

# Analysis of The Enhanced Intel® Speedstep® Technology of the Pentium® M Processor



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June 2004



# Overview

- **Mobile computers challenges**
  - Energy and Average power
  - Thermal Design Power
- **Intel® Pentium® M power management**
- **The experiments**
- **Test results**
- **Conclusions**

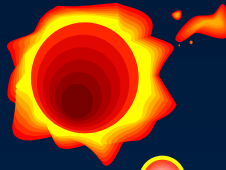
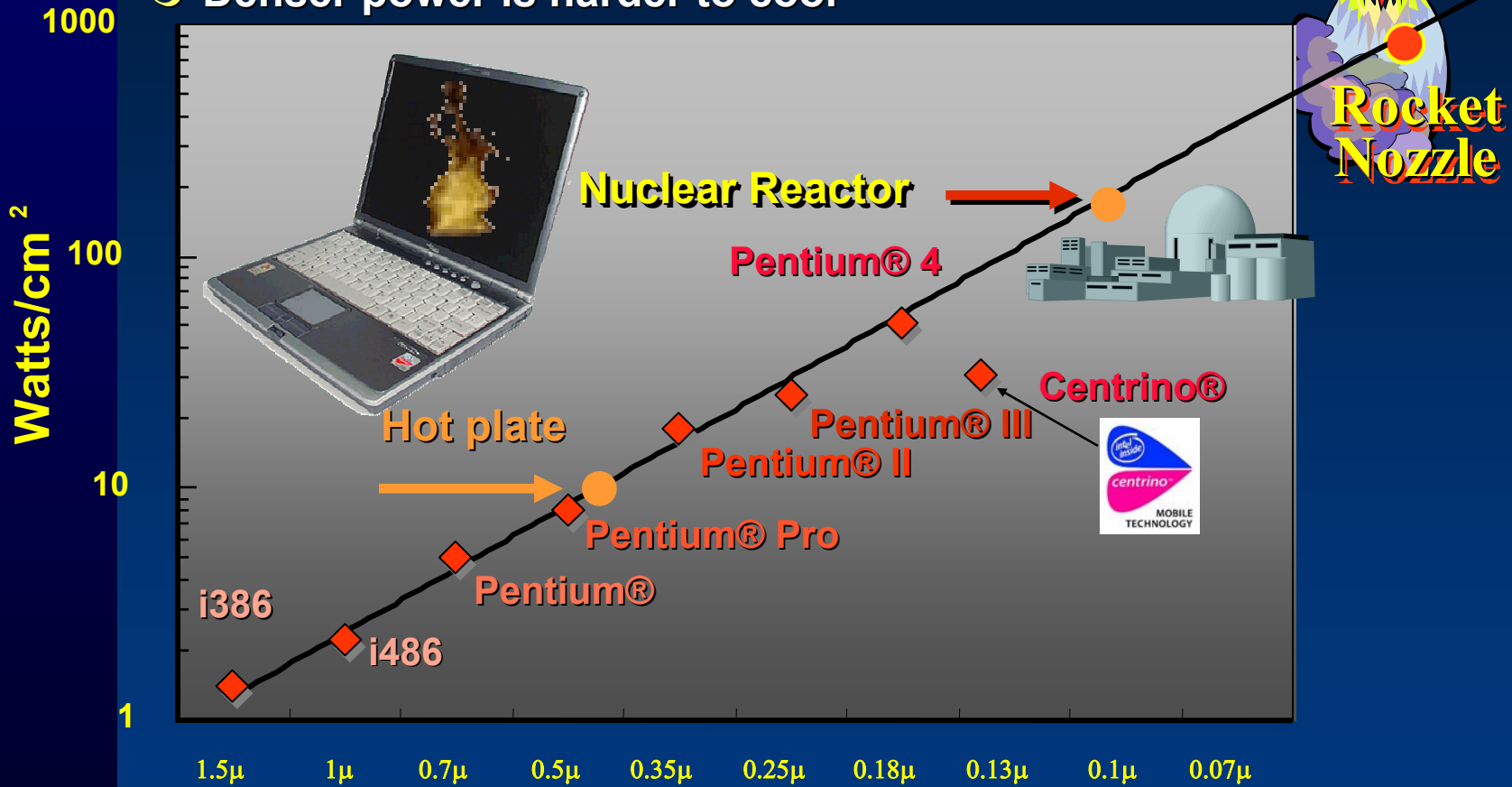
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# Power & Density increases

- Think Watts/Cm<sup>2</sup>
  - Complex architecture at faster and smaller technology
  - Denser power is harder to cool



Sun's Surface

Rocket Nozzle

\* "New Microarchitecture Challenges in the Coming Generations of CMOS Process Technologies" – Fred Pollack, Intel Corp. Micro32 conference key note - 1999.

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# The Mobile Environment

- **Maximize performance & features within given constraints**
  - Power / Thermal
  - Size – form factor
  - Noise
  - Energy / Battery life
  - etc.
- **Mobile platforms offer Tradeoff preferences**
  - **User defined or built-in scheme**
    - Compromise performance for longer battery life, lower acoustic noise, cool box etc.

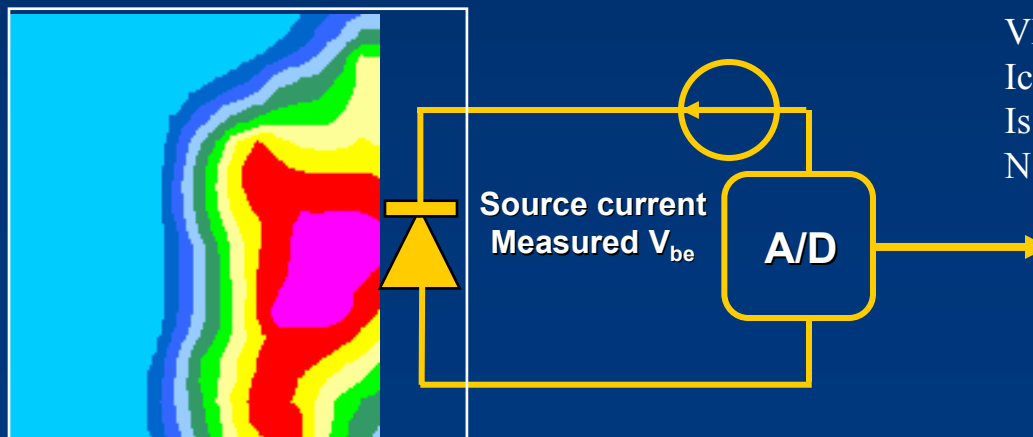
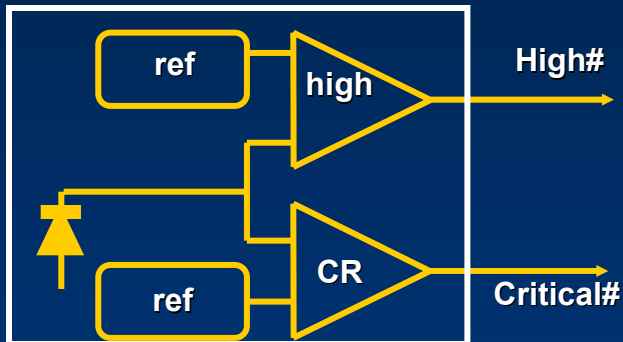


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# Die Temperature measurements

- Temperature based control mechanisms
- A diode connected to an external A/D - reports temperature
- Fixed temperature sensors
  - Max spec junction temperature
  - Critical temperature detector



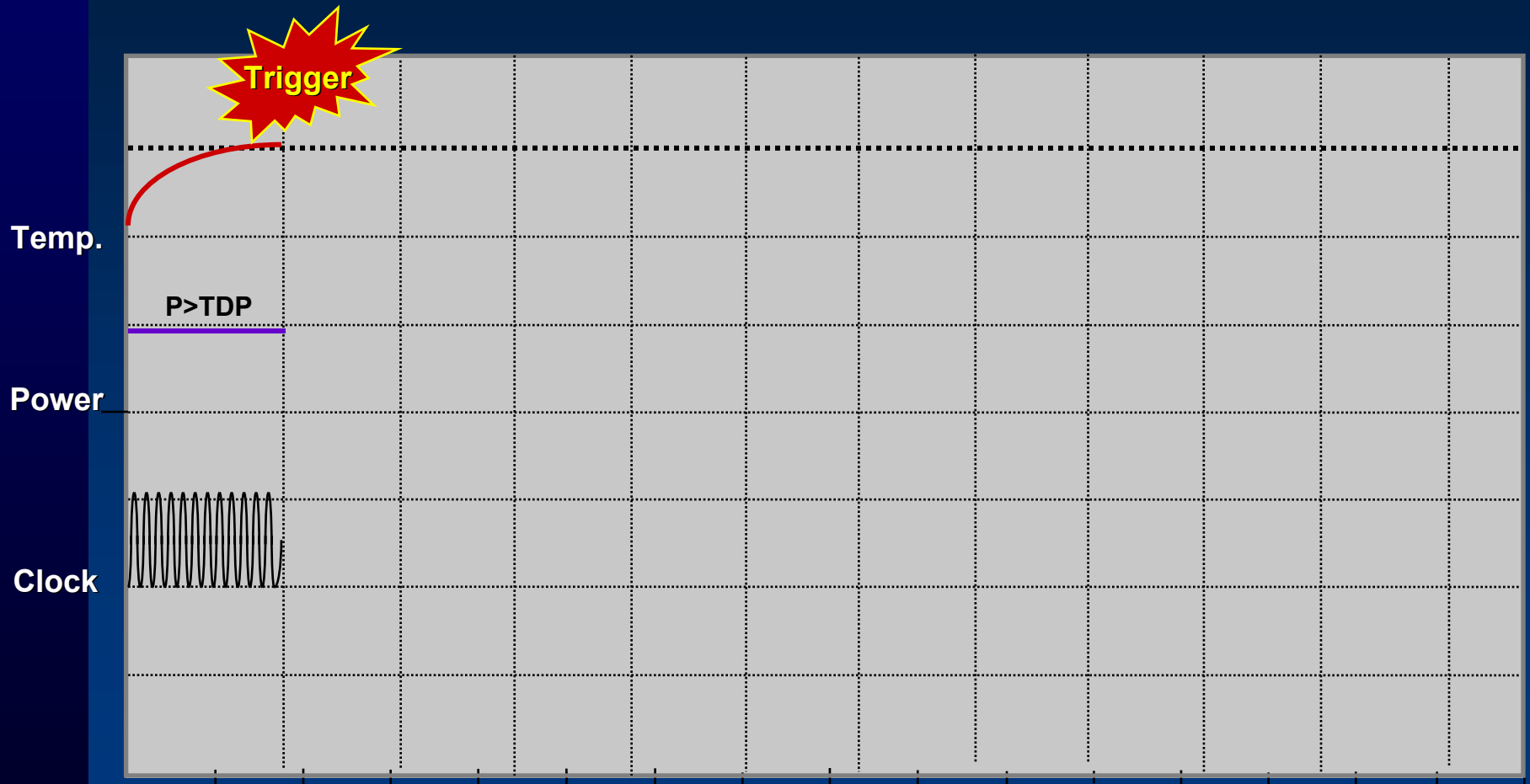
$$T = \frac{\Delta V_{BE}}{n \cdot \ln(N) \cdot \frac{k}{q}}$$

n: diode ideality factor  
k: Boltzmann constant  
q: electron charge constant  
T: diode temperature (Kelvin)  
V<sub>BE</sub>: Voltage from base to emitter  
I<sub>c</sub> : Collector current  
I<sub>s</sub> : Saturation current  
N: Ratio of collector currents

