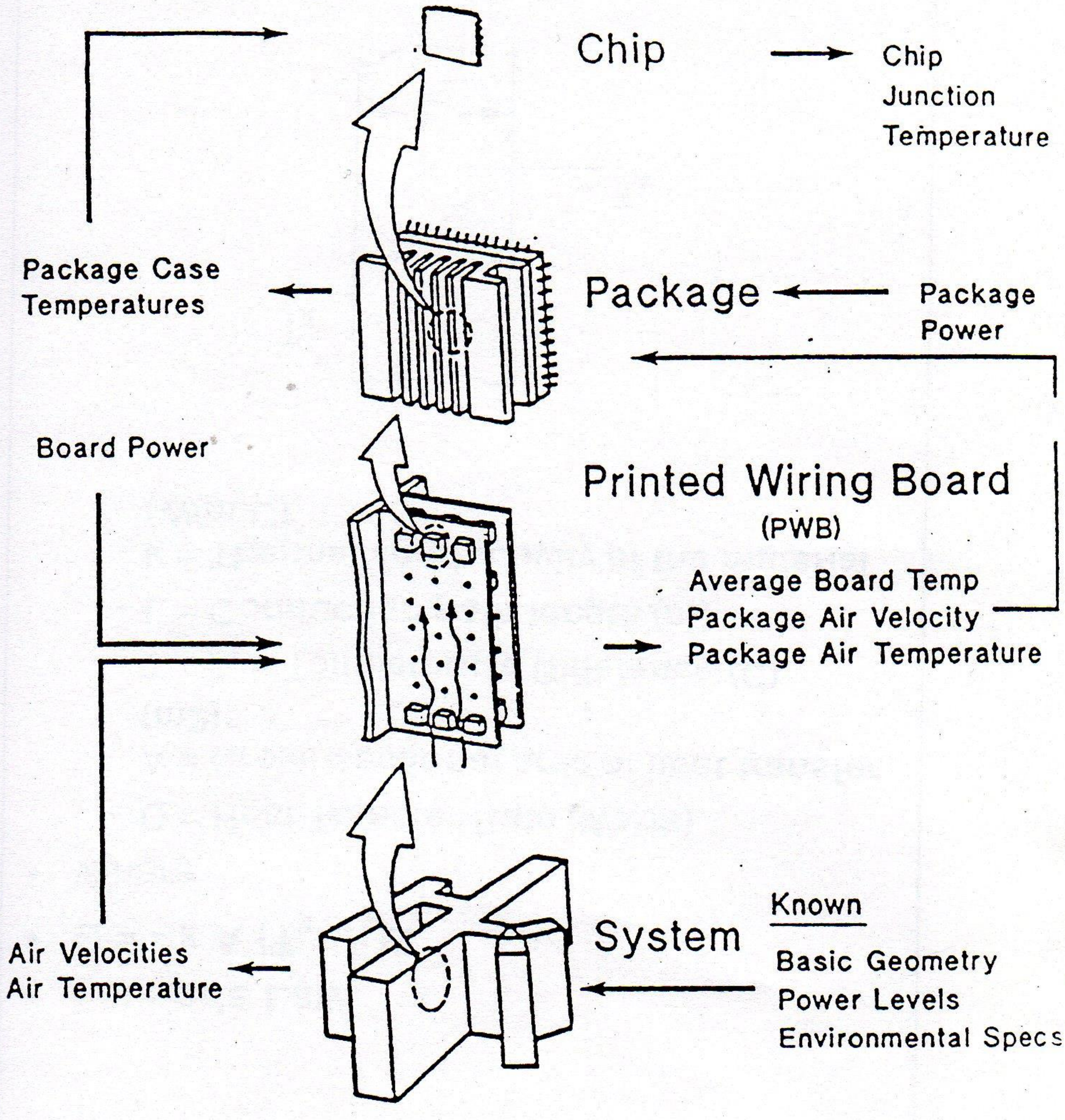
Thermal Design Criteria

- Thermal
  - Junction Temperature Tj
  - Differences in Tj among different components
  - Temperature, Pressure and Humidity Environmental Specifications
  - TCE (Thermal Coefficient of Expansion) mismatch

