A First Order Thermal Model
of a Telecom Chassis

The role of first order analysis is essential for making quick calculations, performing 'what if' scenarios, and examining the pros and cons of changing parameters for a final design. Let's look at a simple first order thermal analysis of a telecom chassis.

A telecom cabinet features a PICMG chassis with 16 PCBs in its front compartment and 16 more in the rear compartment. The overall dimensions of the system are shown in Figure 1. There are three air inlets at the bottom of the shelf and three air exhausts at the shelf's top.

The goal is to find the following:

1. Air flow and velocity in the shelf
2. Air temperature increase in the front cards
3. Front PCB temperatures

The following conditions are assumed:

- A push-pull fan system uses one fan tray at the inlet and the other one at outlet
- There are one front and two side air inlets
- Honeycomb EMI shields are mounted to each of the inlets at the bottom of the shelf
- There are one rear and two side air exhaust outlets
- The fan curve is linear
- The cabinet contains a mid-plane shelf (with card arrays in front and rear)
- The ambient temperature is 55 ^{o}C

Inlet and exhaust areas:

Total area of front inlet at bottom of shelf = 165 cm^2

Total area of side inlet at bottom of shelf = 232 cm^2

Total area of rear exhaust at top of shelf = 200 cm^2

Total area of side exhaust at top of shelf = 316 cm^2

Fan data:

Number of fan trays = 2

Number of fans per fan tray = 9

Fan duct diameter = 12.7 cm

Maximum fan pressure = 225 Pa

Maximum fan flow capacity = 0.09 m^3/sec

Fan power = 16.8 W

Filter data:

Initial loss factor for new filter = 0.039 H_20 $m^4/(m/sec)^2$

Final loss factor for used filter = 0.222 H_2O $m^4/(m/sec)^2$

Honeycomb data:

Fraction of open area = 0.9 (units?)

Front circuit board data:

16 PCBs, each dissipating 189 W

PCB dimensions: length = 27.4 cm, height = 36.0 cm, depth of PCB = 2.54 cm

Volume of all components including PWB =1065 cm3

Surface area of circuit board = 989.6 cm2

Total cross section of components perpendicular to flow = 69.6 cm^2

Maximum blockage cross section perpendicular to flow = 38.7 cm^2

Total volume of the component side of the pack = 1884.5 cm^3

Open area of card guide support under front pack perpendicular to flow = 41.3 cm^2

Rear circuit board data:

16 PCBs, each dissipating 60 W

PCB dimensions: length = 17.1 cm, height = 36.0 cm, depth of pack = 2.54 cm

Volume of all components including PWB = 424.4 cm^3

Surface area of circuit board = 618 cm^2

Total cross section of pack perpendicular to flow = 32.9 cm^2

Total volume of the component side of the pack= 1,178 cm^3

Open area of card guide support under rear pack perpendicular to flow = 32.2 cm^2

The total cross section area of both front and rear circuit packs = 2,787 cm^2

Prior to analyzing the performance of the chassis, it is necessary to calculate the pressure drop of the system and consequently its total resistance. The intersection of the system total resistance and the fan curve will determine the operating point air flow of the system[1]. The pressure drop of the system consists of the pressure drops of all the subcomponents.

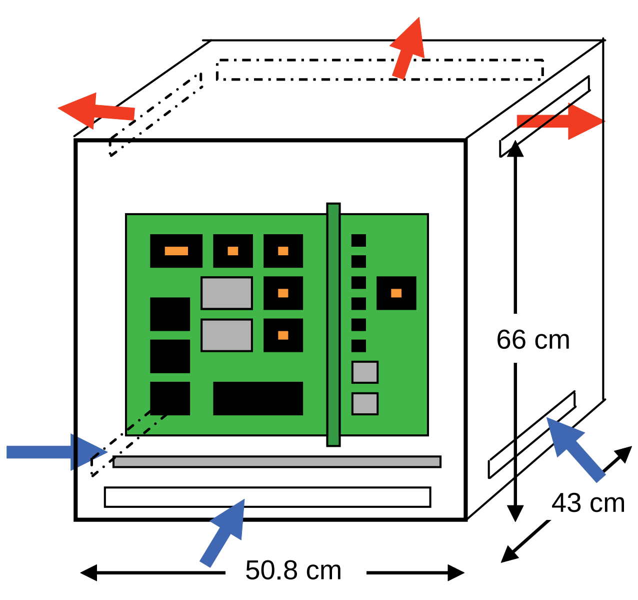


Figure 1. Schematic of Telecom Chassis.

The total pressure drop (system curve), H_{system}, depends on the volumetric flow rate in the system and can be shown as:

$$H_{system} = R_{total} \times G^2$$

Where, $R_{total} = \sum R_i$, R_i are the system component resistances, and **G** is the volumetric flow rate.

