

Thermal Control of Electronics: Perspectives and Prospects

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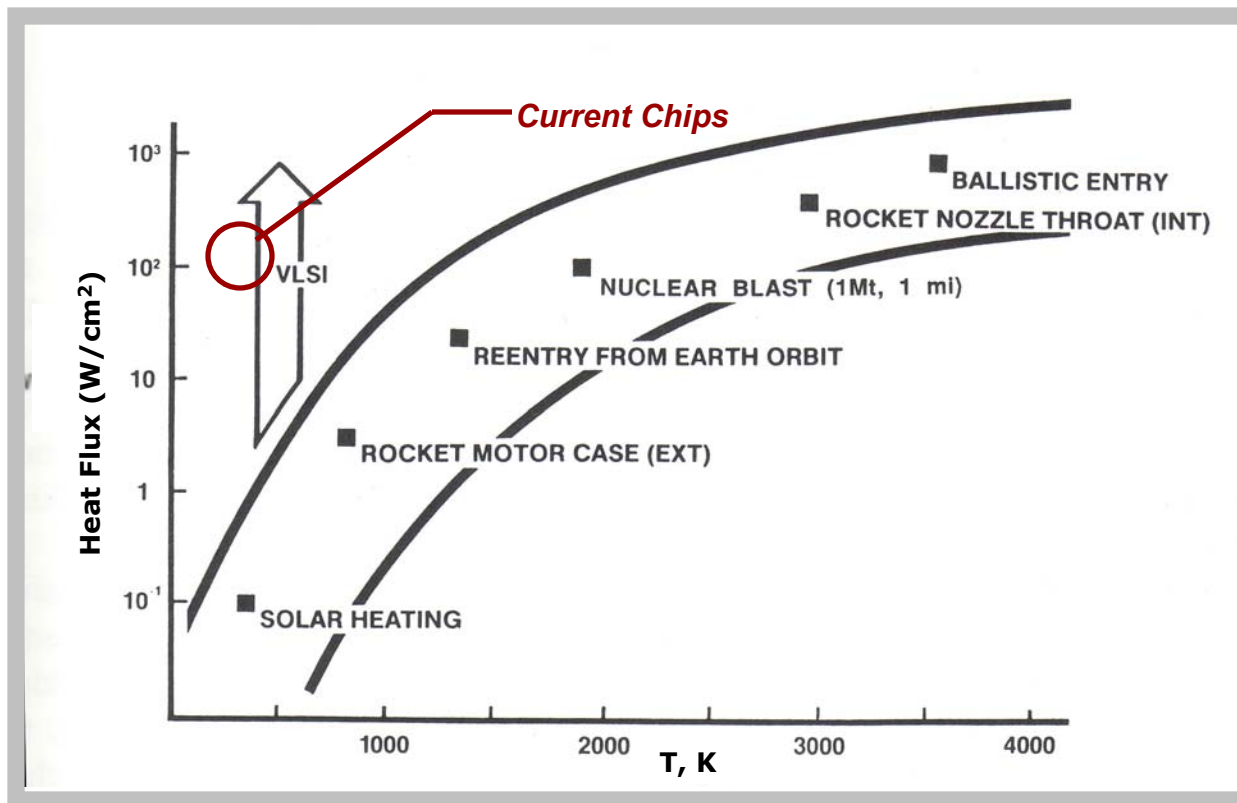
***Rohsenow Symposium on Future
Trends in Heat Transfer***

***Massachusetts Institute of Technology
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Introduction

- Thermal control of electronics is posing significant challenges (again)
- New, or re-invented technologies will be needed
- Moore's Law is the iconic driver of electronics progress – but it will continue until physics gets in the way (cooling!)
- Research and development is needed as never before
- Note: what follows is computer-centric, but...