# Controlling TDP - Linear



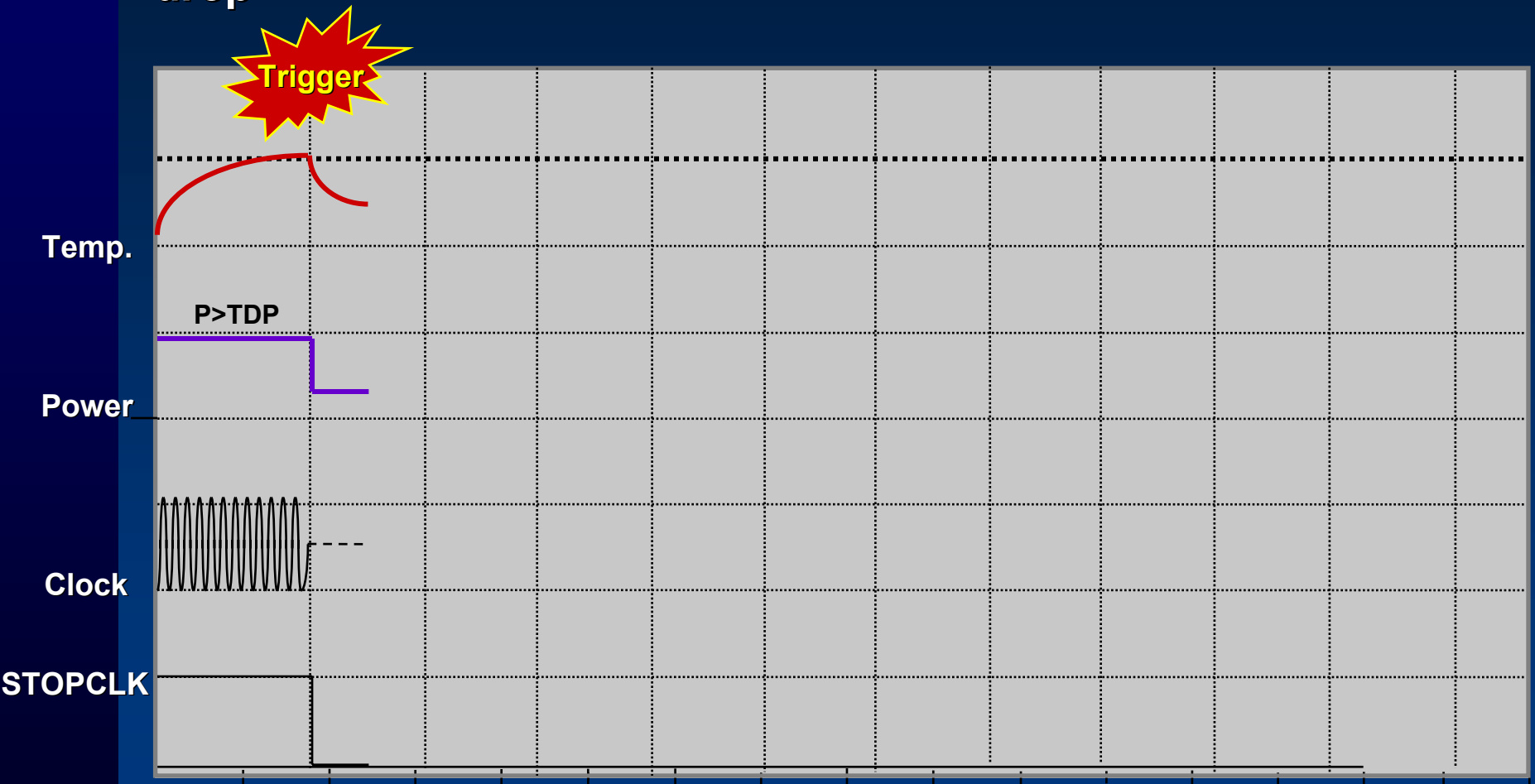
- P states and T states



# Controlling TDP - Linear



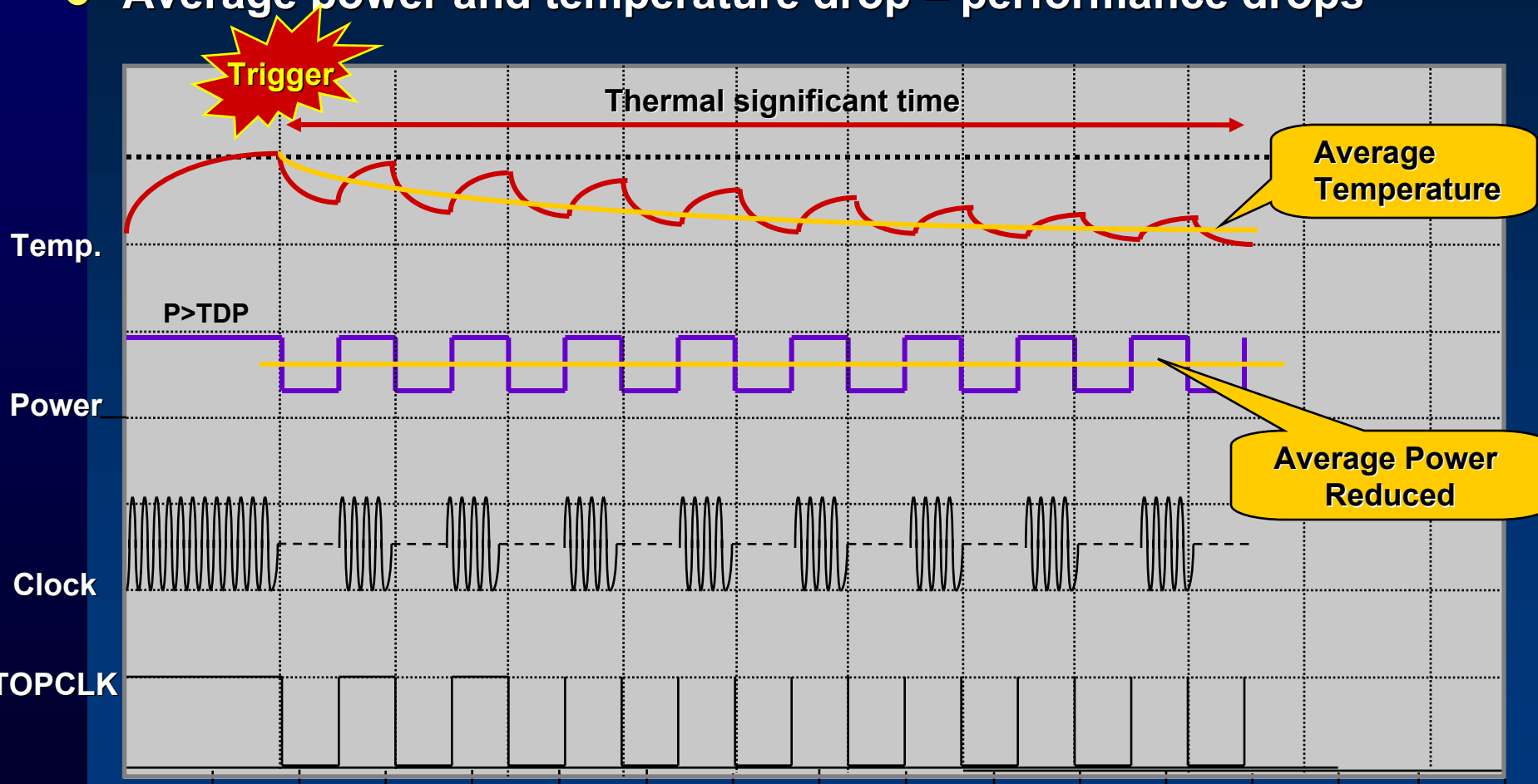
- Self or S/W trigger – Stop clock asserted, Power and temperature drop



# Controlling TDP - Linear



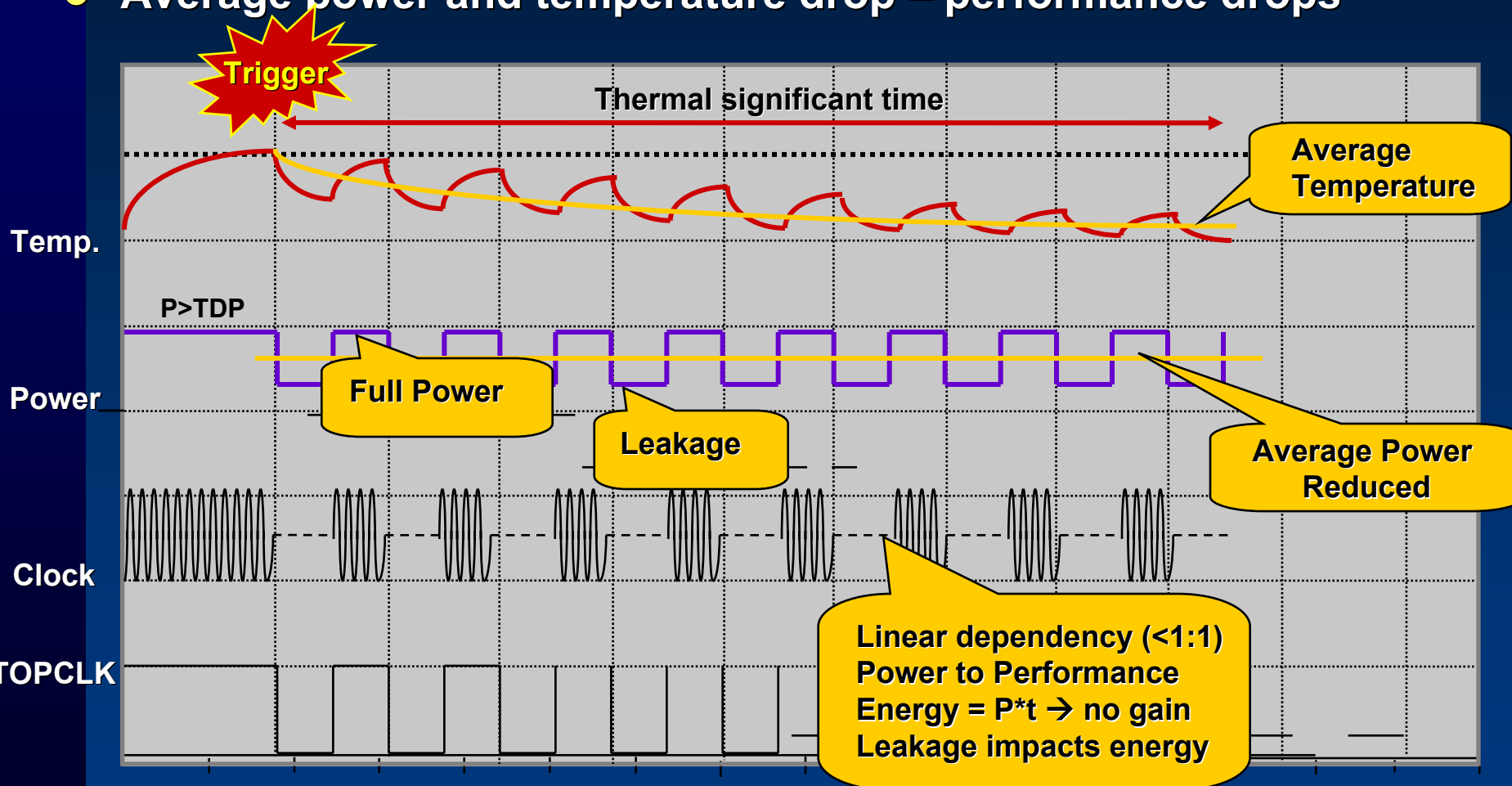
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- Average power and temperature drop – performance drops