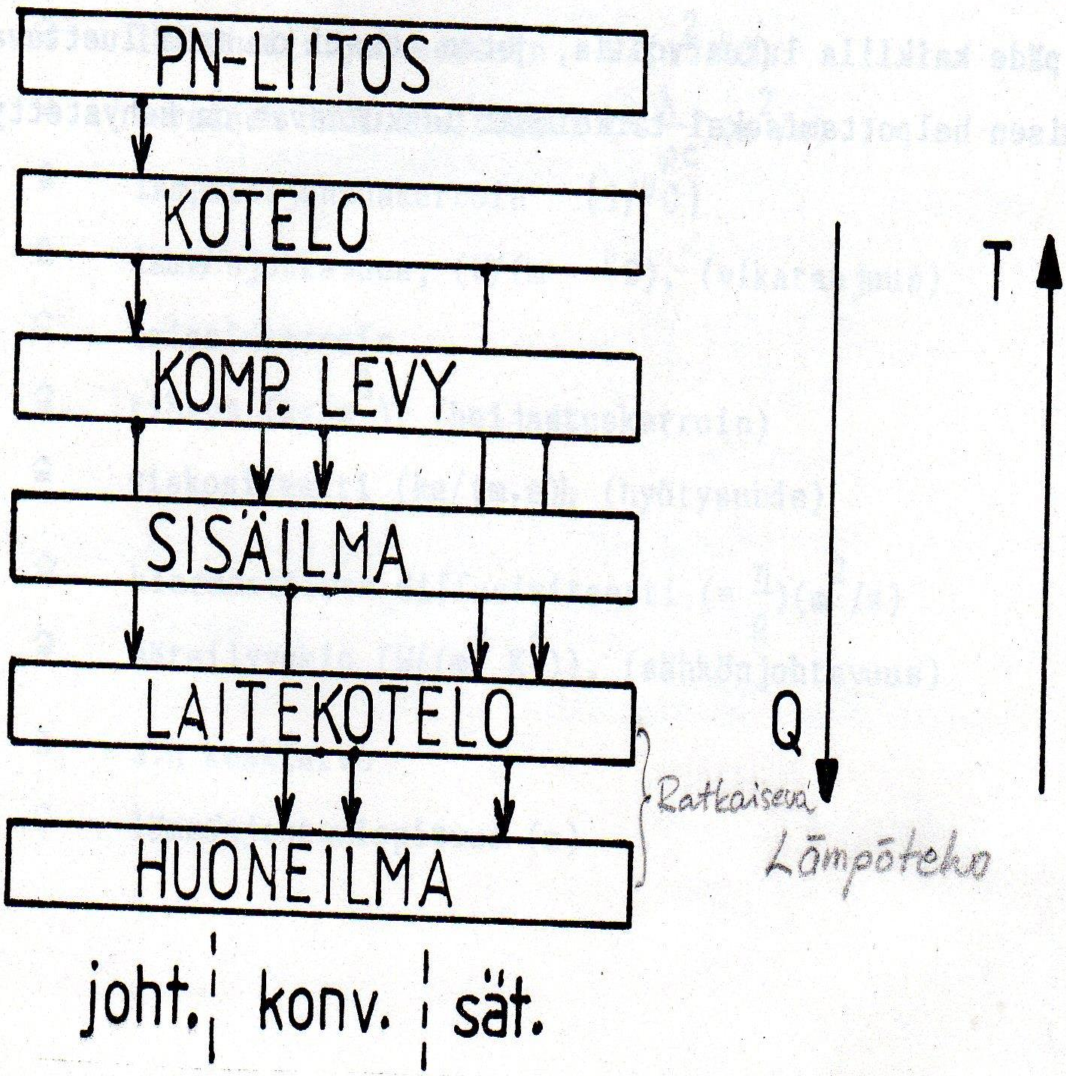
- Environmental
  - noise level (fan)

- Geometrical
  - installation space
  - inlet, outlet location
  - component accessibility

