
Bits of Architecture

— The Power Wall —

Why Don't We Have 10 GHz CPUs?

It's All About the Power

- Power and frequency increased together for decades
- We eventually hit a practical limit
- Why?
 - Difficult to bring
 - in/distribute
 - Difficult to cool

The future of Intel's manufacturing processes

by [Anand Lal Shimpi](#) on December 11, 2000 1:23 AM EST

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[10GHZ BY 2005 RUNNING AT < 1 VOLT](#)

10GHz by 2005 running at < 1 volt

CMOS

CMOS

- Complementary Metal Oxide Semiconductor (**CMOS**)
- Contributors to energy consumption
 - Dynamic Energy - Switching States (0->1, 1->0) (**Dominant**)
 - Static Energy - Due to things like leakage current

Energy and Power Equations (Dynamic)

Energy (Pulse)
(0->1->0 or 1->0->1)

$$Energy \propto CapacitiveLoad \times Voltage^2$$

Energy (Single Transition)
(0->1 or 1->0)

$$Energy \propto \frac{1}{2} \times CapacitiveLoad \times Voltage^2$$

Power Per Transistor?

$$Power \propto \frac{1}{2} \times CapacitiveLoad \times Voltage^2 \times Frequency$$

What Drove Frequency Scaling?

Dennard Scaling

- Scale transistor dimensions
 - Decrease in **Capacitance, Voltage, Delay**
 - Increase in **Frequency**
 - **Power** remains constant!

Design of Ion-Implanted MOSFET's with Very Small Physical Dimensions

ROBERT H. DENNARD, MEMBER, IEEE, FRITZ H. GAENSSLEN, HWA-NIEN YU, MEMBER, IEEE, V. LEO RIDEOUT, MEMBER, IEEE, ERNEST BASSOUS, AND ANDRE R. LEBLANC, MEMBER, IEEE

Where Did it All Go Wrong?

Static Power is Significant

- Transistors are “leaky”
 - Leakage current (never fully off)
- Scaling down voltage exacerbates this problem
 - Major problems at $\leq 90\text{nm}$
- If we can't scale voltage, power increases!

Power Isn't the Only Thing

Energy is Critical

- Mobile devices are everywhere
 - Batteries!
- Powering + cooling warehouse-scale computers
 - Expensive at scale
- Peak power isn't everything...
 - Ubiquitous low-power+inexpensive devices