Perspective on microelectronic heat flux



Hannemann, Bar-Cohen, and Oktay, ca. 1986

Technology generations

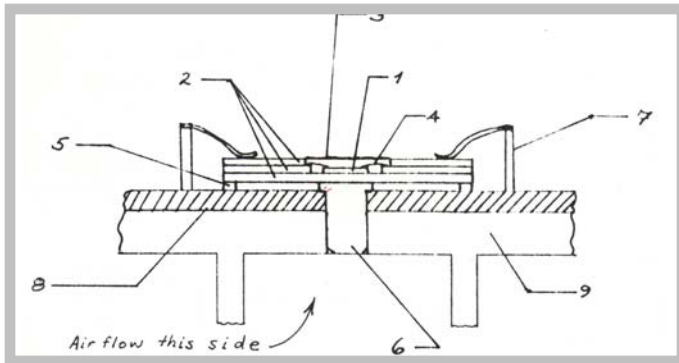
Timeframe	Generation	Representative Product	Chip Power	Module Power Density	Rack Power
1945-1955	Historic	Specialty Computers	Yellow	Green	Yellow
1955 - 1965	Transistor	Early Mainframe	Green	Green	Green
1965 - 1975	SSI	Mainframe	Green	Green	Yellow
1975 - 1985	MSI	Minicomputer	Yellow	Yellow	Yellow
1985 - 1990	LSI	Microcomputer	Yellow	Yellow	Green
1990 - 2000	VLSI	PC, Notebook, Portables	Red	Green	Green
2000 -	ULSI	Micro-based Server	Red	Yellow	Red

 *Trouble*

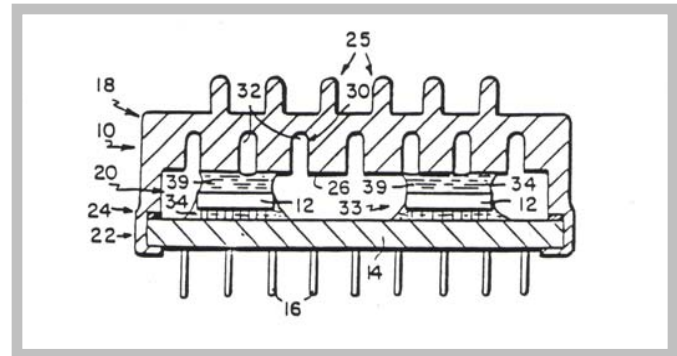
 *Design care*

 *Ignore*

What's old is new again...

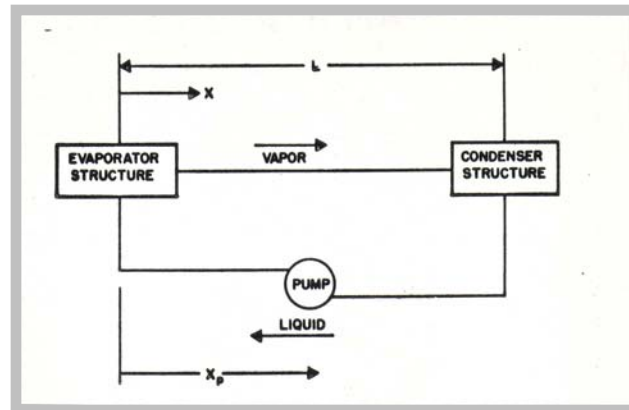


Heroic measures to maintain air cooling...

