere, nor any drop to drink," lamented the becalmed Ancient Mariner. Oddly, the same is true of energy. As with the water that surrounds a desert island, there is abundant energy right under people's noses, in the form of wind, sun, tides and heat. The trouble is that, like saltwater, none of these
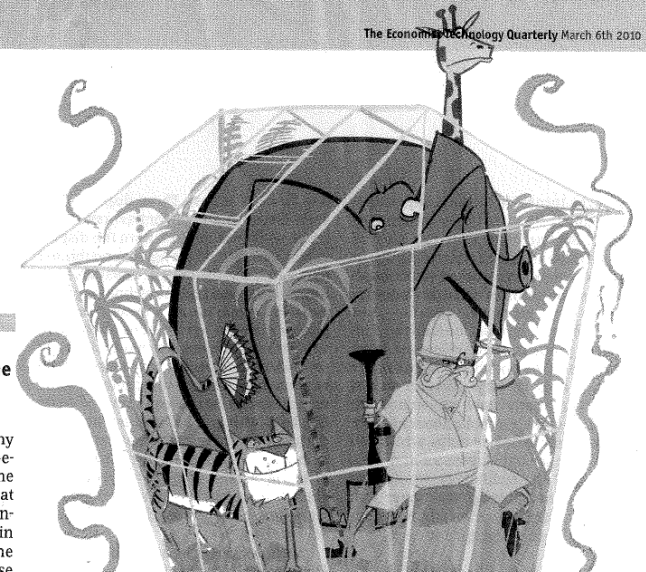
STARTUP TO WATCH
nPower Makes Battery Charging a Walk in the Park

By Jack M. Germain
TechNewsWorld
01/05/10 11:05 AM PT

Print Version
E-Mail Article
Reprints

The idea behind Tremont Electric's nPower PEG technology is to harness the kinetic energy you

guardian.co.uk

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Environment

Nokia developing phone that recharges itself without mains electricity

Prototype harvests radiowaves from TV, radio and other mobiles

~ 5mW from 1000 energy sources.
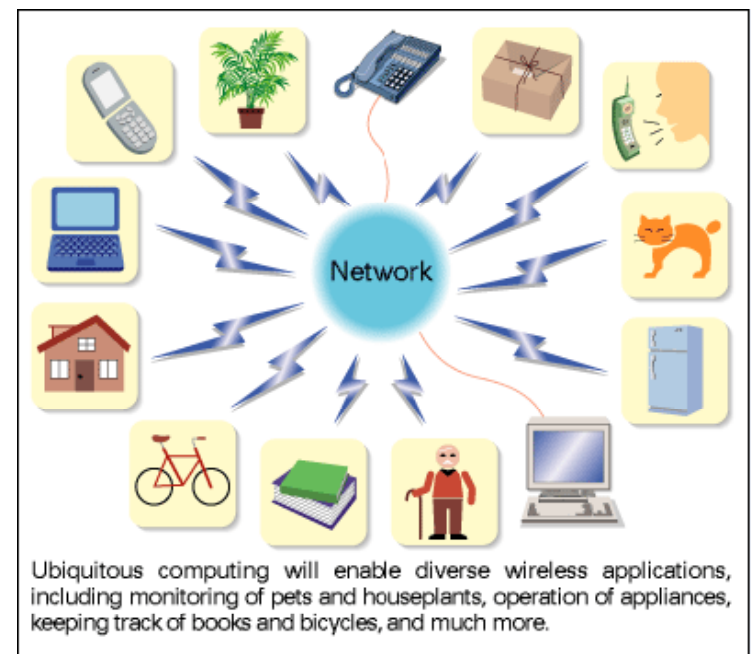
Energy Scavenging Efficiencies

Energy Source	Characteristics	Efficiency	Harvested Power
Light	Outdoor Indoor	10~24%	100 mW/cm^2 100 µW/cm^2
Thermal	Human Industrial	~0.1% ~3%	60 µW/cm^2 ~1-10 mW/cm^2
Vibration	~Hz–human ~kHz–machines	25~50%	~4 µW/cm^3 ~800 µW/cm^3
Embedded Energy	Chemical Radioactive	~90+% ~30%	~90+% ~1- 20 µW/cm^3
RF	GSM 900 MHz WiFi	~50%	0.1 µW/cm^2 0.001 µW/cm^2

$\Rightarrow$Need to look at non-traditional areas for scavenging energy. What else do we have?

$\Rightarrow$Energy generation using biological, micro-fuel cells, etc.

Mobile Internet System

Cloud...

- **A distributed computer system**
  - The internet of things – *THE SWARM*
- **Use multiple energy sources**
  - Battery for general functionality
    - energy management and control, wake-up functions, etc.
  - Storage caps for high current functions
    - storage, communications
  - Energy scavenging for extended battery life
  - Wireless power sources for connection to grid
    - Directional use of RF, light, etc. in localized area for "topping up".
- **Intelligent energy management and control**
  - Highly efficient on-chip power processing
  - Control of energy sources and delivery
  - Management of power demand and access
  - Unreliable energy sources

Swarm.......

Network

Ubiquitous computing will enable diverse wireless applications, including monitoring of pets and houseplants, operation of appliances, keeping track of books and bicycles, and much more.