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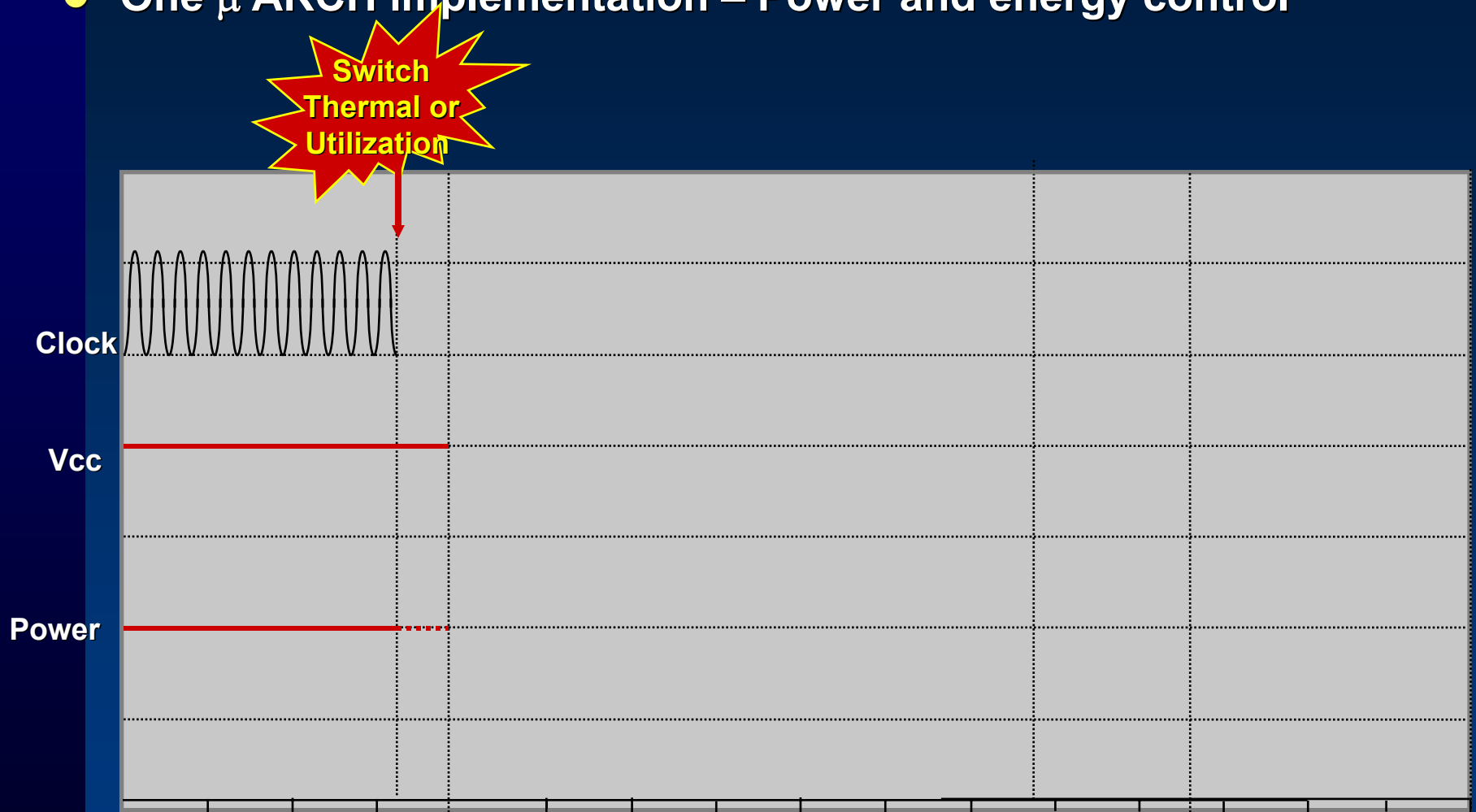
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# Dynamic Voltage Scaling (DVS)



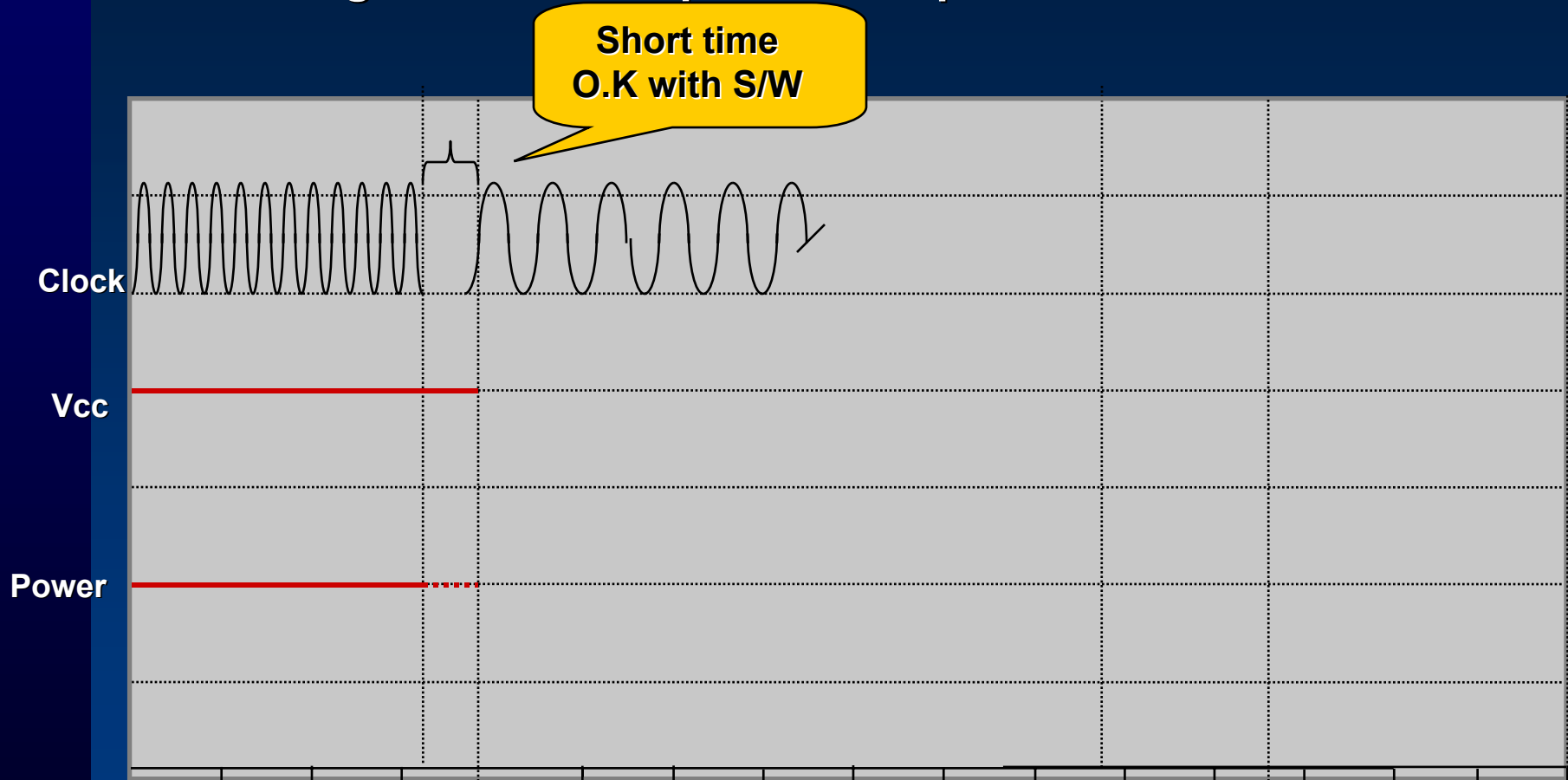
- One  $\mu$  ARCH implementation – Power and energy control



# Dynamic Voltage Scaling (DVS)



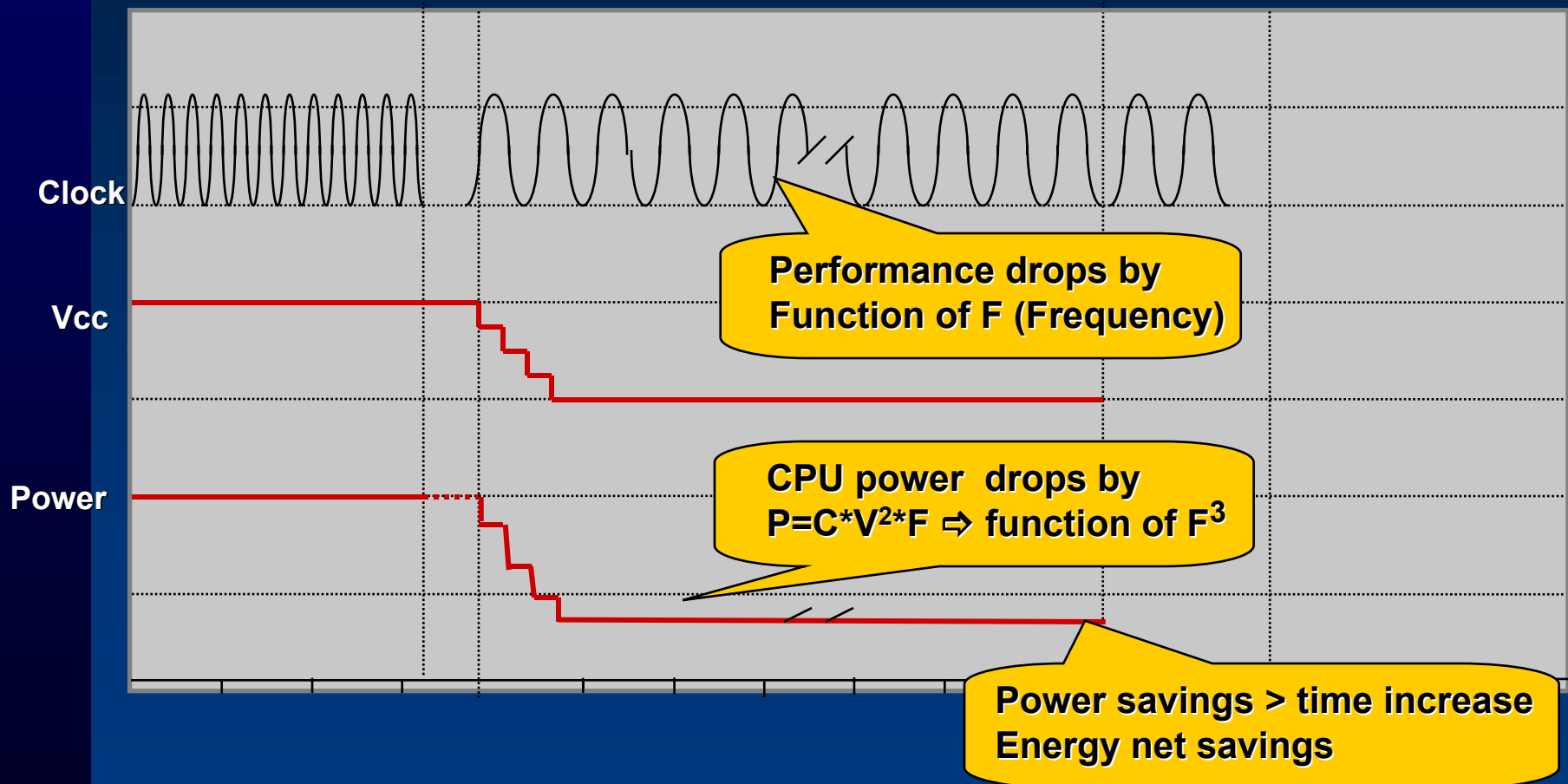
- PLL relock at lower frequency at same  $V_{cc}$
- Fast change – no user experience impact



