# Crusoe Power Management:

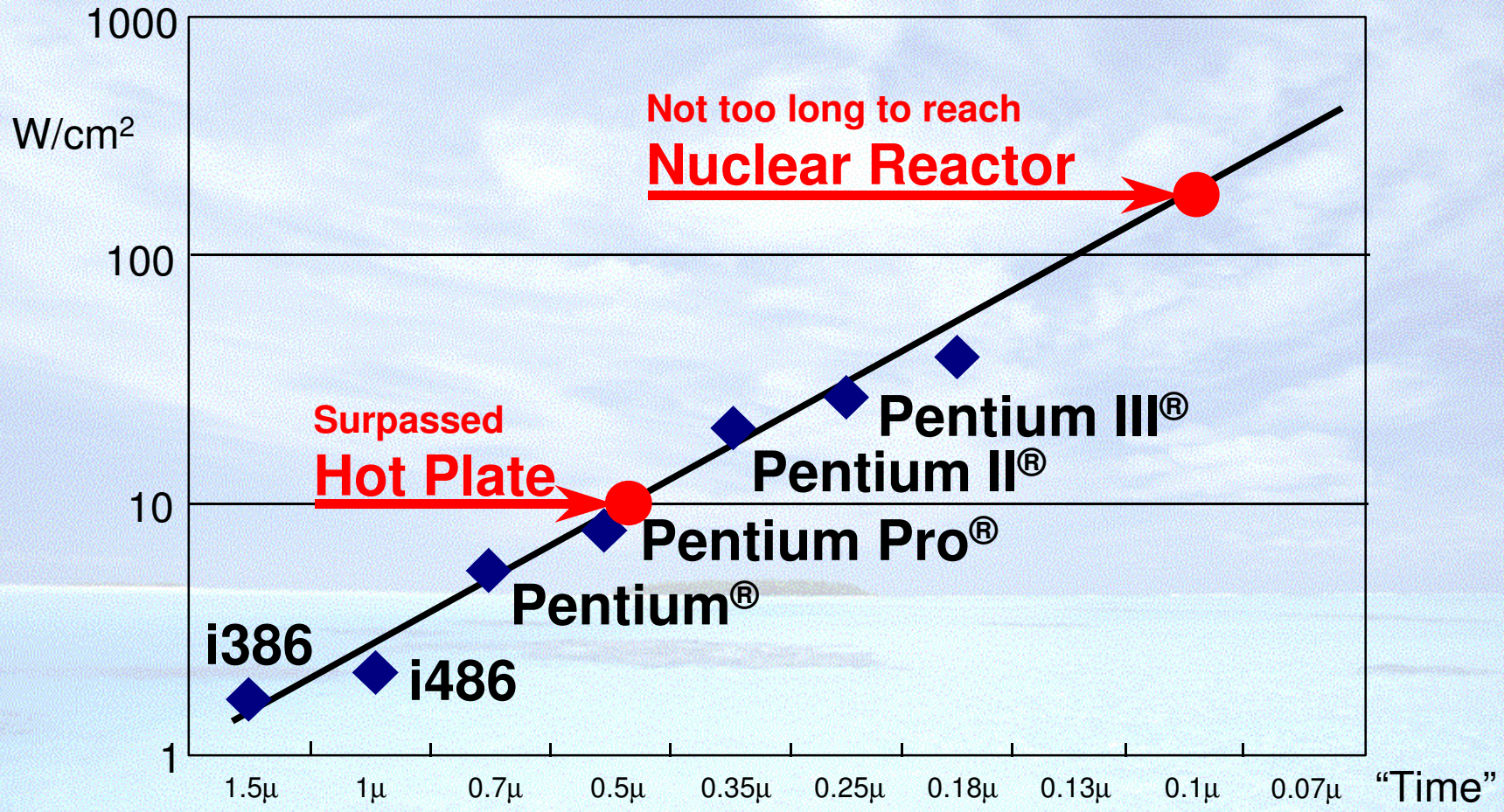
## Cutting x86 Operating Power Through LongRun

**Marc Fleischmann**
**Director, Low Power Programs**
**Transmeta Corporation**

# Overview

- **Key Challenges for Mobile Computing**
  - "Portability" (weight) and "Ease of Use" (battery life)
  - Power consumption is the key limiting factor
- **Solution - Crusoe Processor**
  - Full compatibility with x86 power management model
  - Significantly lower power
- **LongRun**
  - Transmeta's new invention to drive power savings
    - Adaptive Power Control (performance on demand)
    - Advanced Thermal Control (thermal budget expansion)

# Power Density
## The Fundamental Problem




Source: Fred Pollack, Intel. New Microprocessor Challenges in the Coming Generations of CMOS Technologies, Micro32

# X86 Power Management States
## A Quick Primer

| | ACPI Definition<br>Mobile x86 Power States | Mobile x86 Solution | |
|---|---|---|---|
| | Advanced Communication and Power Interface Specification | Processor<br>650 / 500 MHz<br>1.6 / 1.35 V | |
| **Normal (C0)** | • The CPU is actively executing instructions. | 14.0 / 8.0 | **W** |
| **AutoHALT (C1)** | • CPU executes a low power instruction (x86: **HLT**). | 1.7 / 1.1 | **W** |
| **Quick Start (C2)** | • CPU kills internal clocks (driven by South Bridge via STPCLK#).<br>• CPU maintains cache coherence (caches must be snooping). | 1.3 / 0.8 | **W** |
| **Deep Sleep (C3)** | • South Bridge kills external clock input to the CPU.<br>• Maximum power savings w/o losing CPU context.<br>• System enforces cache coherence (caches don't need to snoop). | 0.5 / 0.3 | **W** |