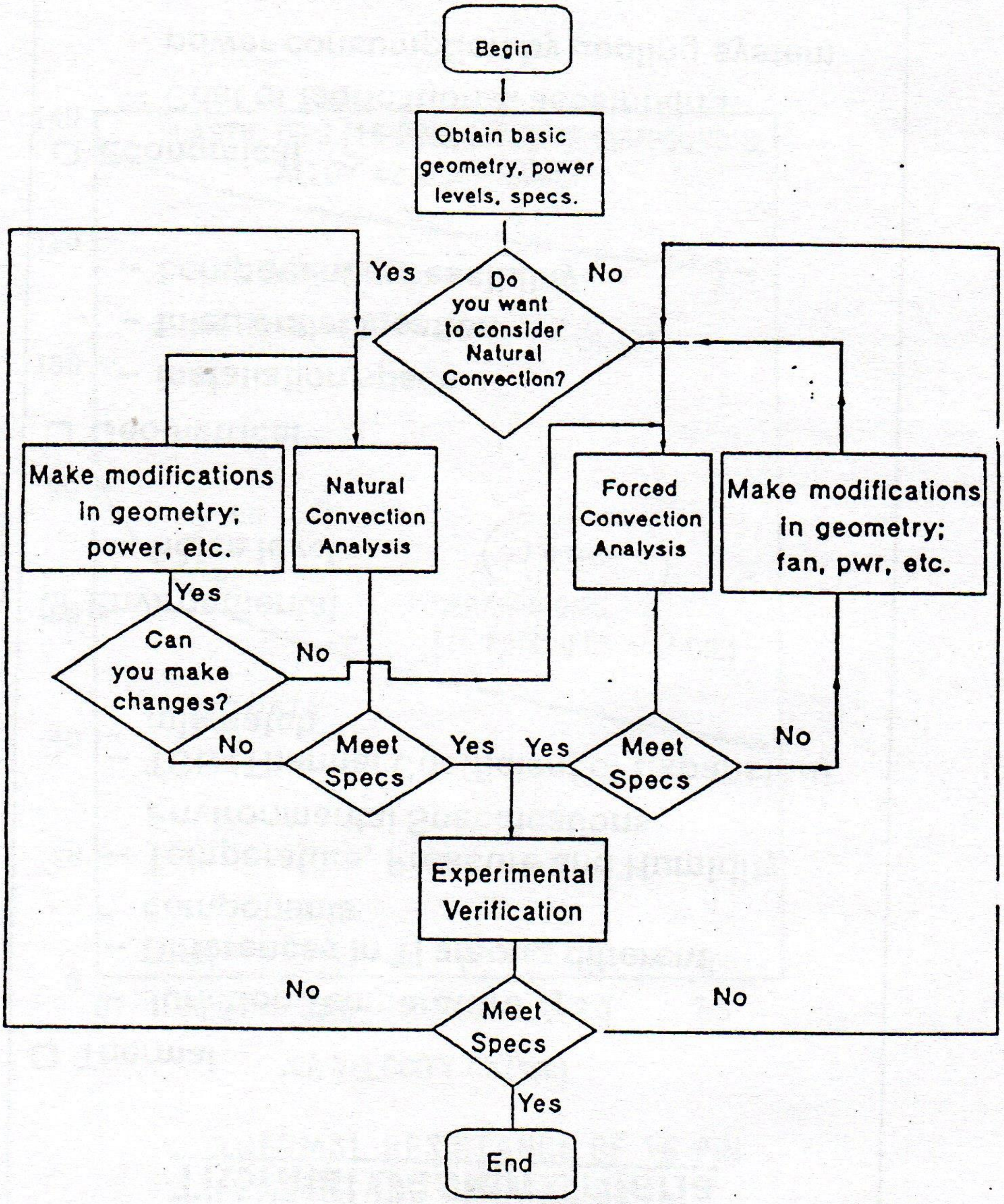
- Economical
  - Cost of fabrication & assembling
  - power consumption by cooling system



Levels of Thermal Analysis



Kuva 1 Lämpötehon kulkeutuminen elektroniikkalaitteesta.



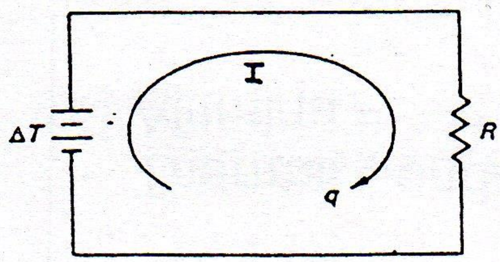
Begin
Obtain basic geometry, power levels, specs.
Do you want to consider Natural Convection?
Yes
No
Make modifications in geometry; power, etc.
Natural Convection Analysis
Forced Convection Analysis
Make modifications in geometry; fan, pwr, etc.
Yes
Can you make changes?
No
No
Meet Specs
Yes
Yes
Meet Specs
No
Experimental Verification
No
Meet Specs
No
Yes
End

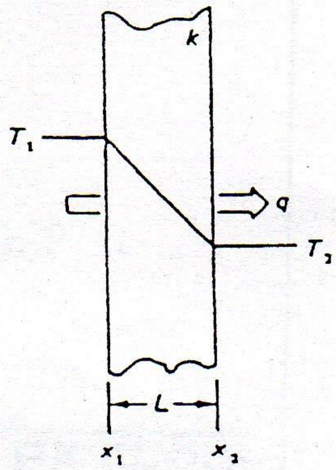
Electrical Thermal Analogy

For cases of one dimensional conduction with constant thermophysical properties, an analogy can be drawn with simple electrical circuits governed by Ohm's Law