# Dynamic Voltage Scaling (DVS)



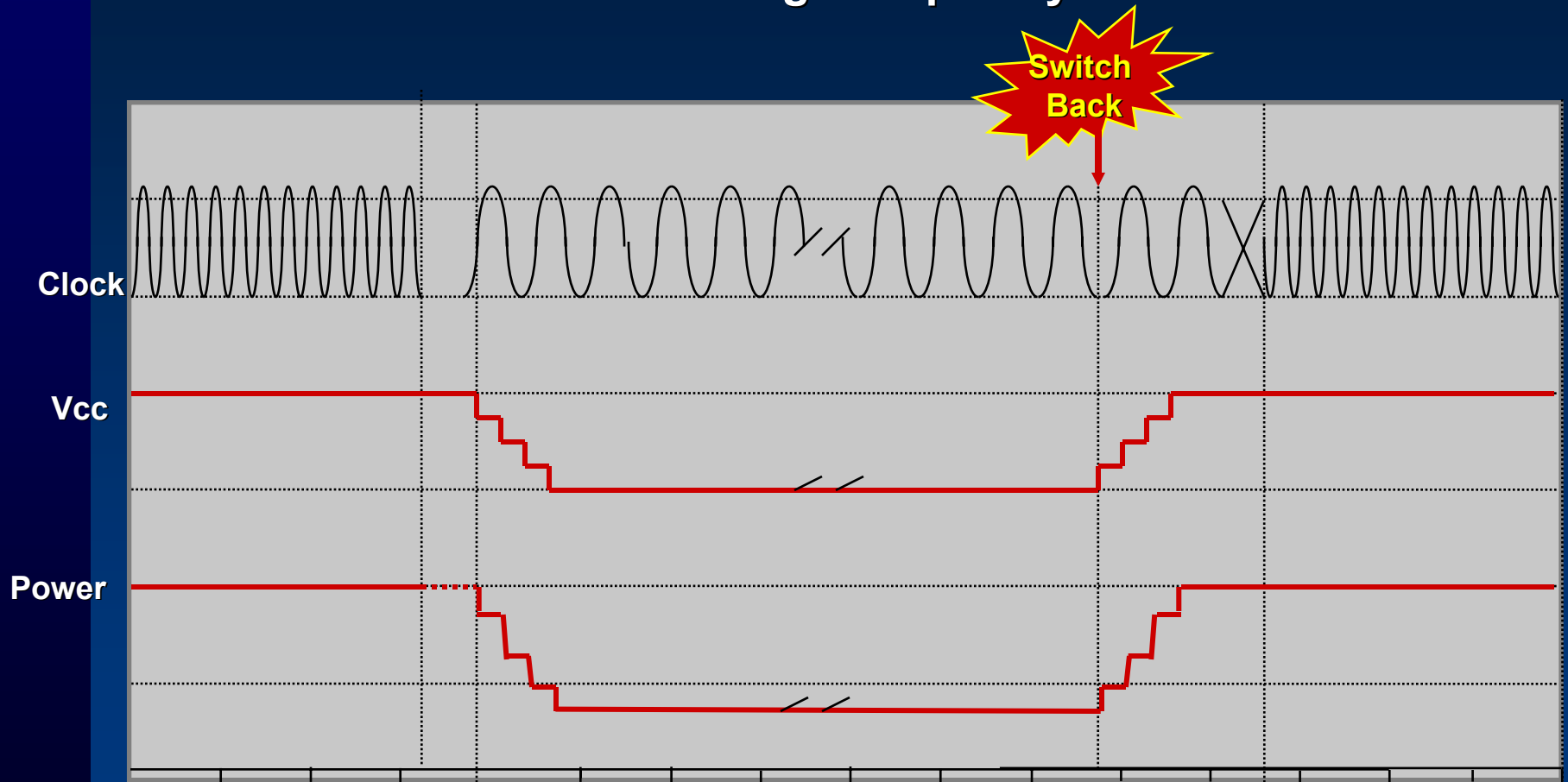
- Vcc drops gradually while CPU active
- Power savings changes from linear to  $F^3$



# Dynamic Voltage Scaling (DVS)



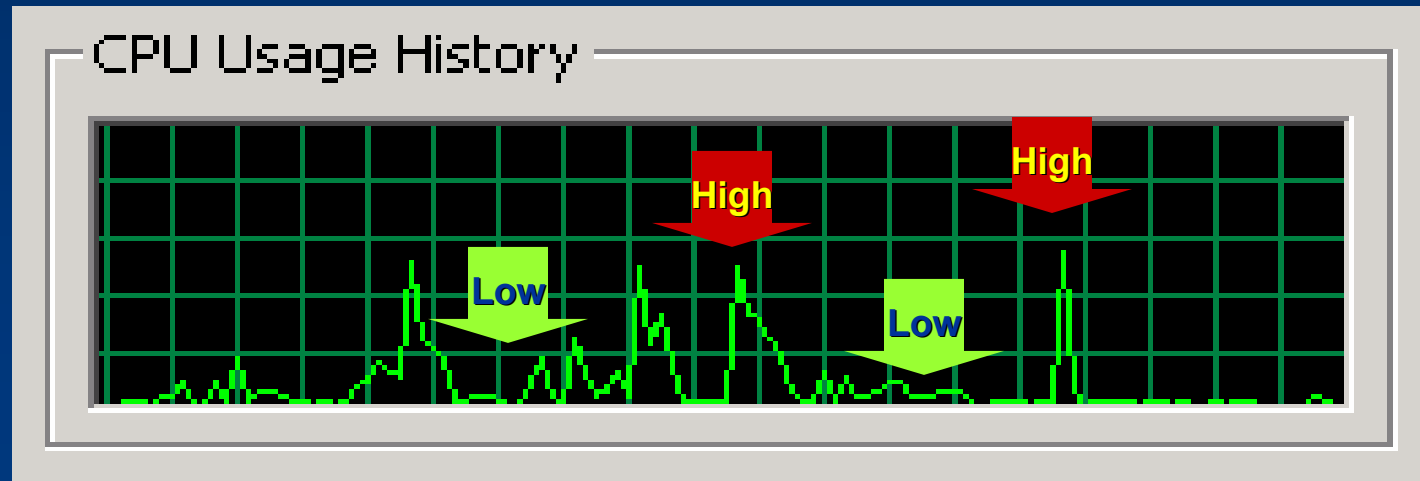
- Vcc is ramped up increasing power
- Once stable – PLL relock at high frequency





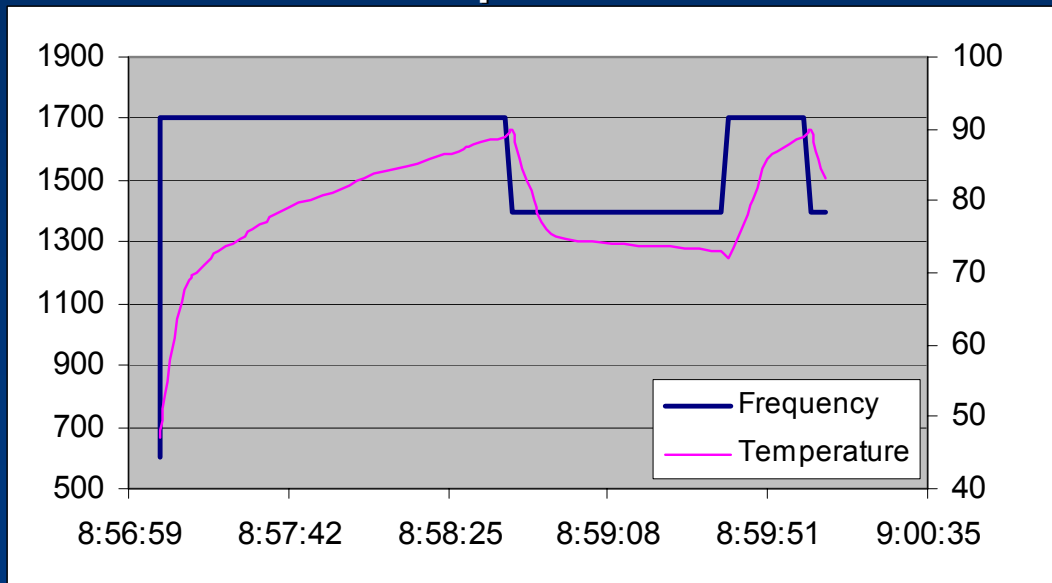
# Adaptive Energy Control

- Applications have wide dynamic power range
- Require high power high performance bursts
  - Determine user experience
- Trade power performance as needed
  - Driven by Operating system ACPI
  - Average power control on the fly - **ADAPTIVE**

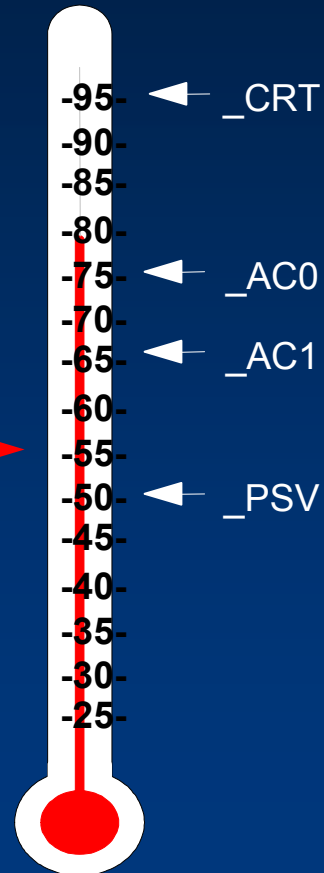


# ACPI Control

- Operating system feature – Industry standard
  - Supported by MS and Linux
  - Passive and active policies defined for each zone
    - Switches `_PSV` and `_ACx`
  - DVS or clock throttling used for passive power control
    - Available Power states published by BIOS
    - DVS and once reached min  $V_{cc}$  - linear
    - Implements PD controller algorithm
  - Fan on/off and speed used for active cooling



`_TMP = 60` →



```

Shortcut to adjustable_power.exe
Duty cycle: .8

Test name:      Adjustable power test <duty cucle: 0.8>
Test version:   1.1
Utils version:  1.1
Compiler:       Visual C++, Win32

Press escape to stop
On loops: 80000, Off loops: 239

```

Intel(R) Frequency Di...  
 File Options  
**P0: 600 MHz**

**Intel® Thermal Analysis Tool**  
 File Options Help

INTEL CONFIDENTIAL    Pentium M    MONITOR

intel.    On Demand Control: 0%    Workload Level: 100%

Start Control    Start Workload

Processor Frequency: 1400 Mhz

Results: Intel Thermal Monitor

Temperature: 74°C

```

Intel® Thermal Analysis Tool: v1.2.1
Processor: Pentium® M Processor
Microsoft Windows XP Professional Service Pack 1
OS version: 5.1.2600 (Build 2600)
On Demand Clock Modulation: Chipset: 0-0 Processor: 0-1
Driver Version: v1.0
Power Source: AC
Workload library returns Context: 0x610002
Polling Period: 2000 mSec.
On Demand Clock Modulation: Chipset: 0-0 Processor: 0-1
8:57:07: *** Monitor Started ***
8:57:07: ACPI\ThermalZone\THM0_0 TMP[ 48°C ]
8:57:09: ACPI\ThermalZone\THM0_0 TMP[ 55°C ]
8:57:11: ACPI\ThermalZone\THM0_0 TMP[ 61°C ]
8:57:13: ACPI\ThermalZone\THM0_0 TMP[ 68°C ]
8:57:15: ACPI\ThermalZone\THM0_0 TMP[ 69°C ]

```

Start Logging    Output Results    Stop Monitor

Windows Media Player    MovieShop    QuickTime Player

4.0 ברוי    TinySheet Manager

WCPULK    Wireless Link    Acrobat Reader 5.0

TAT.exe    Microsoft Outlook    JMP 5.0.1

Shortcut to adjustable\_...    Shortcut to cpuz.exe    WinTel    Recycle Bin    Shortcut to FreqDsp

Shortcut to IRL\_aDSL    Santa Clara Tollfree (US)    Shortcut to Israel Tollfr...