# The Solution - Increase Efficiency

$$Power = Capacitance \times Voltage^2 \times Frequency$$

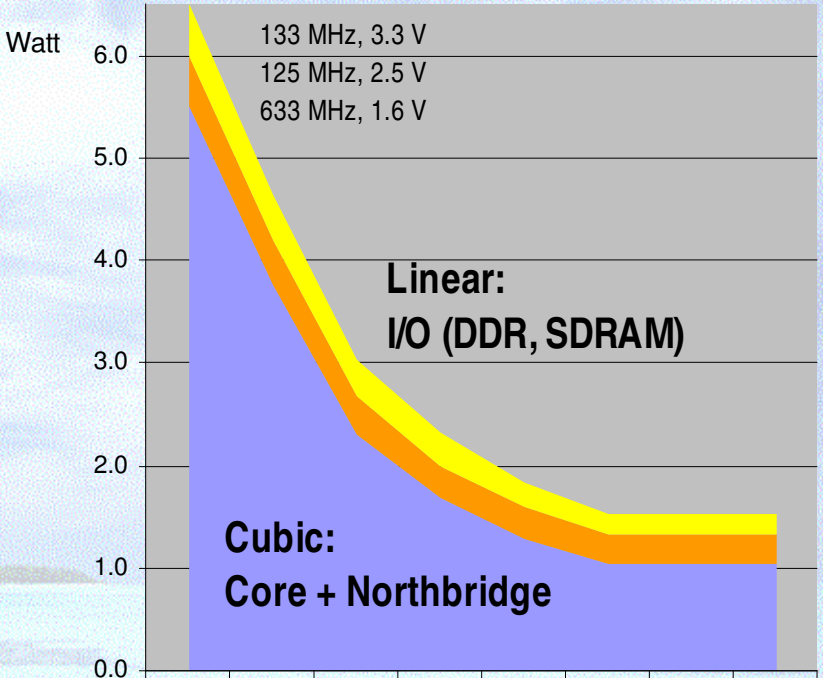
- **Transmeta Innovation - Code Morphing Software (CMS)**
- **Effect - Replace Millions of Logic Transistors with Software**
  - … and transistors translate into capacitance
- **Benefit - Significantly Reduces Power Consumption of x86 Power States**

# LongRun Adaptive Power Control

## Maximize Battery Life With Performance on Demand

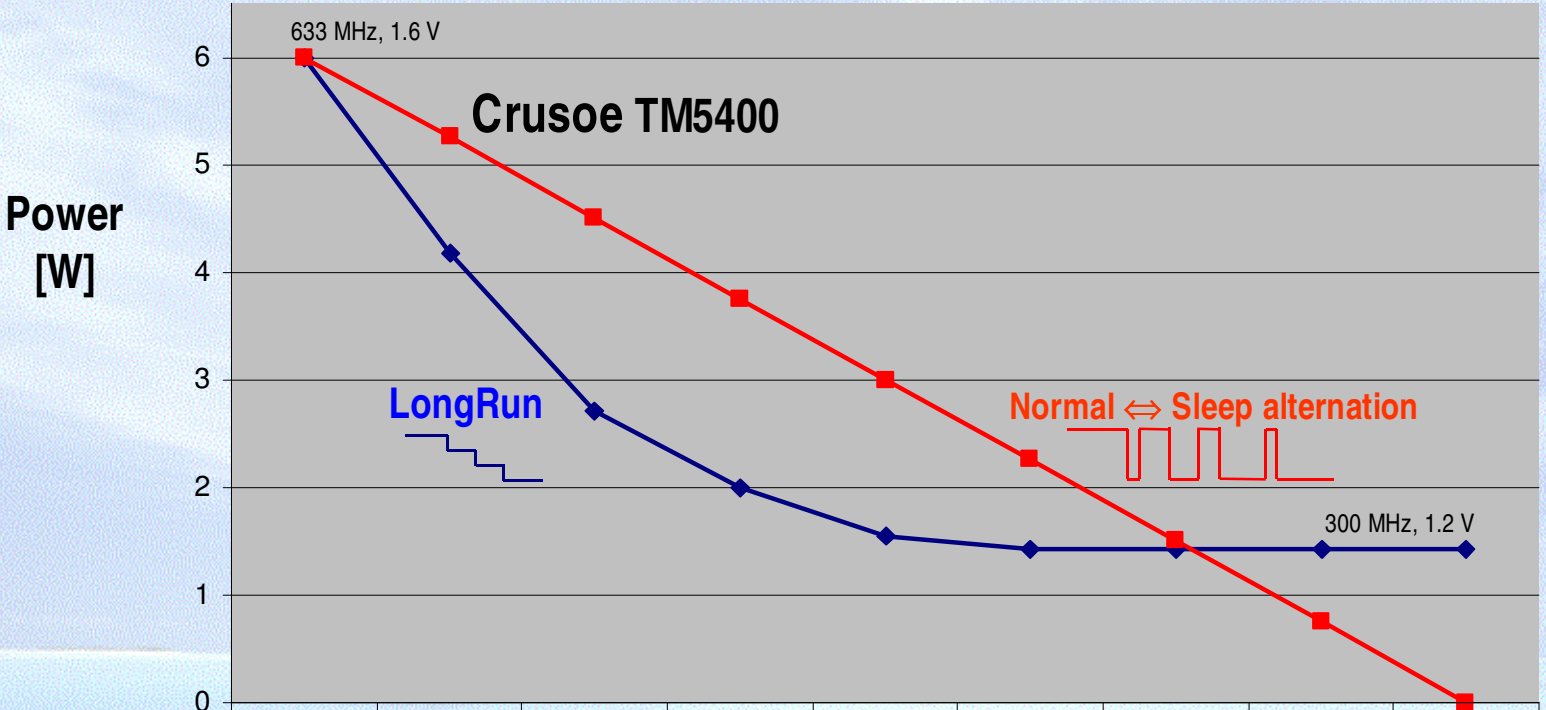
$$Power = c \times v^2 \times f$$

- **Dynamically adapt both frequency and voltage to performance demands**
- **Mechanisms in hardware**
  - Fully programmable
- **Policies in CMS**
  - Adapt *f* to demand
  - Reduce *v* proportionally
  - Cubic power savings!




| | Normal | 12.5% | 25.0% | 37.5% | 50.0% | 62.5% | 75.0% | 87.5% |
|---|---|---|---|---|---|---|---|---|
| SDR | 0.5 | 0.4 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 |
| DDR | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Core+NB | 5.5 | 3.8 | 2.3 | 1.7 | 1.3 | 1.0 | 1.0 | 1.0 |