Current I	⟷	heat flow Q
Potential V	⟷	temp. difference ΔT
Resistance R	⟷	thermal resistance R

$$I = \frac{V}{R} \qquad Q = \frac{KA(T_1 - T_2)}{L}$$

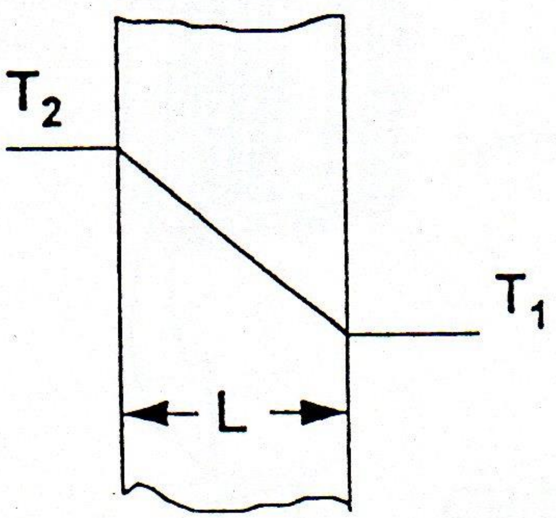




$$R = \frac{L}{KA} = \frac{\Delta T}{Q} \ {}^{o}\text{C/watt}$$

Conduction Heat Transfer

- Fourier's Law
- $Q = - k A (T_2 - T_1)/L$
- Where
  - Q = Heat Transfer Rate (Watts)
  - A = Cross-sectional area of heat transfer (m2)
  - $T_2 - T_1$ = Temperature Difference (C)
  - L = Conduction path length (m)
  - k = Thermal conductivity of the material (W/m C)



Thermal Conductivity of Electronics Packaging Materials

Watts/metre

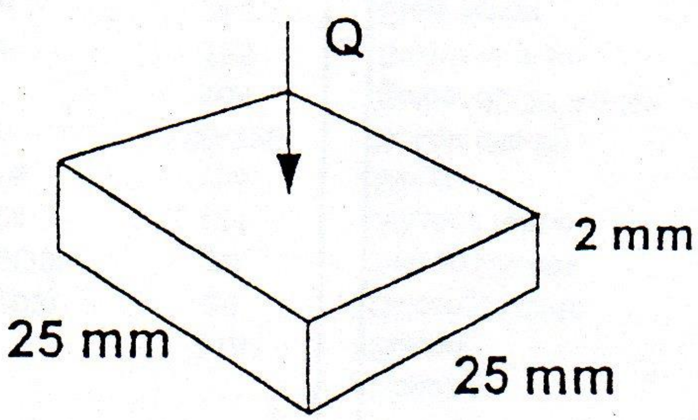
Material	Watts/mC
Solids	
Aluminum pure	216
Alumina (96% Al203)	29
Alumina (90% Al2O3)	13
Aluminum 2024 T4	121
Aluminum 6061 T6	155
Aluminum Nitride	150-220
Berillium	164
Beryllia 95% pure	155
Beryllia 99% pure	242
Brass Red	110
Brass Yellow	95
Copper	398
Diamond	2000- 2300
Epoxy (conductive)	0.35-0.87
Epoxy (dielectric)	0.23
Epoxy glass (PC board)	0.24-0.3
Eutectic bond	68
Gallium arsenide	50
Germanium	60
Gold	297
Iron Cast	55
Iron Pure	74
Iron Wrought	58
Lead	34
Mica	0.5
Molybdenum	140
Nickel	92
Nylon	0.24
Phosphor bronze	52
Platinum	69
Polyimide	0.33-0.4
Quartz	3.0-5.0
RTV	0.31

Material	Watts/mC
Sapphire	30
Silicon	84
Silicon Carbide	220
Silicon Dioxide	10
Silicone rubber	0.19
Silver	418
Solder (Pb-In)	36
Solder 80-20 Au-Sn	52
Stainless steel	15
Steel Kovar	16.6
Steel SAE 1020	55
Tantalum	50
Teflon	0.25
Titanium	22
Tungsten	170
Liquids & Gases	
Water	0.6
FC77	0.065
Air	0.028
Helium	0.15

Conduction Heat Transfer Problem

- Given a 25 x 25 x 2 mm thick Alumina substrate, determine the thermal resistance of the substrate?
- If the power dissipation through the substrate is 10 Watts, determine the temperature drop across the substrate?