Start    I...    My    R...    P...    F...    H...    F...    P...    I...    M...    P...    S...    80%    8:59 AM Wednesday

```
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Intel(R) Frequency Di...  
File Options  
**PO: 1400 MHz**

### Intel® Thermal Analysis Tool

File Options Help

INTEL CONFIDENTIAL    Pentium M    MONITOR



On Demand Control:     Workload Level:   
   

Processor Frequency:     1400 Mhz

Results:     Intel Thermal Monitor

8:58:50: ACPI\ThermaZone\THM0\_0 TMP[ 76°C ]  
8:58:54: ACPI\ThermaZone\THM0\_0 TMP[ 75°C ]  
8:59:09: ACPI\ThermaZone\THM0\_0 TMP[ 74°C ]  
8:59:39: ACPI\ThermaZone\THM0\_0 TMP[ 73°C ]  
8:59:41: Processor Frequency: 1400Mhz -> 1700Mhz  
8:59:47: ACPI\ThermaZone\THM0\_0 TMP[ 80°C ]  
8:59:49: ACPI\ThermaZone\THM0\_0 TMP[ 83°C ]  
8:59:51: ACPI\ThermaZone\THM0\_0 TMP[ 87°C ]  
8:59:57: ACPI\ThermaZone\THM0\_0 TMP[ 88°C ]  
Writing to C:\Program Files\Intel Corporation\TAT\Results.txt  
9:00:01: ACPI\ThermaZone\THM0\_0 TMP[ 89°C ]  
9:00:03: Processor Frequency: 1700Mhz -> 1400Mhz  
9:00:05: ACPI\ThermaZone\THM0\_0 TMP[ 86°C ]  
9:00:07: ACPI\ThermaZone\THM0\_0 TMP[ 83°C ]  
9:00:08: \*\*\* Monitor Stopped \*\*\*  
Writing to C:\Program Files\Intel Corporation\TAT\Results.txt

Temperature:     100°C

Windows Media Player    MovieShop    QuickTime Player

4.0 בן 710    TinySheet Manager

WCPU    Wireless Link    Acrobat Reader 5.0

TAT.exe    Microsoft Outlook    JMP 5.0.1

Shortcut to adjustable\_...    Shortcut to cpuz.exe    WinTel    Recycle Bin    Shortcut to FreqDsp

Start    I...    My    R...    P...    F...    H...    C...    O...    C...    I...    M...    G...    H...    G...    R...    I...    S...    I...    Wednesday