# LongRun Adaptive Power Control
## vs. Traditional Power Management




| | Normal | 12.5% | 25.0% | 37.5% | 50.0% | 62.5% | 75.0% | 87.5% | C3 |
|---|---|---|---|---|---|---|---|---|---|
| LongRun | 6.0 | 4.2 | 2.7 | 2.0 | 1.6 | 1.4 | 1.4 | 1.4 | 1.4 |
| C3 | 6.0 | 5.3 | 4.5 | 3.8 | 3.0 | 2.3 | 1.5 | 0.8 | 0.0 |

Idle Time

Power

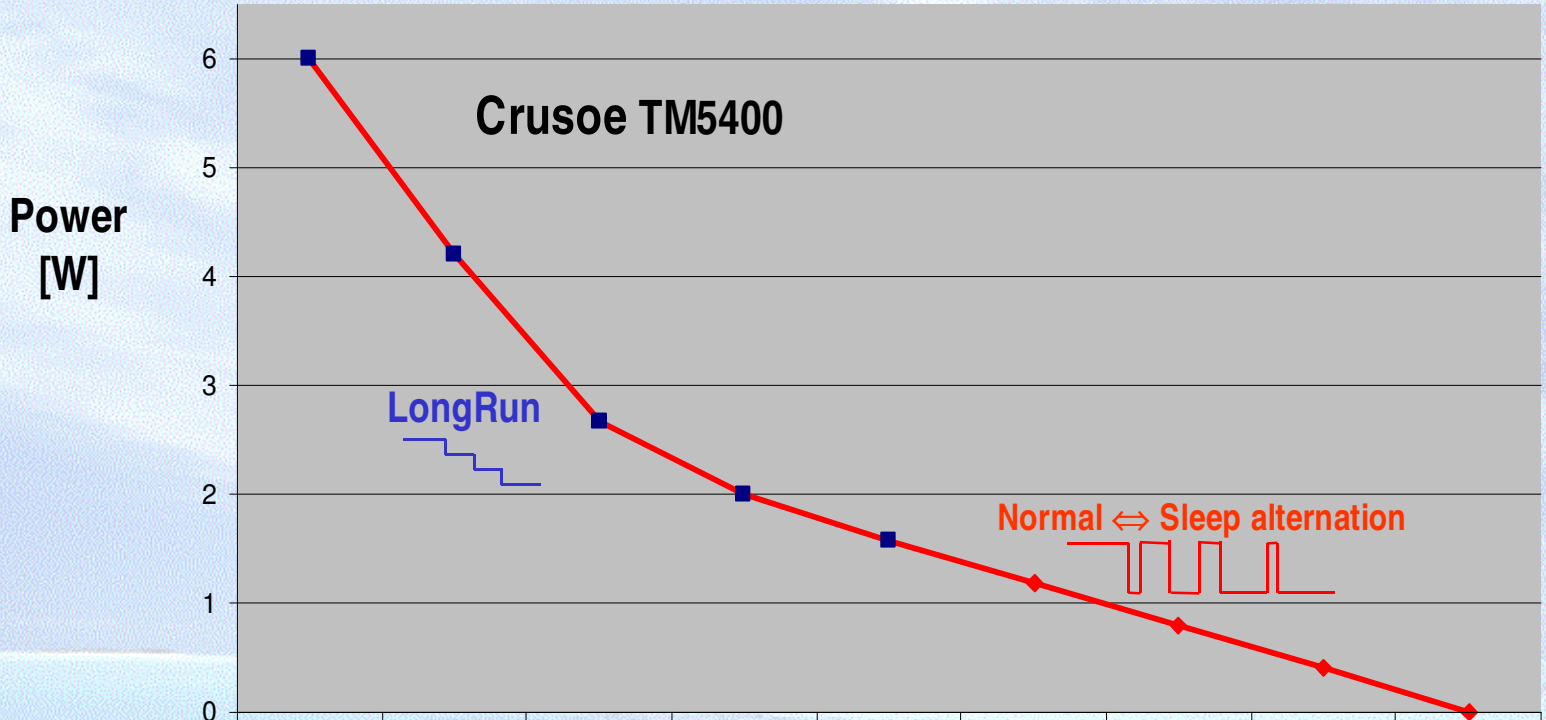
**Notes**

[1] Power numbers include Northbridge

[2] DDR-only configuration

# LongRun Adaptive Power Control

## Crusoe Power Profile




| | Normal | 12.5% | 25.0% | 37.5% | 50.0% | 62.5% | 75.0% | 87.5% | C3 |
|---|---|---|---|---|---|---|---|---|---|
| TM5400 | 6.0 | 4.2 | 2.7 | 2.0 | 1.6 | 1.2 | 0.8 | 0.4 | 0.0 |