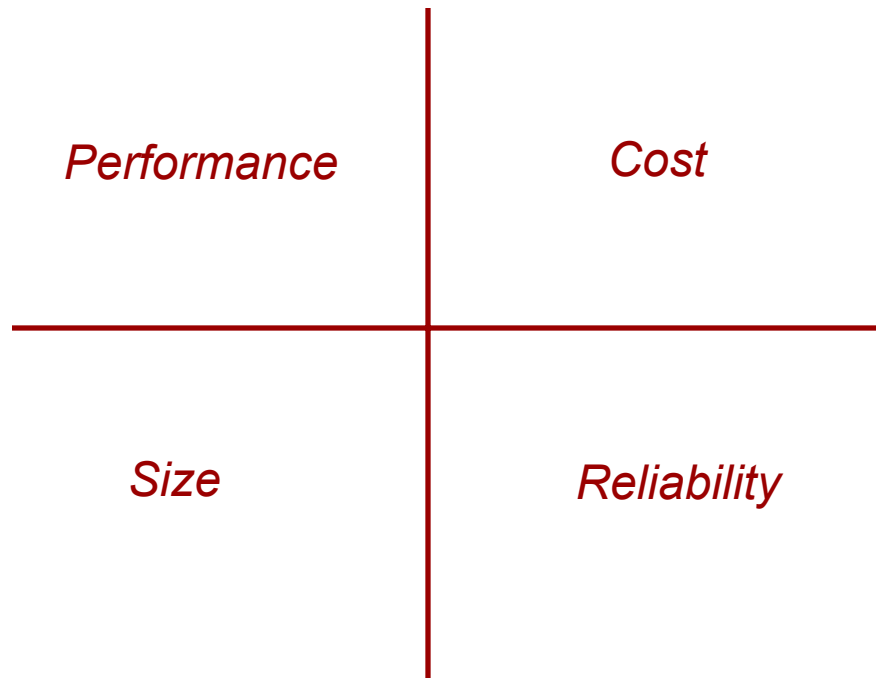


Heat pipe concepts...

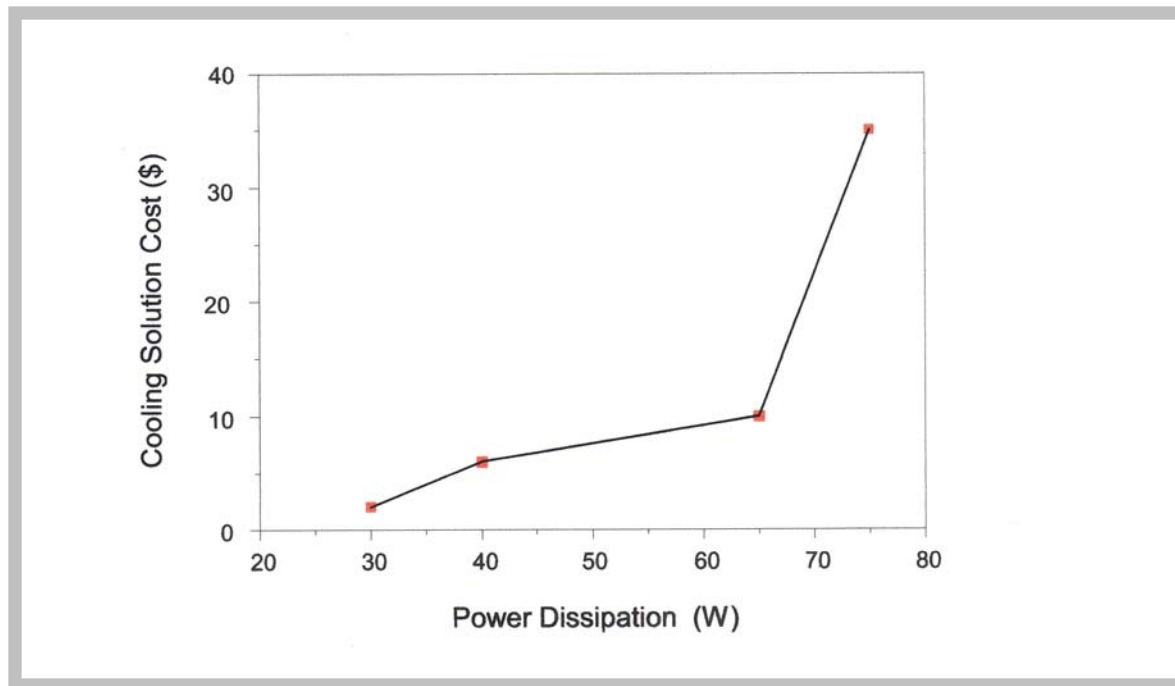
Two-phase system cooling...