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# Test Setup

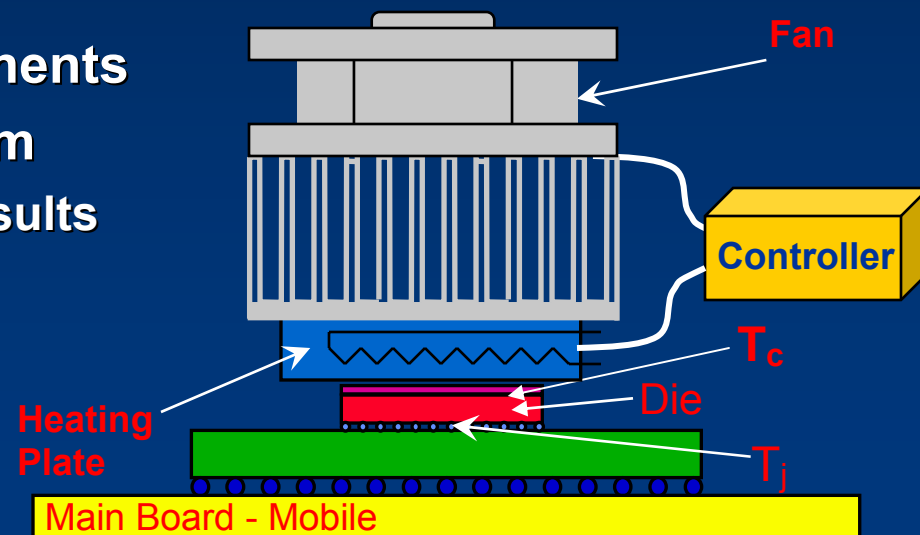
## Thermal control

- CPU temperature is a function of power and ambient temp.
  - Long time to heat the ambient and heat sink
- Case temperature control formed stable environment
  - Heating plate and fan to keep temperature at fixed temperature
  - Force extreme conditions

## Test cases

- SPEC-Int and SPEC-FP components
- Used the self trigger mechanism
  - For repeatable & consistent results
- Collected power temperature and performance

**Testing on real silicon the theoretical expected behavior**



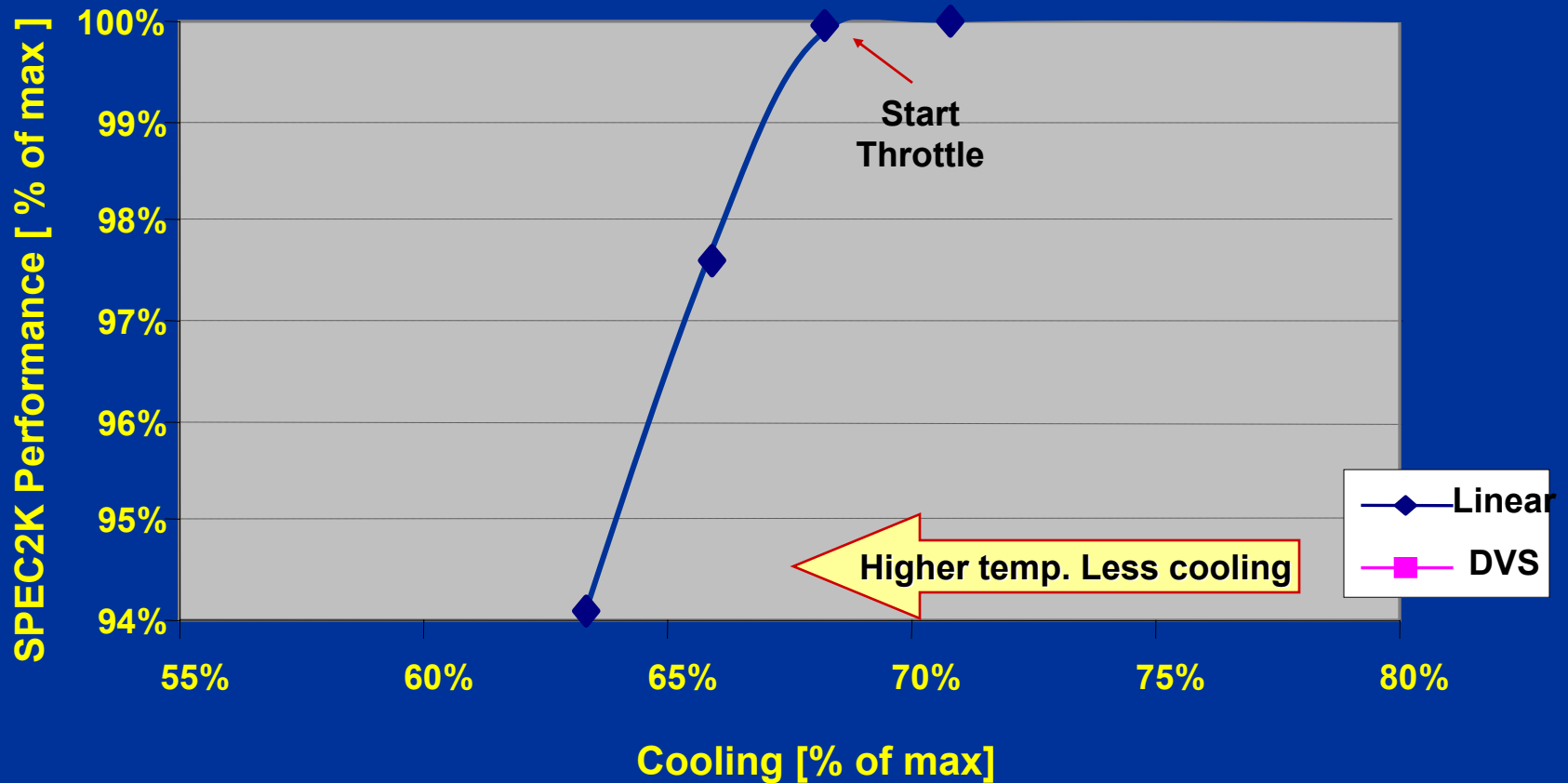
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# Lineal vs. DVS control



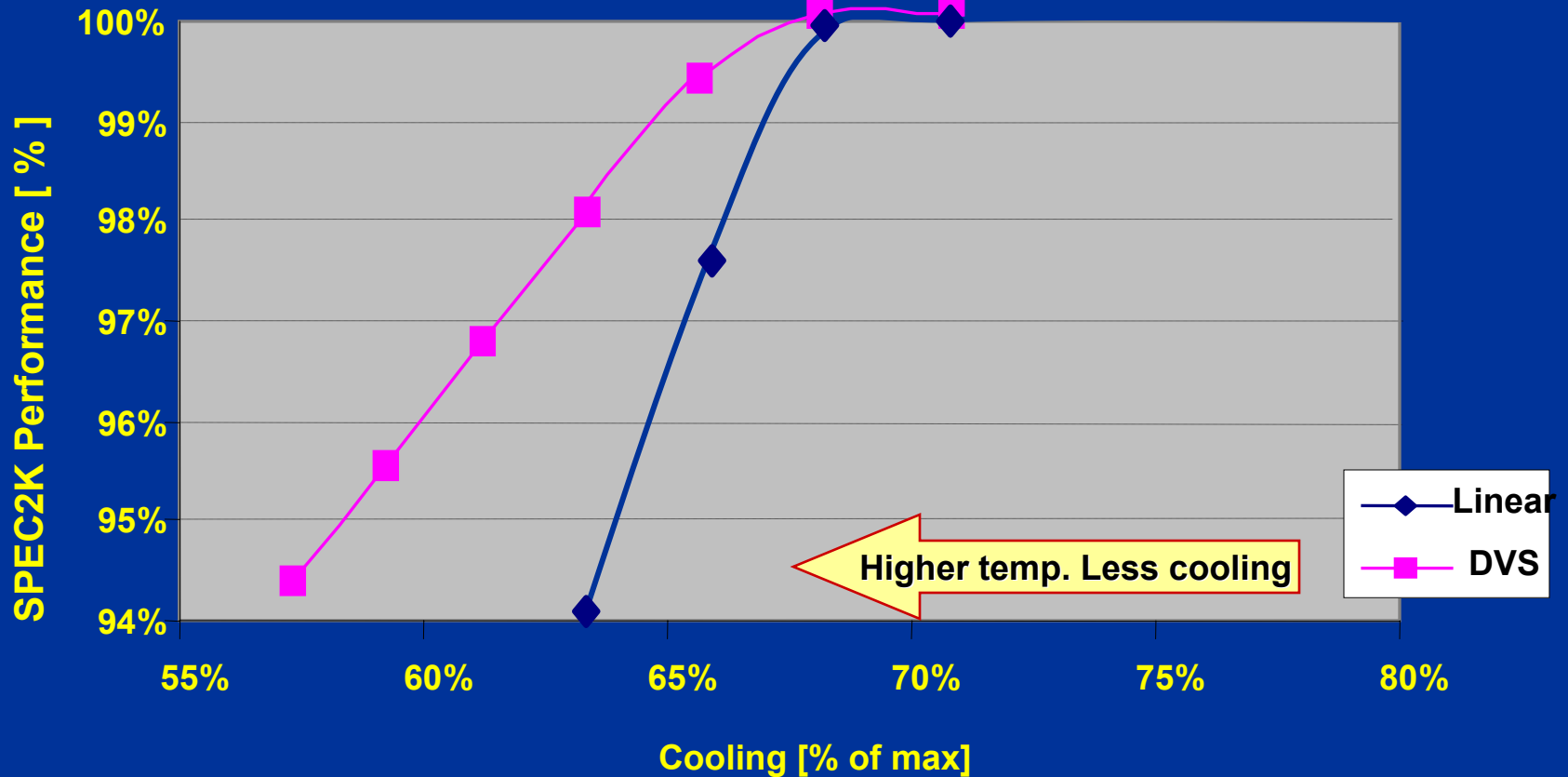
## Thermal Throttle impact



# Lineal vs. DVS control



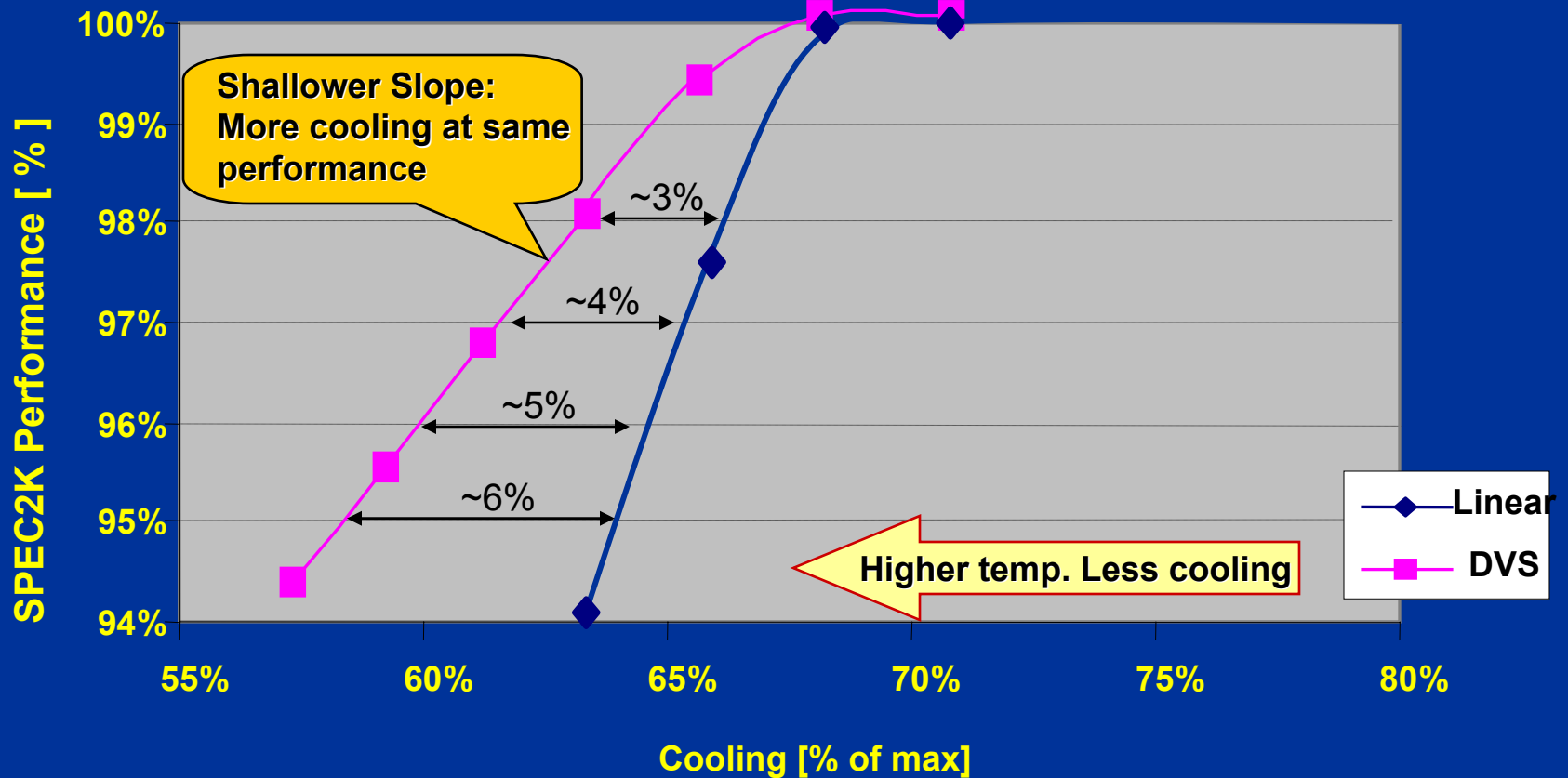
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# Lineal vs. DVS control



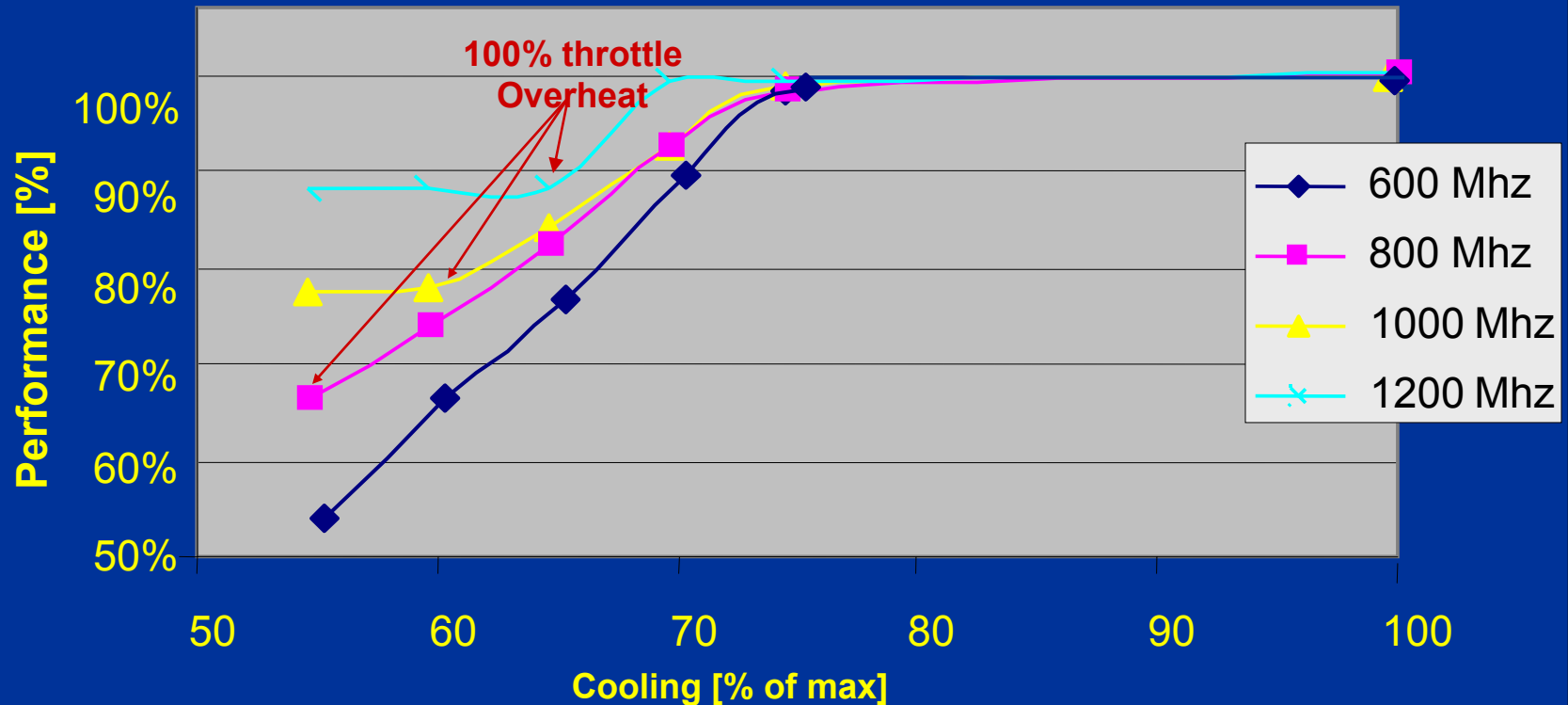
## Thermal Throttle impact



# DVS set point

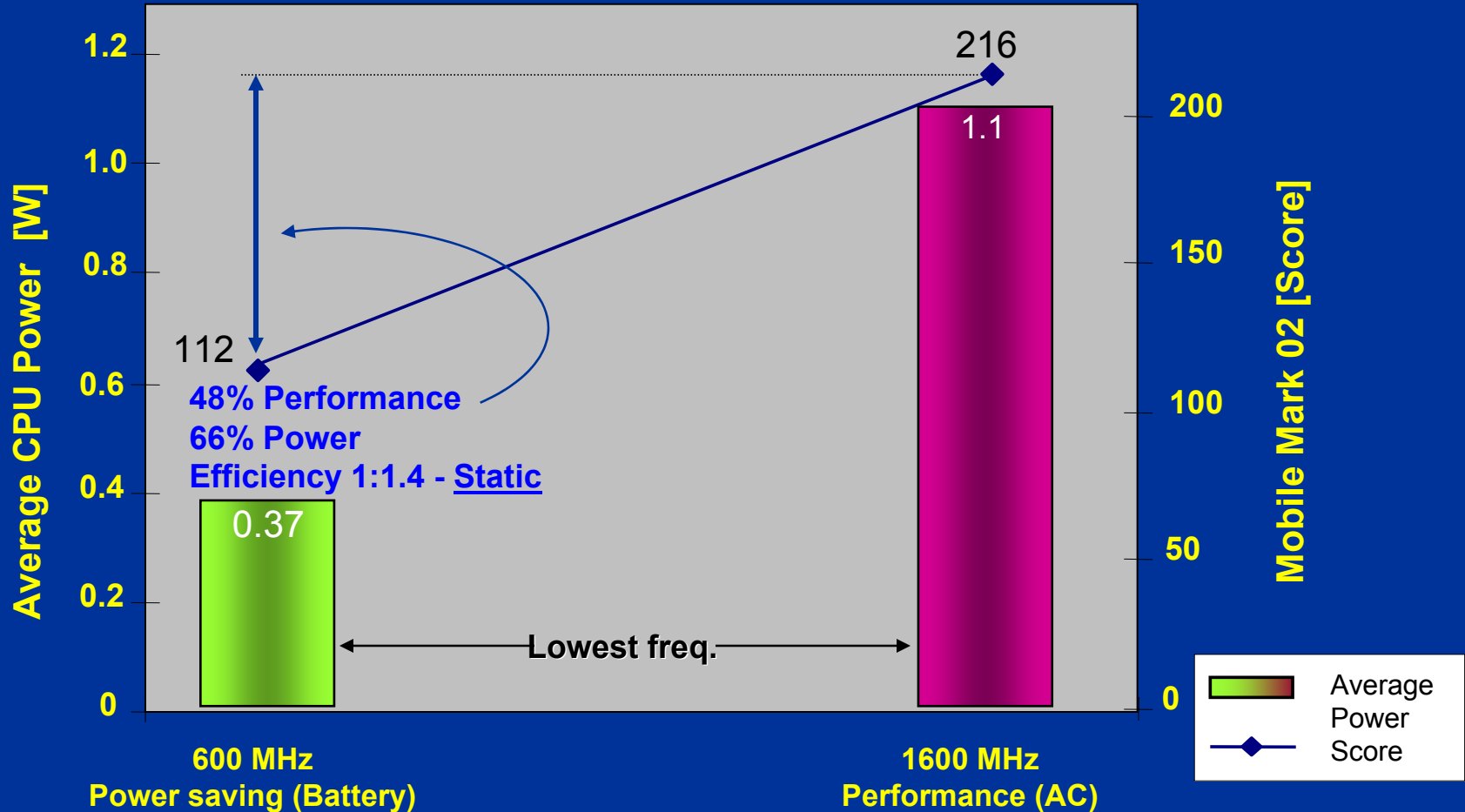


## Throttle impact on performance

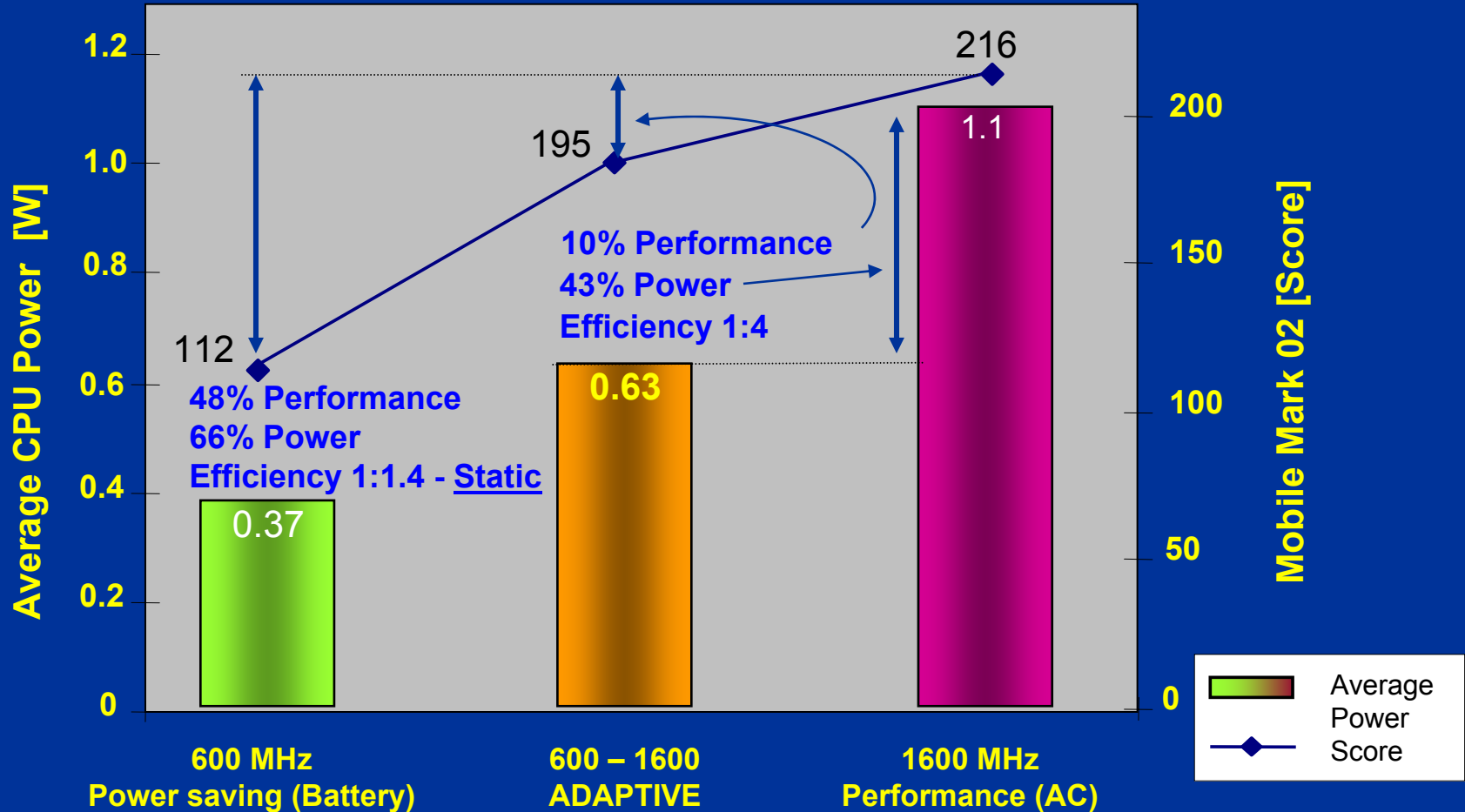


**Optimal point (performance) is at the highest frequency that dose not accede  $T_j\_max$  with no transitions up and down**

# Average Power management

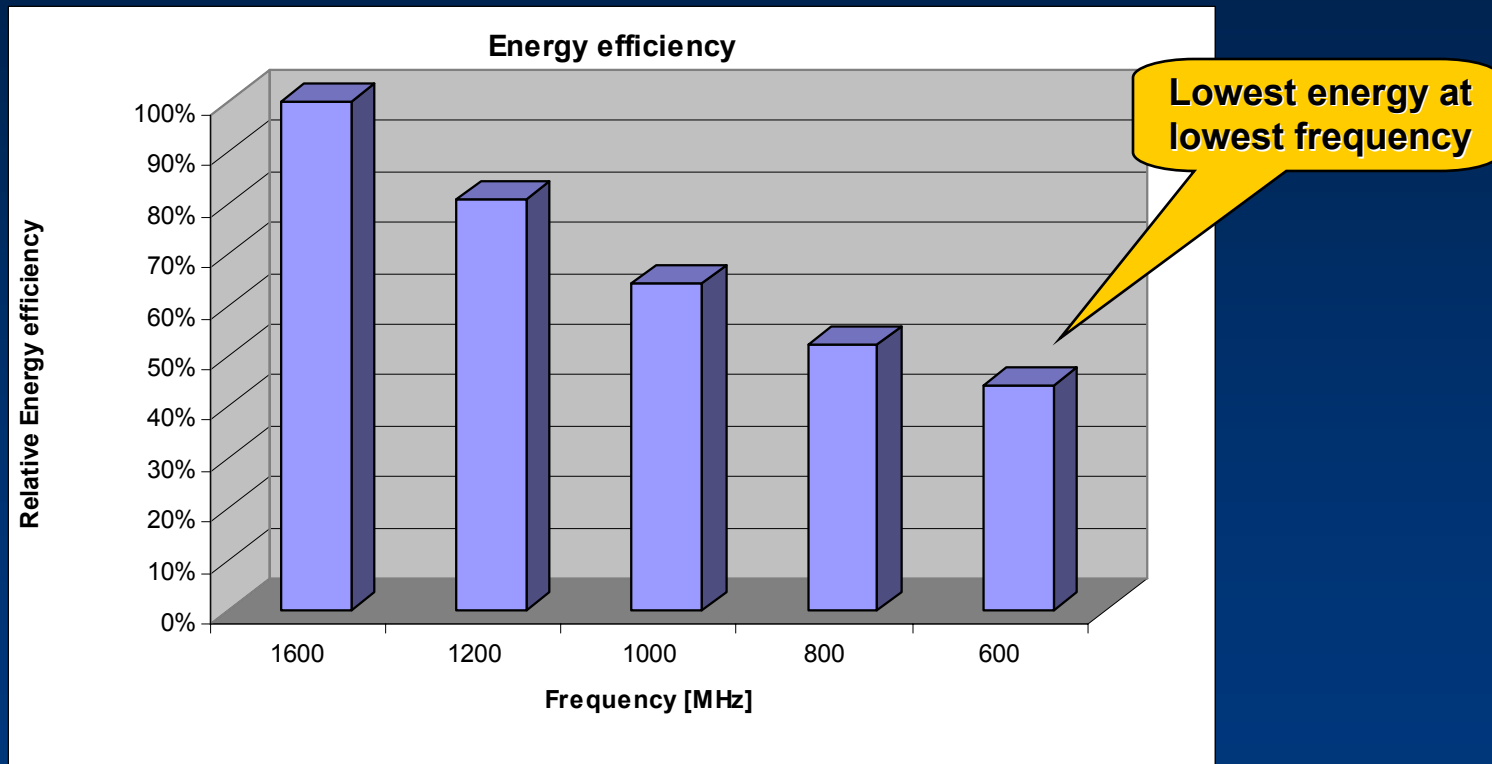


# Average Power management



# Energy efficiency

- Energy consumed for the SPEC-Int and SPEC-FP
  - We measured energy as  $E = \int_t P(t)$
  - Energy consumed at 1600 MHz defined as 100%