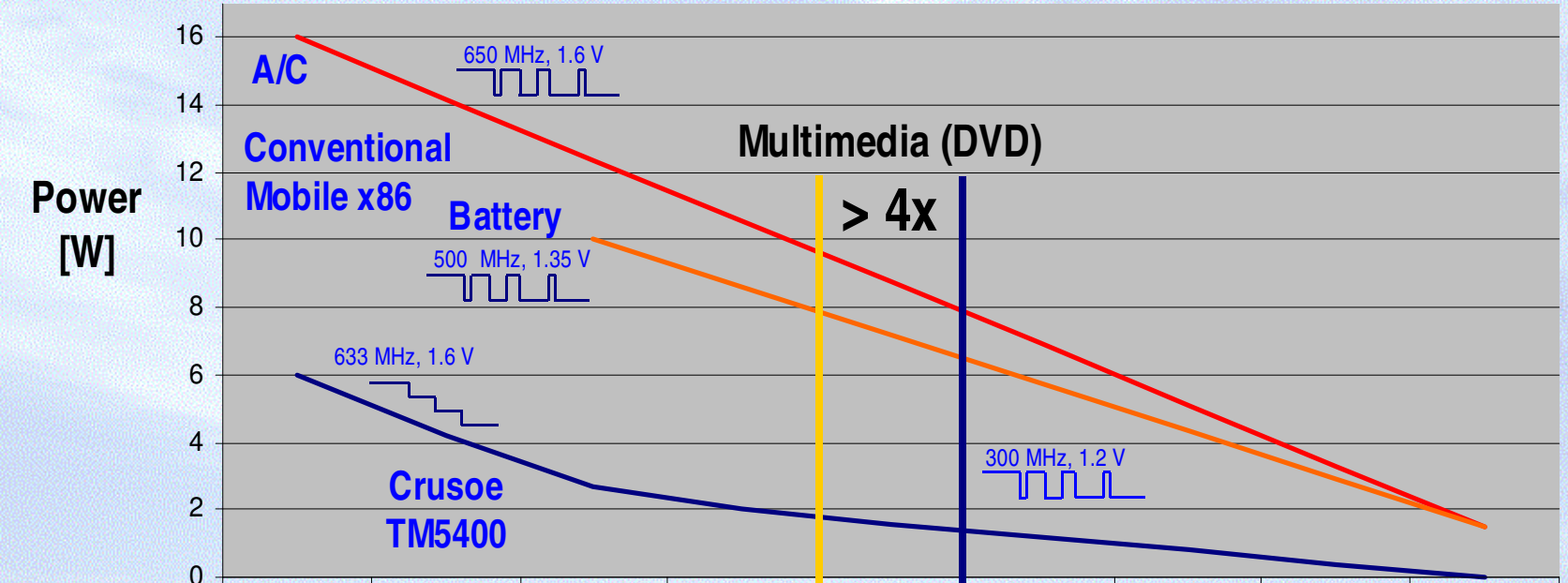
Idle Time Power

**Notes**

[1] Power numbers include Northbridge

[2] DDR-only configuration

# The LongRun Effect
## Power Profiles




| | Normal | 12.5% | 25.0% | 37.5% | 50.0% | 62.5% | 75.0% | 87.5% | C3 |
|---|---|---|---|---|---|---|---|---|---|
| TM5400+NB | 6.0 | 4.2 | 2.7 | 2.0 | 1.6 | 1.2 | 0.8 | 0.4 | 0.0 |
| A/C | 16.0 | 14.2 | 12.4 | 10.6 | 8.8 | 6.9 | 5.1 | 3.3 | 1.5 |
| Battery | | | 10.0 | 8.6 | 7.2 | 5.8 | 4.3 | 2.9 | 1.5 |

