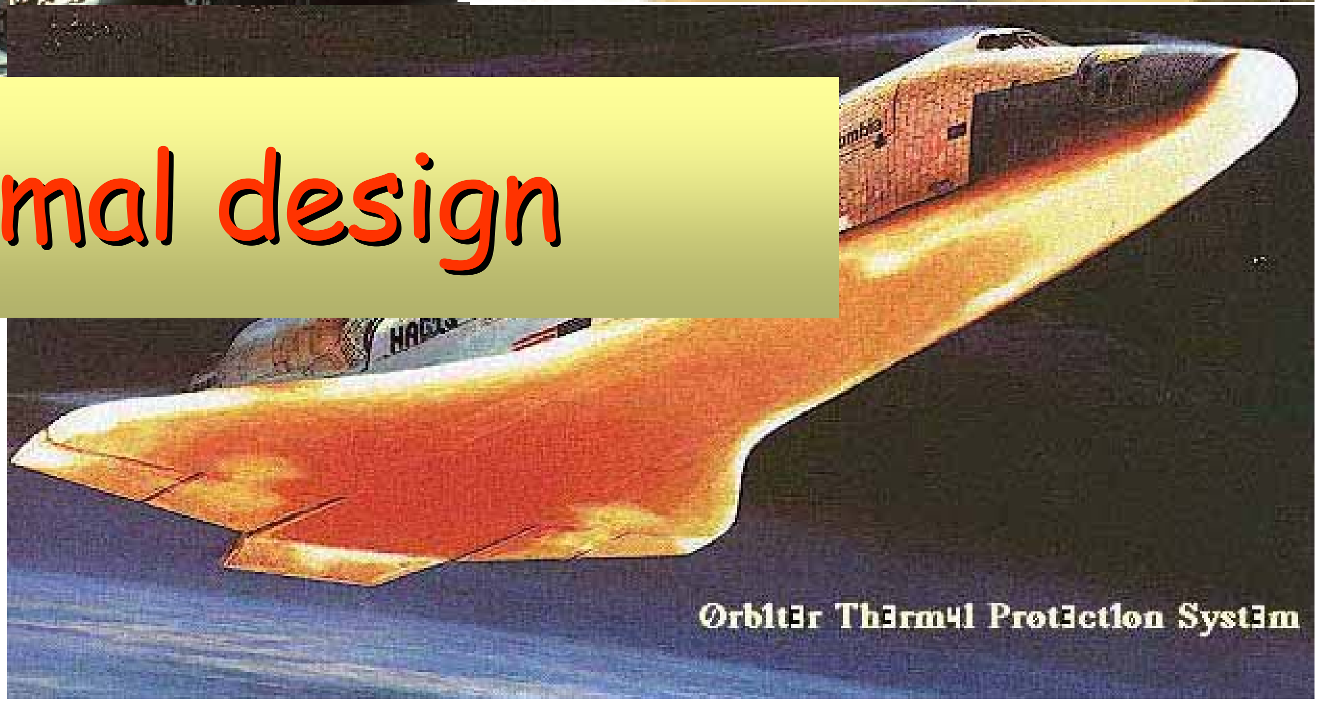


Thermal design

applied to electronics

P.Jahkonen 2007

Thermal design of electrical components, motivation

- Why to use thermal design ?
  - improving product reliability/ availability
  - improving product safety and liability
  - reducing product costs
  - solving specific design and application problems -->
  - enhancing concurrent engineering / faster development

- What does it require ?
  - professional attitude to PD
  - some theoretical background
  - Calculating or measuring the dissipated power
  - ability to make a model from the problem (comparative analysis)
  - test the model and improve it

Thermal design of electrical components, applications

Application area	typical problems
• drive design,	high power
• power supplies	small area!
• powerful CPU boards	thermal interaction
• cabinet design	layout
• signal elements	high power density
• braking resistors	high power
• control room design	ventilation
• outdoor design	environmental effects
• fire approvals	preparation
• motor design	hot spots
• feasibility check of tests	efficiency

Improving product reliability

- proper component temperatures
- minimize average temp.(Arrhenius !)
- corrosion of connectors
- thermal capacity for power peaks
- from testing to simulation
- thermal model of products

Improving product safety

- functions in extreme conditions
- fire protection (wires, resistors, chokes)
- simulate abnormal situations
- simulate fire tests (thermal capacity !)
- calculate surface temperatures

Reducing product costs:

- optimize component rating
- optimize cooling components
- eliminate heat sinks
- integrate functions (case as heat sink)
- eliminate fans
- free physical resources (thermostat !)