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# Summary and Conclusions

- **Intel Pentium M Specifically designed for mobile**
  - Targeting energy and power efficiency
- **Mobile systems trade performance for power**
  - To meet user preference
- **Enhanced Intel SpeedStep Technology provides significantly improved power to performance and energy control scheme**
  - Silicon measurement confirm the theoretical work
  - Optimal point for performance to power is at the highest frequency that dose not accede  $T_j\_max$ 
    - Policy implemented into ACPI algorithm
  - Optimal point for energy and battery life is at the minimum frequency possible with DVS

# Thanks

The authors would like to thank **Nachum shamir**, **Irina Ilatov** and **Riad Durr** for the thermal clamping measurements, to **Jessie Garcia**, **Ali Saeed**, **Marco Wirasinghe** for the evaluation and data collection for this article and to **Cohen Aviad** and **Lev Finkelstein** for results verification using simulation.



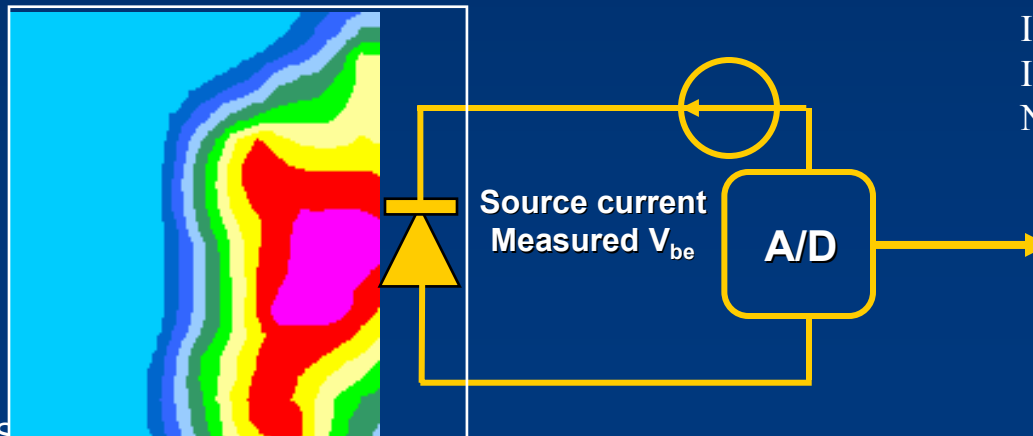
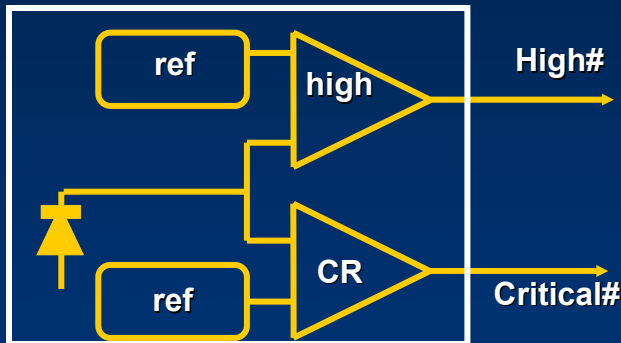
# Die Temperature measurements

- A diode connected to an external A/D reports temperature
- Fixed temperature

$$V_{BE} = \frac{nkT}{q} \cdot \ln\left(\frac{I_C}{I_S}\right)$$

Applying 2 Currents

$$T = \frac{\Delta V_{BE}}{n \cdot \ln(N) \cdot \frac{k}{q}}$$

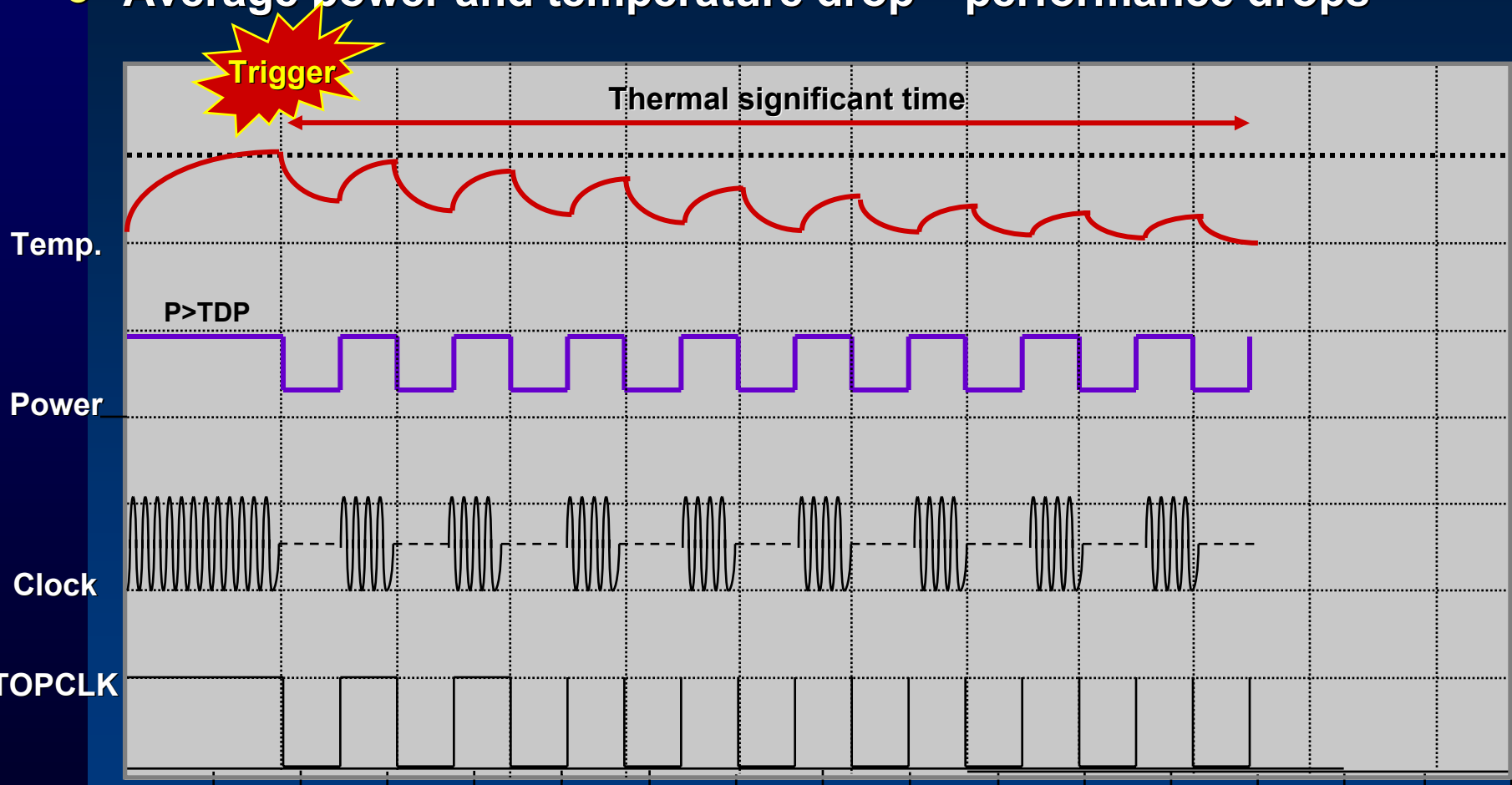


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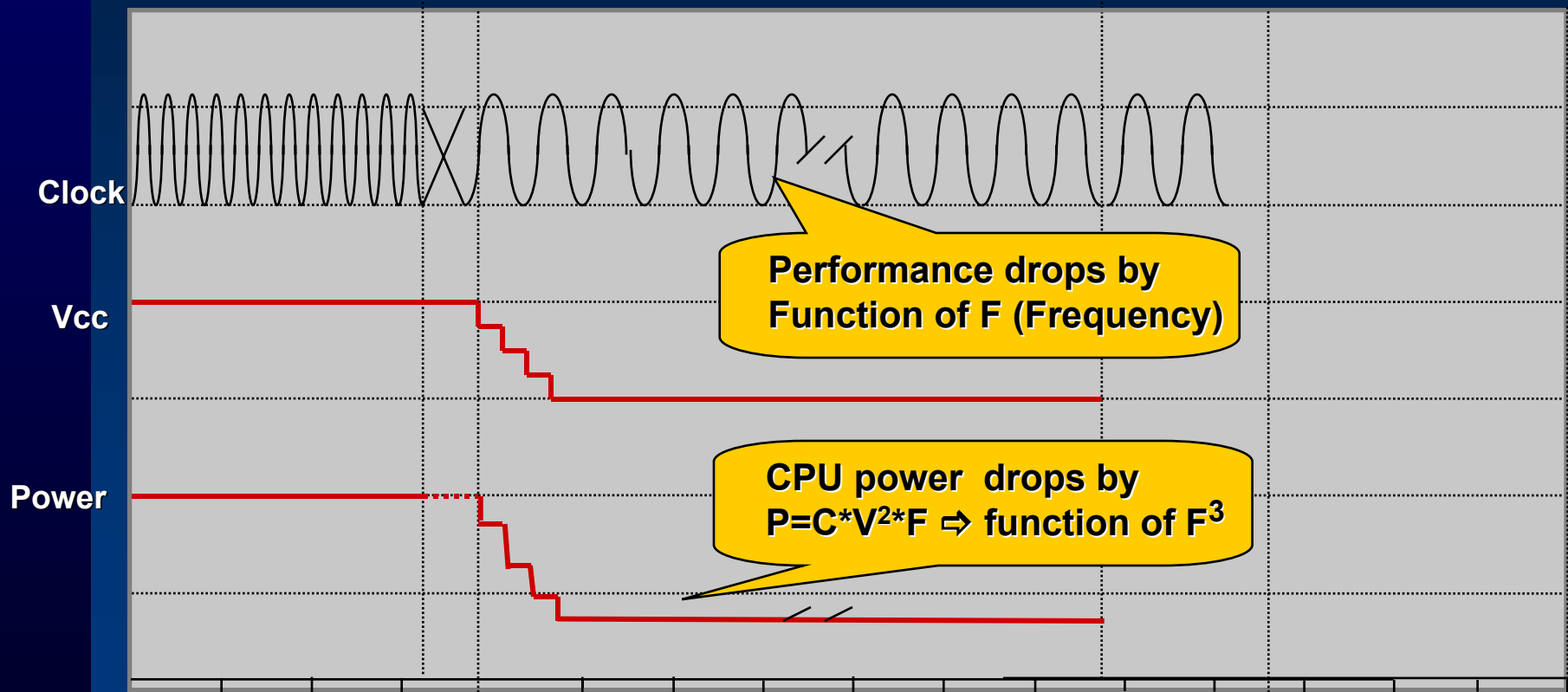
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- Average power and temperature drop – performance drops



# Dynamic Voltage Scaling (DVS)



- $V_{cc}$  drops gradually while CPU active