**Notes**

[1] Power numbers include Northbridge

[2] DDR-only configuration

# System Architecture

**Standard Applications**

No changes required


Closed loop

**Standard Operating System**

No changes required

Closed loop

**Standard BIOS**

No changes required

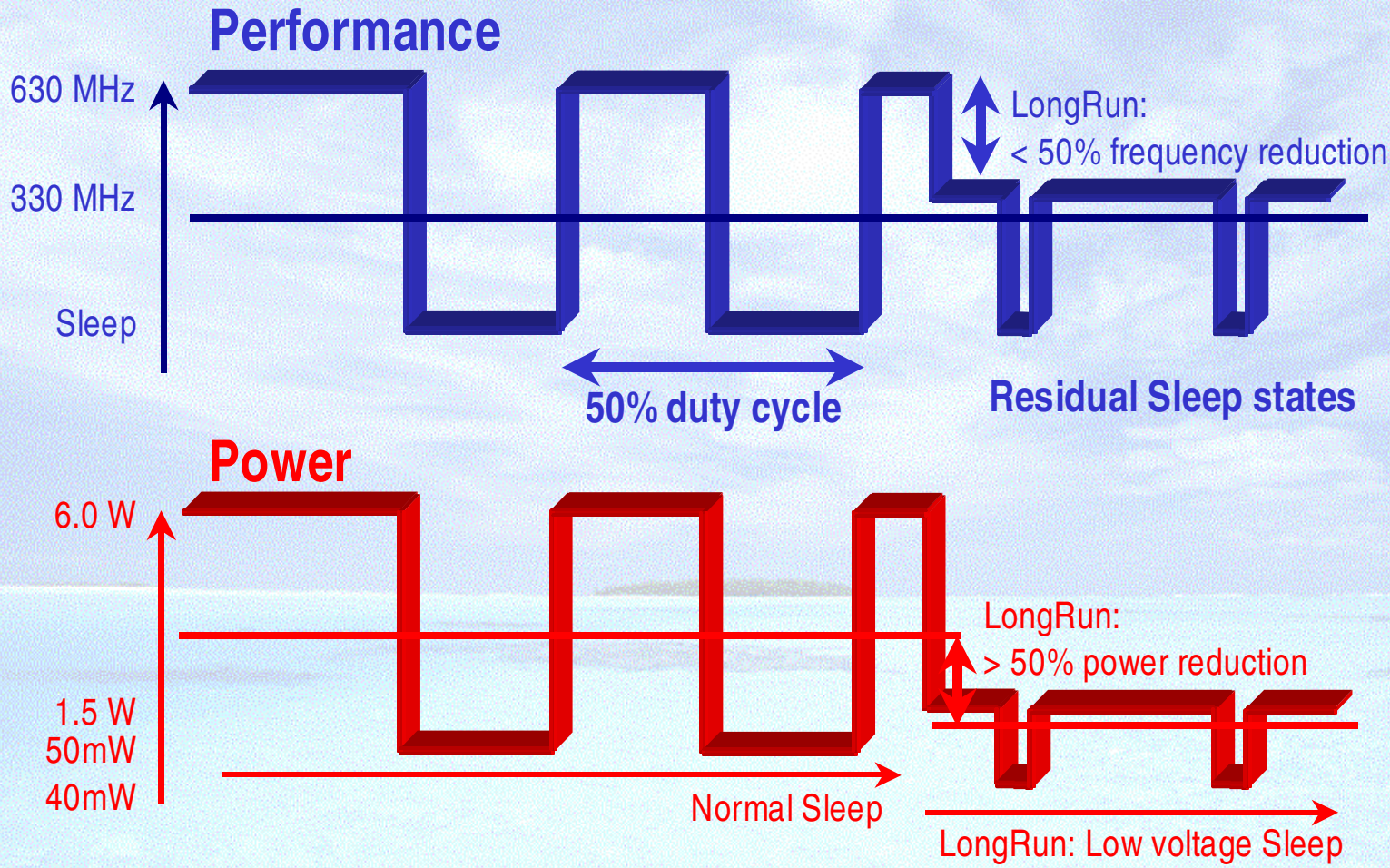
Closed loop

**Crusoe TM5400 processor featuring Transmeta LongRun technology**

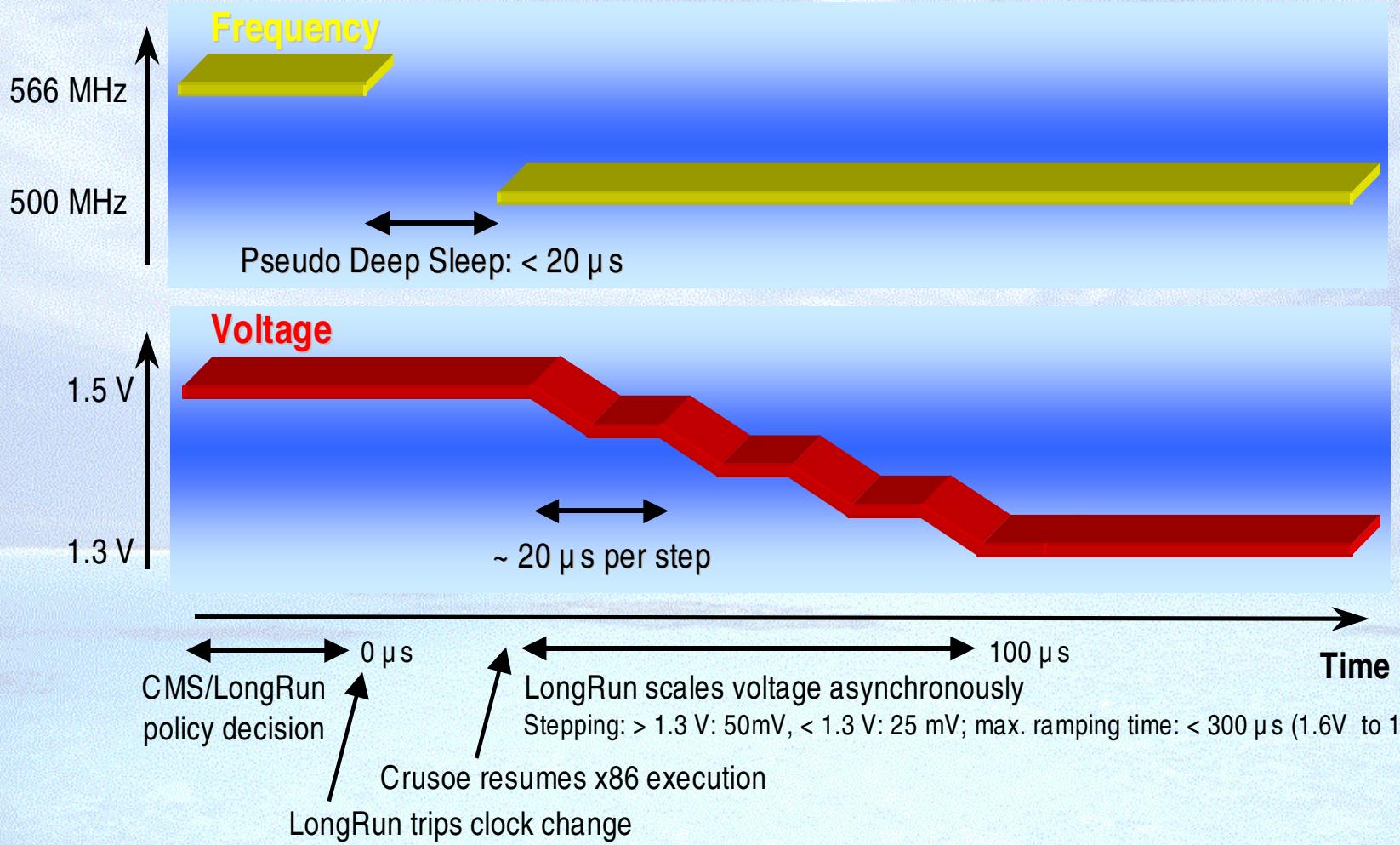
Code Morphing software monitors system activity and dynamically adapts LongRun performance levels