Design / technology drivers

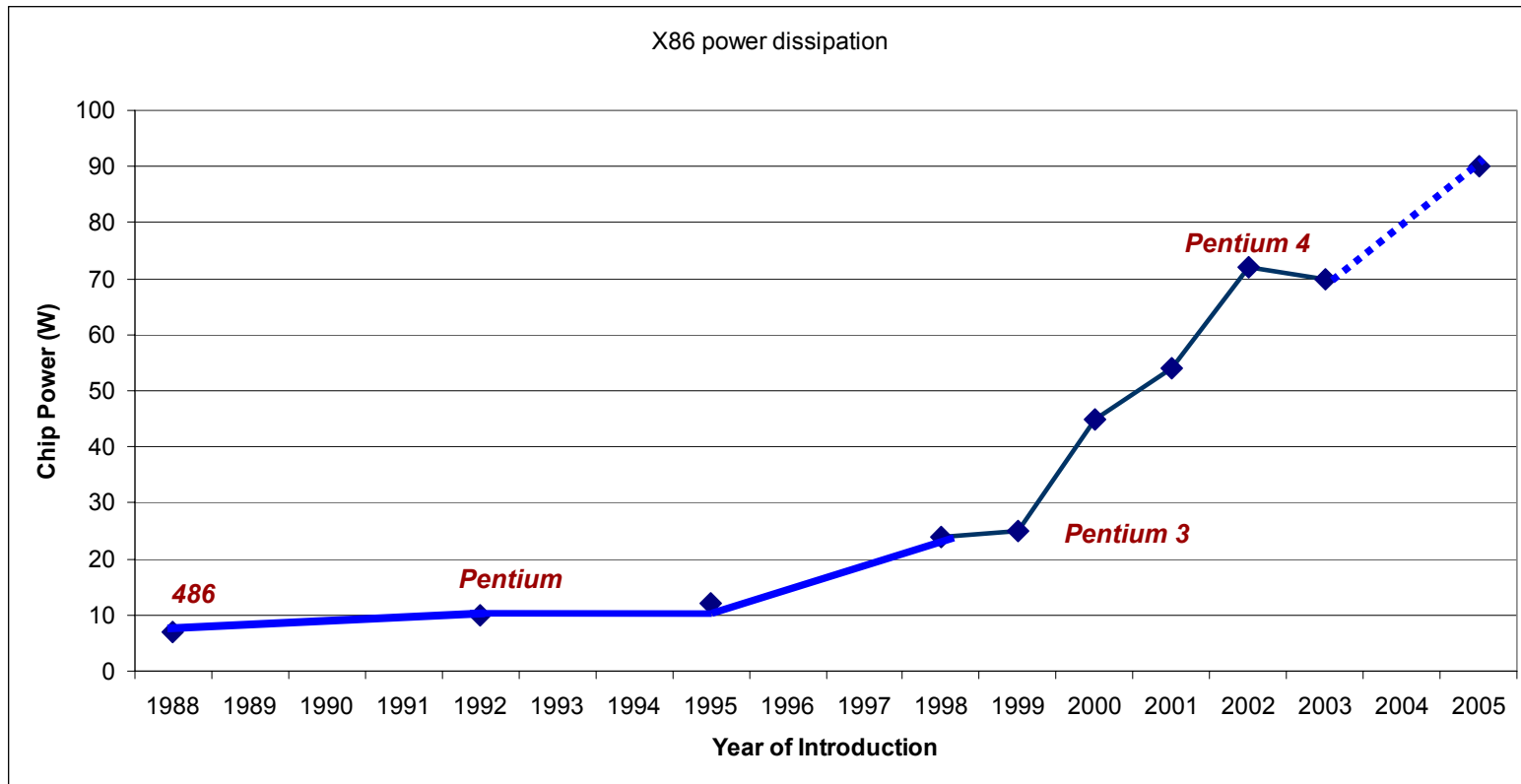


Cost of cooling

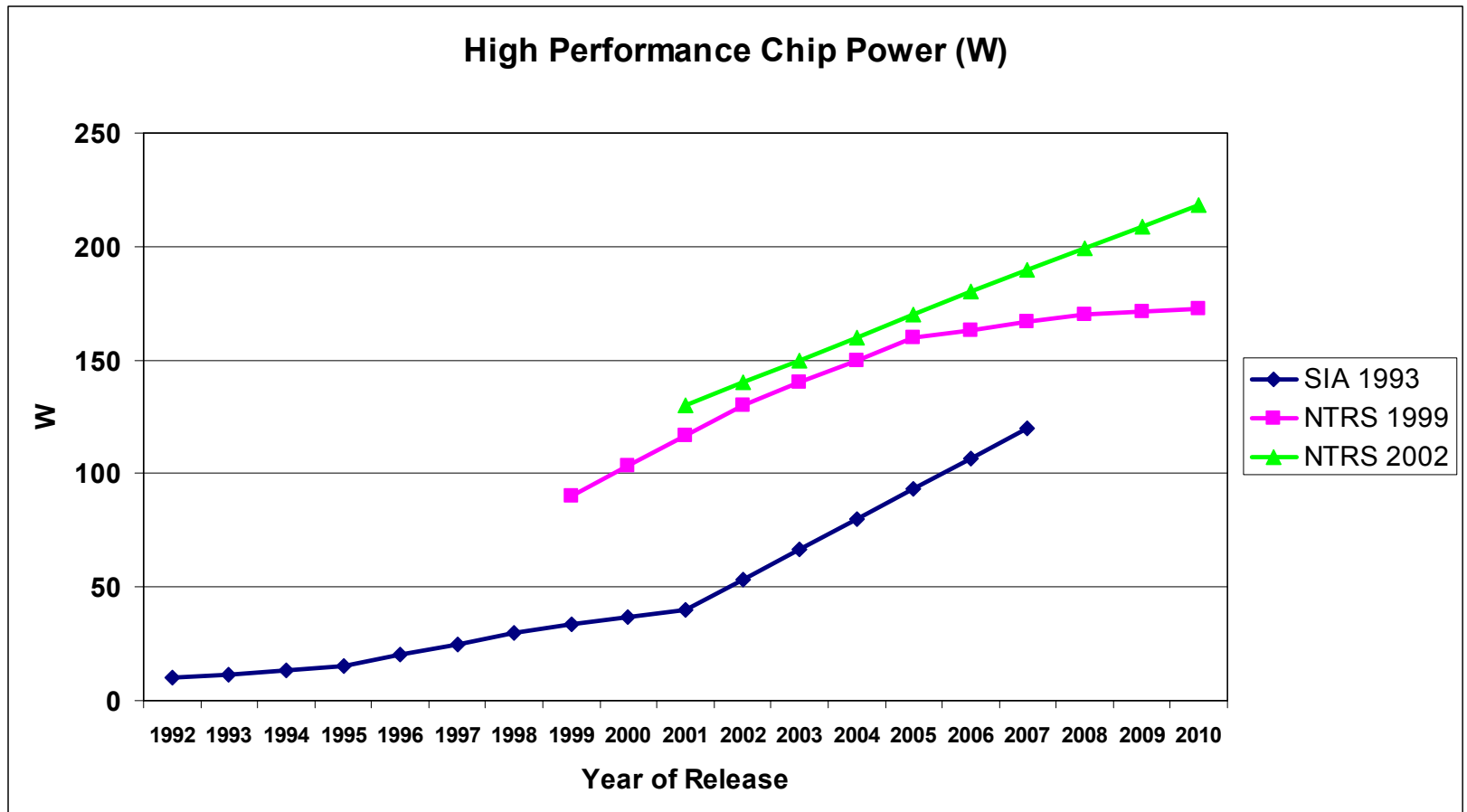


Cost of cooling a microprocessor, Intel

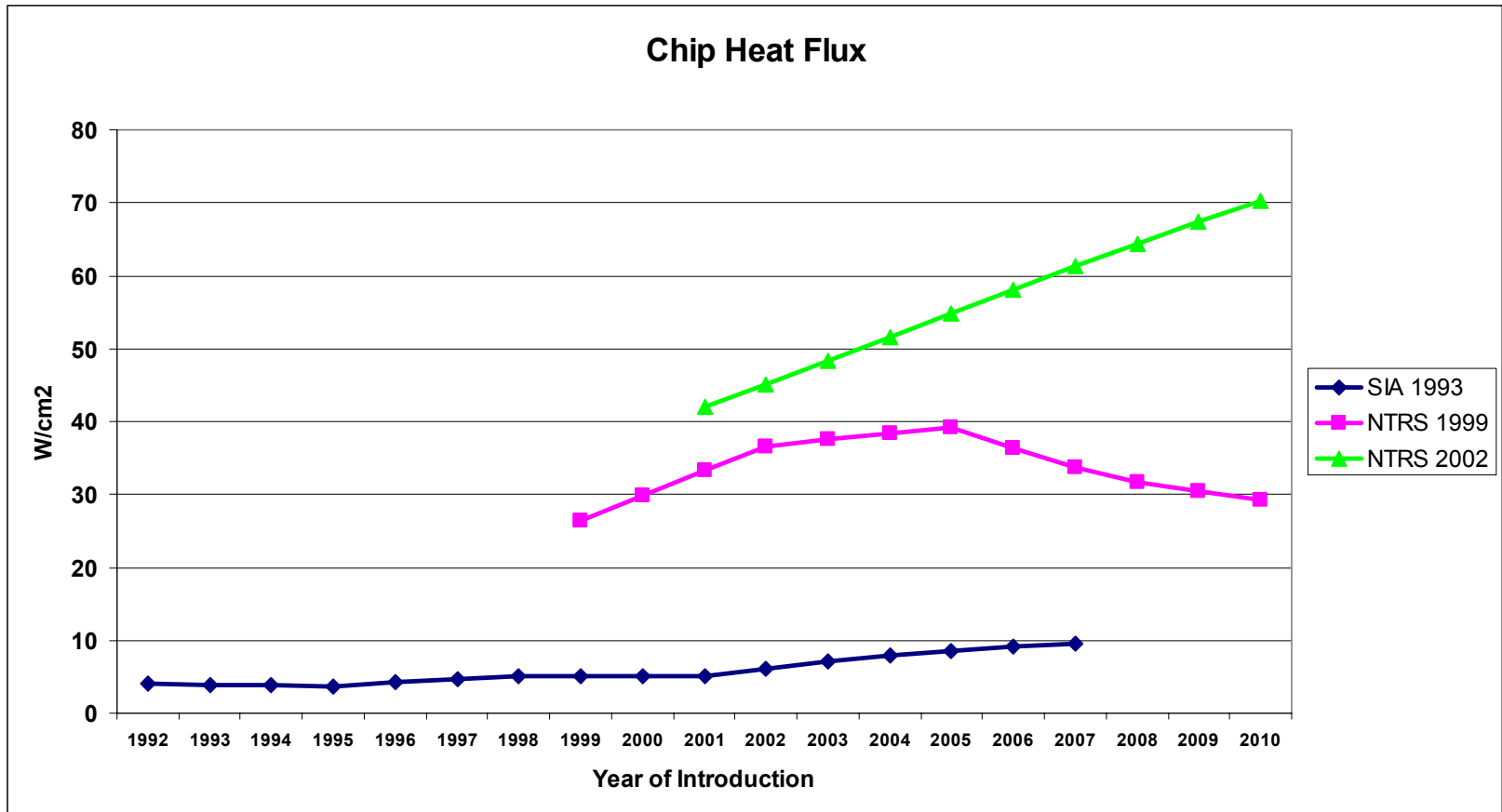
Intel's inflection



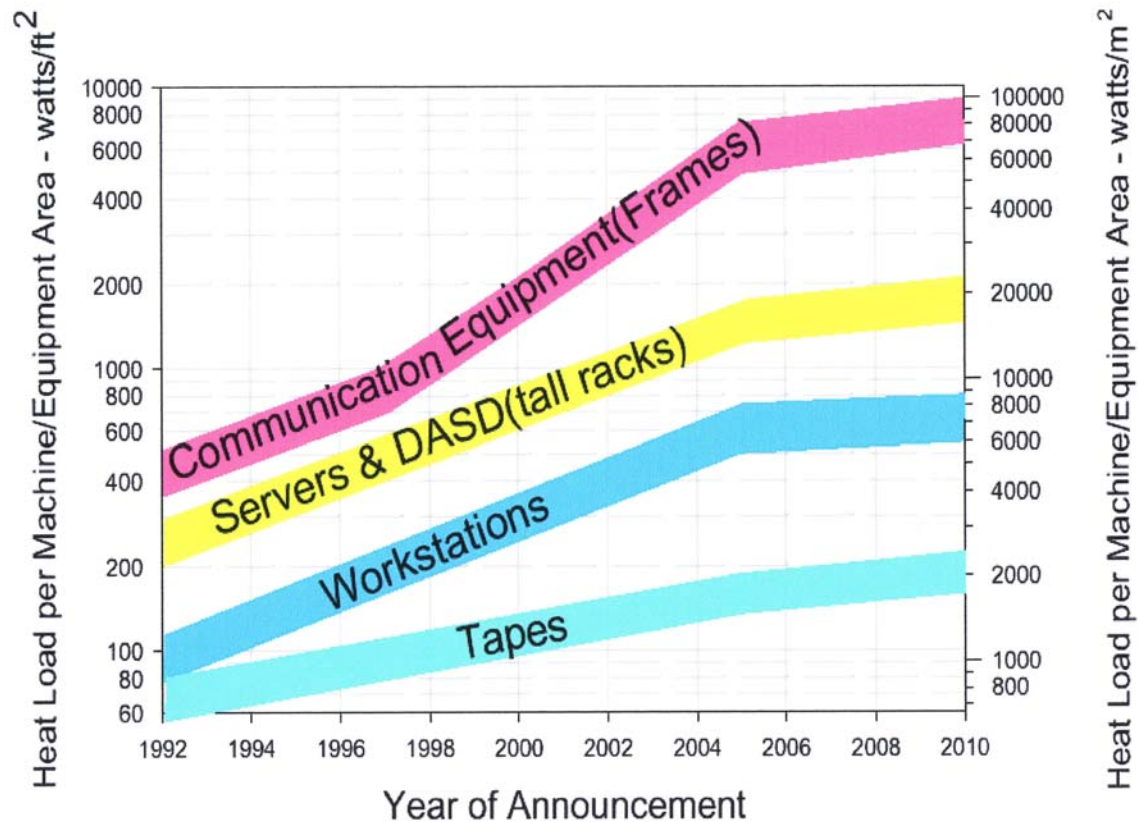
Chip power trends



Heat flux trends at chip level



A new problem: machine-room heat density



Data from
Amdahl,
Compaq,
Dell, HP,
IBM, SGI,
Sun,
Unisys,
Lucent,
Nortel, and
Cisco

Key challenges: large systems