- Power savings changes from linear to  $F^3$



# The Pentium M Power Control Schemes

## Linear power scaling

- **Change CPU frequency only**
  - reduces both power and performance linearly with frequency
  - Saves power, No energy savings

## New Dynamic Voltage Scaling (DVS)

- **Reduces Voltage and frequency on the fly**
  - Frequency is dependent ~ linearly on Voltage
  - Power is a function of  $C \cdot F \cdot V^2$
- **Reduction of both voltage and frequency provides  $F^3$  power reduction for linear performance reduction**
  - Also results with energy savings

# ACPI Interface

**Battery MaxiMiser Wizard**

## Power Scheme settings

**Shut off devices and timers you don't need.**

Use extended power schemes to manage power according to your needs. Select an extended power scheme and click **OK**, or click **Create New Power Scheme** to create a customized scheme.


**Long Battery Life** (highlighted in green)

**High Power Use** (highlighted in purple)

List of Predefined Power Schemes



- Personal
- Super Power Saver
- ThinkPad Default
- High Battery Performance
- High Battery Performance
- CD Audio
- CD Audio
- Word Processing/E-mail
- Dark Room
- Word Processing/E-mail
- Dark Room
- High System Performance
- High System Performance

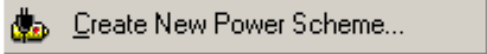
### Super Power Saver

When using battery power: 

System standby:	5 mins.
Turn off monitor:	3 mins.
LCD brightness:	Level 0 (Low)
Turn off hard disks:	3 mins.
CPU speed:	Slow

Maximizes your power savings.

 **Create New Power Scheme...**

**OK** **Cancel**

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- See details...