# Performance on Demand

## Duty Cycle  Effective Performance Level

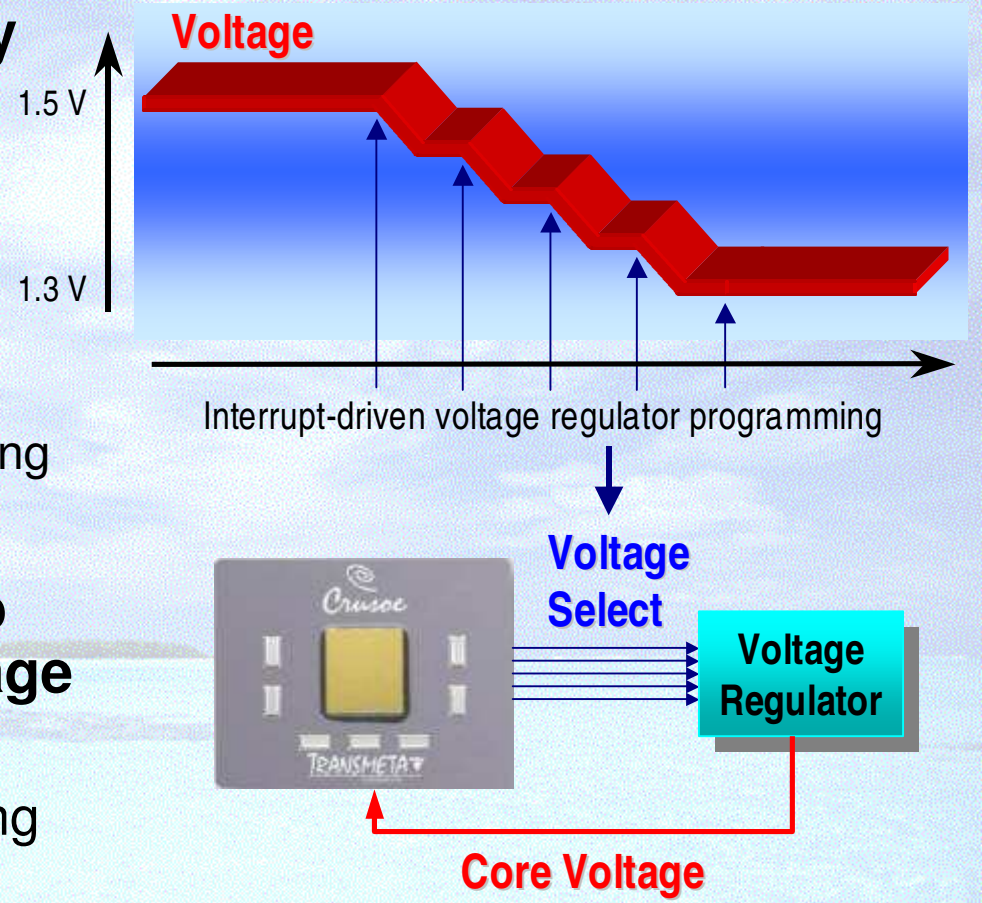


# Transition Dynamics
## Fast Frequency/Voltage Scaling



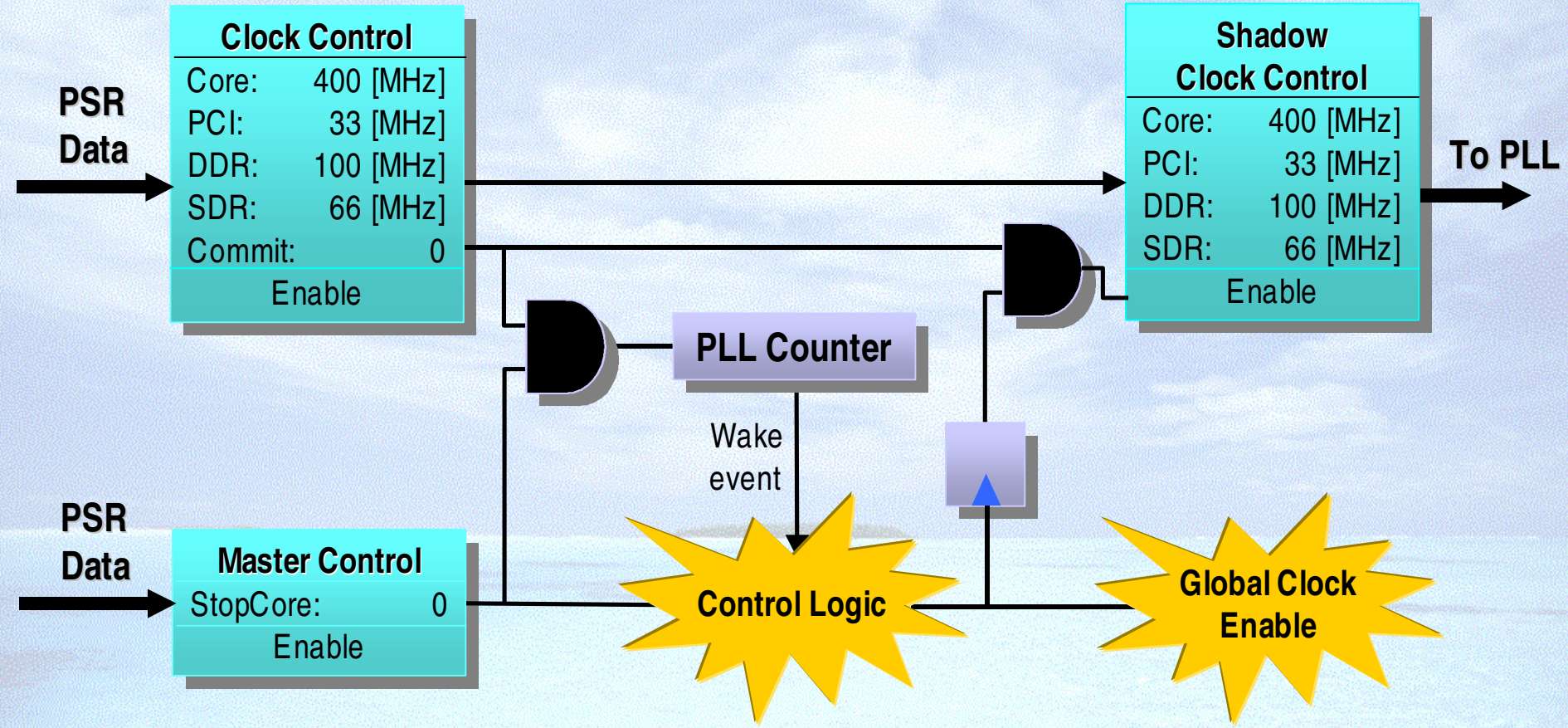
# Transition Details
## Voltage Scaling

- **TM5400 Core Voltage is Fully Under Software Control**
  - CMS directly controls voltage regulator pins (via internal processor register)
  - OEM configurable
    - CPU output pin/voltage mapping
    - Voltage settling interval
- **CMS Schedules Interrupts to Asynchronously Ramp Voltage**
  - Allows sustained x86 forward progress during voltage ramping



# Transition Details

## Frequency Scaling - Establish/commit control



# Programming Interface
## Processor and Northbridge

### Adaptive Power Control
CPU interface

**CPUID 8086 0001h**

| | |
|---|---|
| EDX:0 | LongRun supported |
| ECX | Nominal core frequency |

**CPUID 8086 0007h**

| | |
|---|---|
| EAX | Current core frequency |
| EBX | Current core voltage |
| ECX | Current performance percentage |

**MSR 8086 8010h**

| | |
|---|---|
| EDX | Upper boundary (% of max. performance) |
| EAX | Lower boundary (% of max. performance) |