Ubiquitous Computing

KEY CHALLENGES
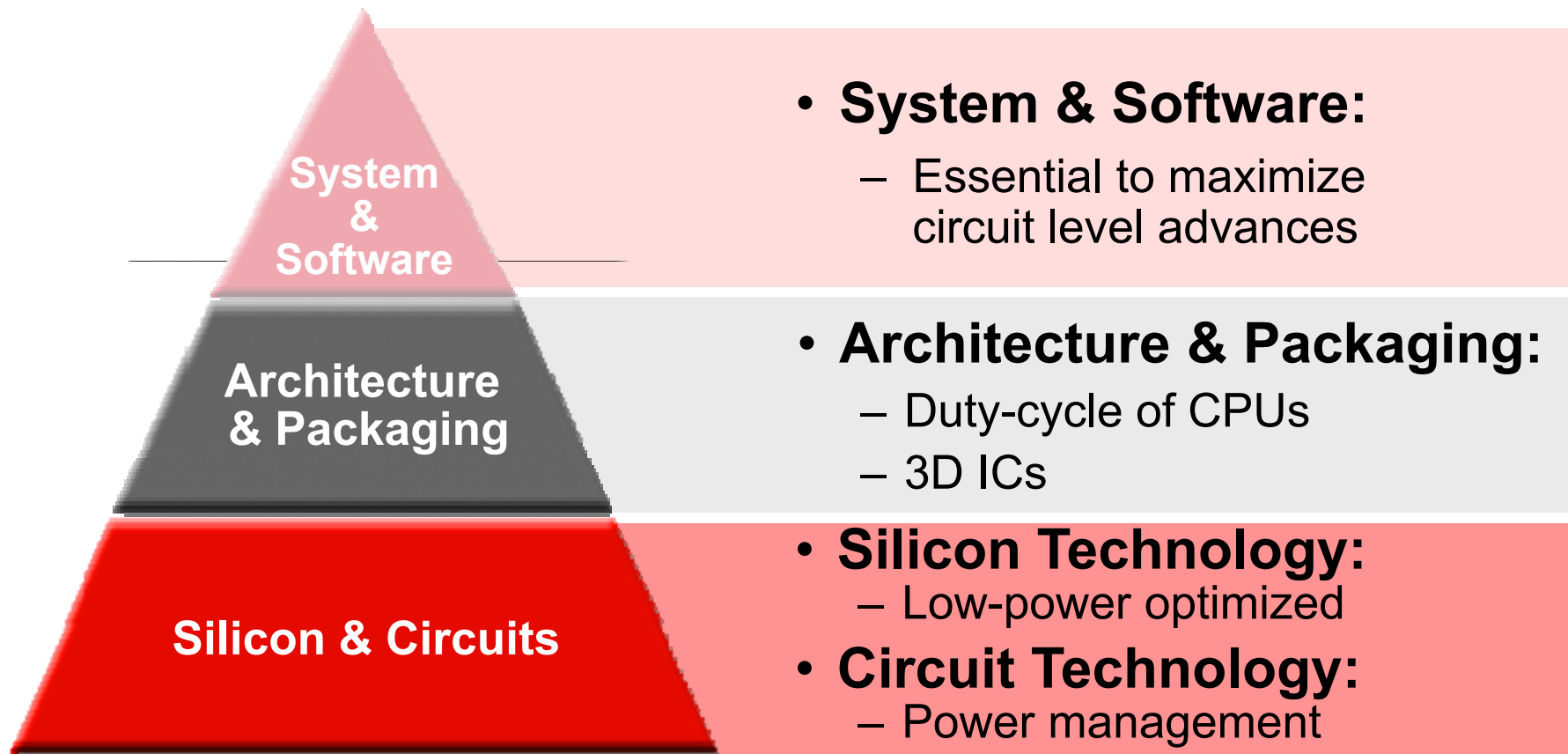
Challenges for Next Decade - 1

- **Low-Power Electronic Design**
  - Need another two to three orders of magnitude of power reduction.
  - Most known circuit design approaches have been utilized
  - System-level power optimization is needed
  - Can the process technology help? Not just digital any more.

- **System Design**
  - Managing interconnectivity: wireless and network connectivity; protocols are expensive in power and complexity
  - Partitioning for power optimization
  - Security

- **Low-Power Sensor Technology**
  - The intelligent environment requires a wide range of high performance sensors
  - Sensor interface and control needs to become sophisticated

Challenges for Next Decade - 2

- **Battery and Storage Technology**
  - We need micropower and nanopower battery capability
  - Nanotechnology can provide some of the solutions
  - Smart Batteries, intelligent power management

- **Energy Scavenging**
  - Truly scavenged from waste
  - Efficiency in collection and storage.
  - We need more work in understanding availability, applicability, and harvest/storage.

- **Off-grid power distribution**
  - Local wireless power to storage elements
  - Sense and deliver on-demand
  - Connecting to the grid

CHANGING PARADIGM

Optimizing the system requires collaboration and co-design

- **System & Software:**
  - Essential to maximize circuit level advances

- **Architecture & Packaging:**
  - Duty-cycle of CPUs
  - 3D ICs

- **Silicon Technology:**
  - Low-power optimized
- **Circuit Technology:**
  - Power management

Delagi ISSCC 2010

CONCLUSIONS

Concluding Reflections

- We are on the threshold of a new wave of electronic technology as we move into the decade.

- Applications driven roadmaps will define what we do.
  - Process technology not driving the roadmap any more

- Ubiquitous intelligence is going to drive wireless connectivity.

- Energy generation and management are critical.

- Low power and cost are key drivers for market growth.

- Close collaboration across all disciplines of electronic engineering from transistors to systems to software.

THANK YOU!!