$R_t = \frac{2\cdot10^{-3}}{40\cdot40\cdot10^{-6}\cdot13} = 0,$



$R_t = \frac{2\cdot10^{-3}}{25\cdot25\cdot10^{-6}\cdot13} = \frac{2}{8,1} = 0,25\ K/W$

Convection Heat Transfer

Convective heat transfer deals with heat exchange between a solid surface and a circulating viscous fluid.

It deals with fluid circulation or movement and therefore requires a firm grasp of fundamentals of fluid mechanics.

Convective flows may be:

- Natural Convection
  - Laminar flow → Internal flow / External flow
  - Turbulent flow → Internal flow / External flow
- Forced Convection
  - Laminar flow → Internal flow / External flow
  - Turbulent flow → Internal flow / External flow

Newton's Law of Cooling

$$Q = hA\,(T_w - T_\infty)$$

- Q - heat transfer due to convection watts
- A - area of heat transfer m^2
- T_w - surface temperature °c
- T_∞ - fluid free stream temperature °c
- h - convective heat transfer coefficient

  $W/m^2\,°c$

Approximate Values of Heat Transfer Coefficients

Mode of Heat Transfer	h W/m2
Natural Convection	
Ts = 100, Ta = 55, Air	
Vertical Plate 0.2m high	5
Vertical Plate 0.02m high	9
Circular Cylinder Vertical 0.02m high 0.01m diameter	6.5
Horizontal Plate 0.2m long	5
Horizontal Plate 0.02m long	8
Circular Cylinder Horizontal 0.02m long 0.01m diameter	8.5
Vertical Plate 0.3m high in Water	3500
Forced Convection	
Ts = 100, Ta = 55, Air	
Flat Plate 0.3m high 1 m/s	7
Flat Plate 0.3m high 2 m/s	10
Flat Plate 0.3m high 3 m/s	12
Flat Plate 0.3m high 4 m/s	14
Flat Plate 0.02m high 1 m/s	25
Flat Plate 0.02m high 2 m/s	38
Flat Plate 0.02m high 3 m/s	47
Circular Cylinder 0.01 m diameter 2 m/s	45
Flat Plate 0.03m high 3 m/s in water	9000
Boiling Water	25000-100000

Radiation Heat Transfer

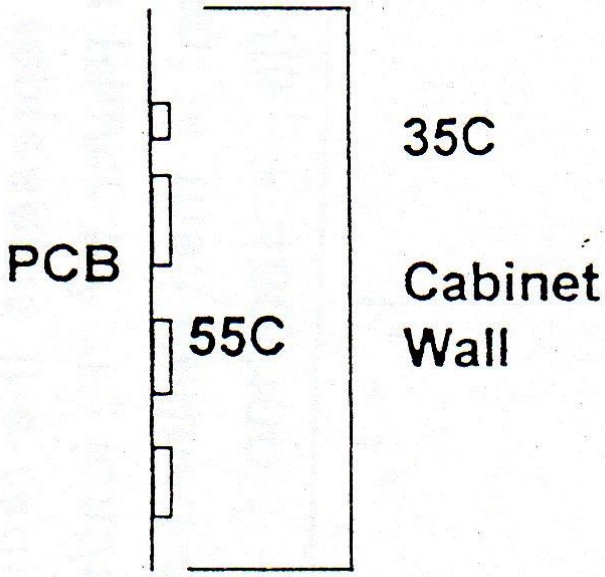
- Stefan Boltzman Law

- $Q = \sigma f e A (T_1^4 - T_2^4)$

  - Where:
  - Q radiation heat transfer Btu/hr or Watts
  - σ Stefan Boltzman Constant
    - » 0.1713×10^{-8} Btu/hr.sq.ft R^4
    - σ » 5.669×10^{-8} W/sq. m K^4
    - » f view factor sq.m = m^2
  - e emissivity
  - A radiation surface area ft^2 or m^2
  - T absolute temperature F + 460 = R
    - » C + 273 = K

Radiation Heat Transfer Problem

- For a pcb, 25 cm by 40 cm, at an average surface temperature of 55 C, calculate the heat transfer by radiation to the cabinet wall at 35 C?



≈ 12 W

=>

Assume: Emissivity = 0.8
view factor f = 1