### Advanced Thermal Control
Northbridge interface

**Function 0, Register A8h**

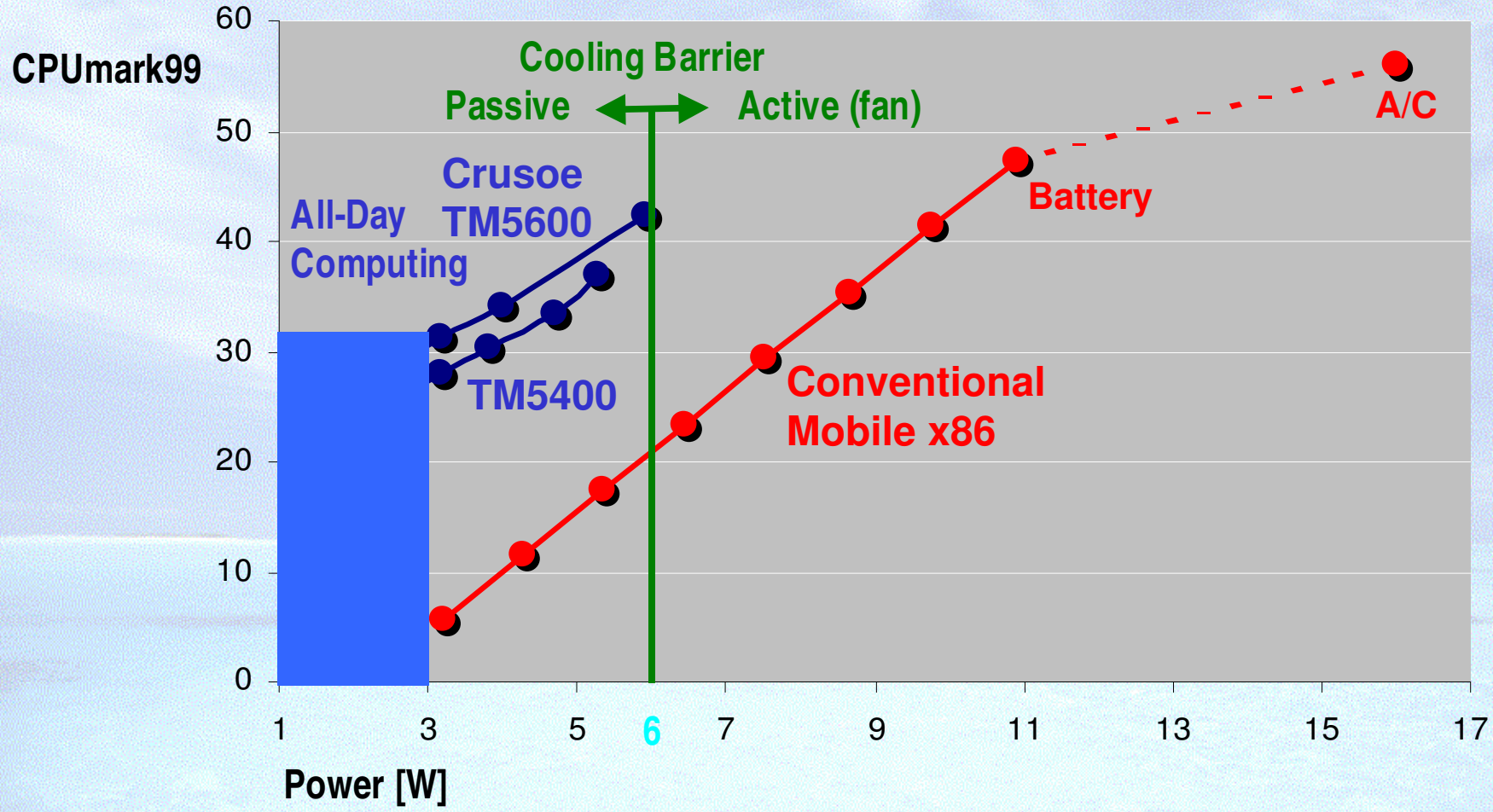
| | |
|---|---|
| Bit 4 | Thermal Management enabled |
| Bit 1:3 | Power reduction level |

| Bits | Mode |
|---|---|
| 000 | Reserved |
| 001 | Reserved |
| 010 | 75.0% |
| 011 | 62.5% |
| 100 | 50.0% |
| 101 | 37.5% |
| 110 | 25.0% |
| 111 | 12.5% |

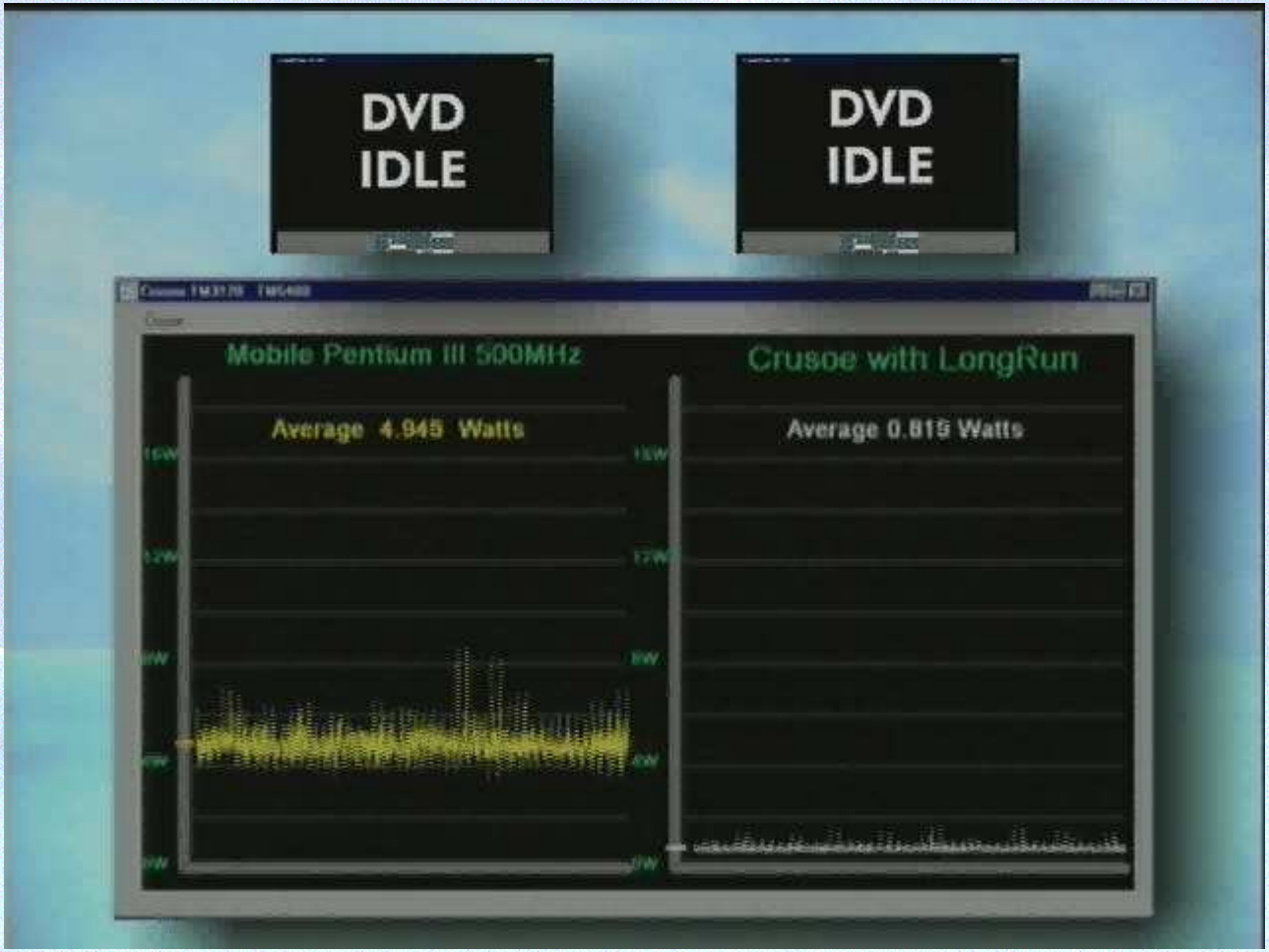
| | |
|---|---|
| Bit 0 | LongRun supported |