Solving specific problems:

- extend environmental range
- improve accuracy of functions
- improve accuracy of measurements
- extend component application range
- handling big dissipation power
- thermal compensation
- analyze competitors products

Thermal design of electrical components & PD process

- Common design procedure (wrong method)
  - specify functional requirements
  - design hardware and software
  - make tests and fix the problems (add a fan)
  - calculate the product costs

- Professional design procedure
  - analyze own and competitor products (benchmarking)
  - feasibility study for making new product (costs, new features)
  - simulate and confirm your ability for better and cheaper product
  - realize the new product (implementation project)
  - make verification and approval tests

! <u>thermal design is one essential tool to make professional design</u>

Thermal design of electrical components, some warnings

- Common mistakes and wrong knowledge

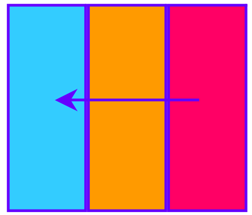
  - "digital thinking" ; the product either works or not
  - thermal problems are secondary and very rare
  - good thermal properties increase costs (EMC analogy !)
  - " the temperature of the product is 40 C "
  - all components can stand 60 C air temperature
  - temperature tests must be done in test chamber
  - the most important heat transfer media is air (radiation)
  - PCB components are cooled by the component case
  - SMD components are specified for plastic based PCB
  - heat sinks are always needed in power electronics
  - heat sinks are difficult to design and speciality of ….
  - some holes in the cabinet reduce the temperatures efficiently
  - CAE software packages will solve the problems

Thermal design of electrical components, theory

- The mechanisms of heat transfer

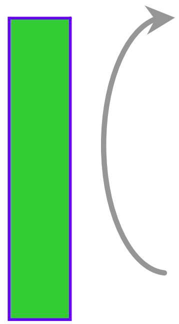
  - <u>thermal radiation</u> $Q = 5.7 \exp(-8) * A * e * (T_s^4 - T_a^4)$
    - most important method generally and at higher temperatures
    - heat sink does not have to be black (better not)
    - the surface can have effect in ratio of 1:5

  - <u>thermal conduction</u> $Q = k * A / l * dT$



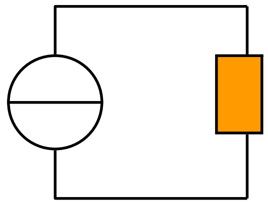
    - most important method on component level
    - material and surface pressure are key issues
    - the enclosure material is not important

  - <u>thermal convection (natural or forced)</u> $Q = h * A * dT$

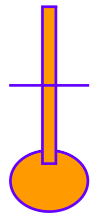


    - most important method at high power and product level
    - the air should be directly conducted out
    - the surface has no essential effect (natural convection)

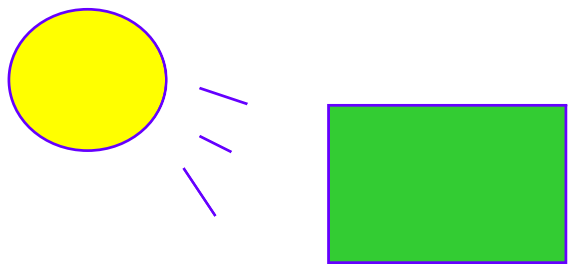
Thermal design of electrical components, tools



- thermal networks
  - power sources, thermal resistances
- simulation programs
  - Sauna , MATLAB PDE, Flowtherm, custom programs



- measuring equipment
  - temperature and flow meters
  - thermal pads
  - IR camera



- simulating environment
  - solder iron, cold spray
  - blowers, heat plates
  - artificial heat sources
  - test chambers (owen, sauna, …..)

Thermal design of electrical components, simple formulaes

- natural convection: $h = 1.3 * (dT / L)^{1/4}$
- forced convection: $h = 1.3 * (dT)^{1/3}$
- thermal conduction: k = thermal conductivity
  - cylinder (l=length) $Q = 2 * pi * k * l * dT / \ln(do/di)$
  - disc on thick conductor $Q = 2 * k * d * dT$ (d=diam.)
- thermal transport: $Q = r * c * dV/dt * dT$
- thermal capacity: $Q = m * c * dT$
- boundary layer: l = flow length
  - natural convection $d = 0.1 * (l/dT)^{1/4}$
  - forced convection $d = 0.02 * \mathrm{sqrt} (l / v)$
- conduction length
  - plate (b=thickness) $lc = 2 * \mathrm{sqrt} (k*b / (2*h))$
  - wire (r=radius) $lc = 2 * \mathrm{sqrt} (k*r / (2*h))$
- pressure losses unit = $0.5 * r * v^2$
  - input 0.5
  - output 1
  - 90deg angle 1.5
  - friction 0.5…1.5

Thermal design of electrical components, some hints

- **Rules of thumb:**
  - SMD components can handle 30% from the rated power on PCB
  - E1 PCB can stand 5W total power, E2 10W (3 & 5 W recom.)
  - Approx. 2W can be dissipated from TO220 using heat sink on PCB
  - Std electrolytic capacitors can stand 50 C ambient temp.
  - Small components can handle higher power density (W/cm^2)
  - Conduct power out from the enclosure !
  - Heat sink temperatures should be generally below ~75 C
  - Lower part of PCB has the highest thermal transfer coefficient
  - Natural convection requires > ~ 10 mm fin distance
  - Forced convection increases with < 10 mm fin distance
  - The fan is the weakest link in the product
  - Do not place several PCB´s horizontally

Thermal design of electrical components, additional information

- **Literature:**
  - KOTEL 82-001-A, Elektroniikkalaitteiden lämpösuunnittelun teoria (48s)
  - VTT Tiedotteita 168, Elektroniikkalaitteiden lämpösuunnittelu, P.Jahkonen (112s)
  - KOTEL työryhmäraportti 228, Elektroniikan lämpösuunnittelun ohjelmistot ja tietolähteet
  - Electronics Cooling (journal)

- **Courses:**
  - Cooling electronics, theory and application, Kaveh Azar Ph.D
  - KOTEL: Piirikorttitason lämpösuunnittelu elektroniikassa