- Solutions for very high chip powers (100 – 200W)
- High reliability / availability
- Rack-level cooling
- Machine-room cooling
- Cost management

Key challenges: office systems

- Cost / performance microprocessors will reach 80 – 100W within 2 years
- Air cooling must be optimized
- Acoustics
- Reduced cost

Other challenges

- Telecom systems: central offices already stretching power limits
- Photonic components provide very serious cooling challenge
 - Thermal control at heat fluxes $\sim 2 \times 10^3 \text{ W/cm}^2$
 - Performance very sensitive to temperature
- Harsh environments
 - Automotive
 - Telecom
 - Military

Research areas

Materials

- Optimized fluids for liquid cooling
- Materials for package construction / thermal spreading
- Phase change materials for transient applications

Devices

- High static pressure, low acoustic noise blowers
- Micro heat pipe structures
- Two-phase cooling approaches
- MEMS components for liquid / two phase cooling

Design

- Small-footprint liquid cooling systems
- Package-scale jet impingement / spray cooling
- Advanced, integrated thermal design tools
- Frame and rack coolers
- Equipment room thermal design

Conclusion

- The importance of thermal management in electronics devices and systems has waxed and waned over the past 50 years
- Current technologies and applications are once again providing a serious challenge – perhaps show-stopping – to heat transfer engineers
- Breakthroughs are needed in advanced cooling technologies (and pragmatic design!) at all levels