# Energy Efficiency

## Superior Performance in Small Form Factors



# The LongRun Advantage
## DVD Playback - Performance on Demand



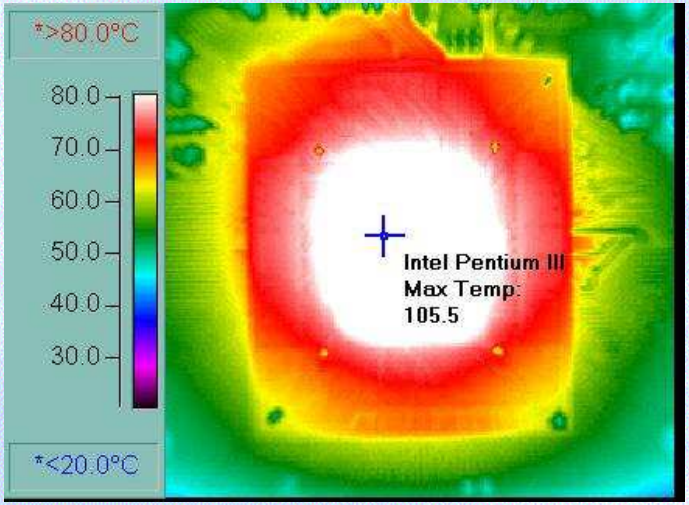
# Power Comparison

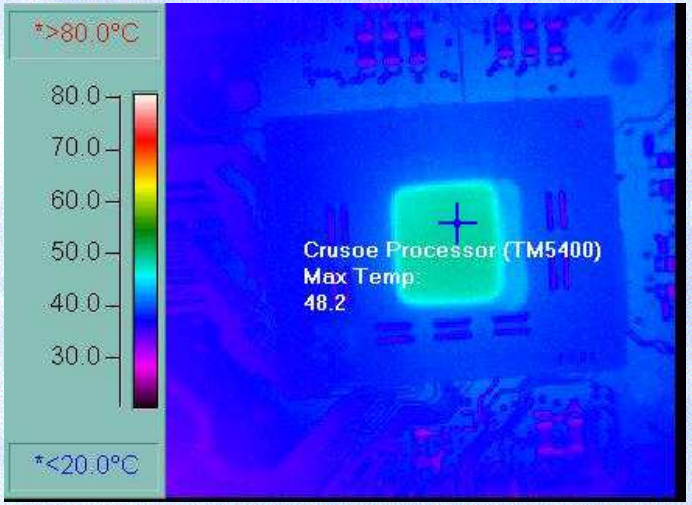
## Substantial Power Reduction, Delivered by Crusoe

| | Conventional Mobile x86 Solution | | | Crusoe TM5400 Integrated North Bridge | | |
|---|---|---|---|---|---|---|
| | Processor 650 / 500 MHz 1.6 / 1.35 V | North Bridge 3.3 V | Total 650 / 500 MHz 1.6 / 1.35 V | LongRun 633 300 MHz 1.6 1.2 V | | |
| Normal (C0) | 14.0 / 8.0 | 2.0 | 16.0 / 10.0 | 6.5 | 1.5 | Watts |
| AutoHALT (C1) | 1.7 / 1.1 | 2.0 | 3.7 / 3.1 | 0.9 | 0.3 | Watts |
| Quick Start (C2) | 1.3 / 0.8 | 2.0 | 3.3 / 2.8 | 0.6 | 0.2 | Watts |
| Deep Sleep (C3) | 0.5 / 0.3 | ~1.0 | 1.5 / 1.3 | 0.05 | 0.05 | Watts |

- **Crusoe plays Soft-DVD at the same power that conventional mobile x86 processors use in Deep Sleep!**

# The LongRun Advantage
## DVD Playback - Thermal Comparison




**Conventional Mobile x86 Processor**

**105.5º C  221.9º F**

**Active thermal solution required (Fan or overload protection)**

**Crusoe TM5400 Processor with LongRun**

**48.2º C  118.8º F**

**Passive thermal solution (No fan or overload protection)**

# Summary

- **Crusoe Supports the x86 Power Management Model with Significantly Reduced Power Consumption**
  - Sleep: 4× (C1) - 30× (C3) power savings
- **Crusoe Leverages Code Morphing Software to Drive Performance on Demand - LongRun**
  - Normal: 2× - 10× power savings
- **Crusoe Leverages LongRun to Expand the Thermal Budget**
- **Crusoe's Innovative Low-Power Technology Portfolio**
  - Enables a whole new class of battery-powered devices
  - The full PC and Internet experience - Anywhere and Anytime


Crusoe