Pressure drop is generally caused by the following subcomponents, which may be present in a given system:

1. Air filter
2. Honeycomb
3. Fan tray due to sudden expansion and contraction of flow through blades
4. Flow bending from inlet to plenum
5. Contraction to the inlet plenum
6. Expansion from inlet to plenum
7. Circuit cards component blockade
8. Circuit card friction (generally small)
9. Flow bending to exit plenum
10. Contraction to exit of plenum
11. Expansion from exit of the plenum

The following shows the values of the resistances of each component:

Perforated plate:

$$R = \frac{0.828}{A^2} \text{Pa/(m}^3\text{/sec)}^2$$

Where **A** is the area of open holes exposed to air flow

R_{perfi} **= 7.8X10^{-7}** At the inlet

R_{perfo} **= 4.6X10^{-7}** At the outlet

Filter:

$$R = \frac{L \times 510.79}{A^2}$$

Where **A** is the filter exposed area and **L** is the filter loss coefficient provided by manufacturer

R_{fili} **= 4.2X10**$^{-6}$ Initial flow resistance

R_{filf} **= 3.0X10**$^{-5}$ Final flow resistance

Expansion after inlet into plenum below fan tray

$$R = 0.46 \times \left[\frac{1}{A1} \times \left(1 - \frac{A1}{A2}\right)\right]^2$$

Where A_1 is the small area and A_2 is the larger

R_{ex} **= 2.5X10**$^{-7}$

Bend in airflow from inlet to fan tray

R_{bend} **= 4.7X10**$^{-7}$

Fan tray

There is a contraction from plenum into fan and an expansion out of the fan

$$R = 0.46 \times \left[\frac{1}{A1} \times \left(1 - \frac{A1}{A2}\right)\right]^2$$

Sudden expansion: Where A_1 is the small area and A_2 is the larger area

$$R = \frac{0.321}{A^2}$$

Contraction: Where **A** is the small area

R_{fanexp} **= 1.2X10**$^{-6}$ Expansion resistance

R_{fancon} **= 1.6X10**$^{-6}$ Contraction resistance

R_{fancon} **= 2.8X10**$^{-6}$ Total resistance for single

For the two fan tray assembly:

$$R_{fantot} = \left[\frac{1}{\left(\frac{N_f}{\sqrt{R_{fan}}}\right)}\right]^2$$

R_{fantot} **= 3.5X10**$^{-8}$

Where N_f is the number of fans in one fan tray, and R_{fan} is the total resistance for one fan.

Boards:

$$R = \frac{4.2 \times L}{A^2}$$

Where **L** is the board length (m), and **A** is the effective free area of the channel (m^2).

If there are **N** similar boards mounted in a chassis in parallel, their equivalent resistance is calculated as:

$$\frac{1}{\sqrt{R_{combined}}} = \frac{N}{\sqrt{R_{board}}}$$

R_{boardf} **= 2.6X10**$^{-6}$ Front boards resistance

R_{boardr} **= 4.6X10**$^{-6}$ Rear boards resistance

R_{boardt} **= 8.5X10**$^{-7}$ Total boards resistance

Outlet resistances

R_{bfe} **= 2.8X10**$^{-7}$ Resistance for bend from fan tray to exhaust

Total resistances

The sum of all the resistances will provide the total system impedance:

H_{system} **=** R_{toti} **= 7.4X10**$^{-6}$ Total resistance for a fresh filter

H_{system} **=** R_{totf} **= 3.3X10**$^{-5}$ Total resistance for an old filter

System flow rate

The total system flow rate can be calculated by equating the system overall impedance and the fan characteristic curve.

If the individual fan curve is stated as:

$$\Delta P = f(G)$$

Where **G** is the volumetric flow rate for one fan,
The total head generated by a push pull system is:

$$\Delta P = 2f\left(N_f G\right) + 0.658 \times \left(\frac{G}{A_f}\right)^2$$

Where A_f is the fan duct size and $\mathbf{N_f}$ is the number of fans in one fan tray.

Solving the following equation, would yield the system pressure drop and volumetric flow rate.

$$\Delta P = H_{system}$$

$$G_{newfilter} = 0.199\ m^3/sec$$

$$G_{oldfilter} = 0.100\ m^3/sec$$

The volumetric flow rate in the front cards can be calculated as:

$$\frac{G_{front}}{G_{total}} = \frac{1}{1+\sqrt{\frac{R_{front}}{R_{back}}}}$$

G_{front} = 0.113 m³/sec For the new filter

G_{front} = 0.057 m³/sec For the old filter

Next, calculate the volumetric flow rate between the two front boards.

$$G_{chann} = \frac{G_{front}}{N_B - 1}$$ Where $\mathbf{N_B}$ is the number of boards

G_{chann} = 0.0075 m³/sec For the new filter
G_{chann} = 0.0038 m³/sec For the old filter

Dividing the volumetric flow by the cross sectional area between the boards would result in the following velocity between the boards:

V_n = 0.84 m/sec For the new filter

V_o = 0.42 m/sec For the old filter

To calculate the temperature rise across the front PCB we can use the following simple energy equation:

$$\Delta T = \frac{q}{C_p \dot{m}}$$

Where $\mathbf{C_p}$ is the heat capacitance and $\dot{m}$ is the mass flow rate

Given that, **q = 60 watts**

ΔT = 8°C For the new filter

ΔT = 15.8°C For the old filter

To calculate the surface temperature of the PCB we use the following equation:

$$T_{board} = q/hA + 0.5 \times (T_{Air\,inlet\,to\,board} + T_{Air\,outlet\,to\,board})$$

The inlet temperature to the board is considered to be the same as ambient temperature. The outlet temperature is simply calculated as:

$$T_{Air\,outlet\,to\,board} = T_{ambient} + \Delta T$$

The heat transfer coefficient h can be calculated as [2]:

$$h = 5.064\left(\frac{V}{Y}\right)^{0.5}$$

Where **V** is the velocity (m/sec) between the boards, and **Y** is the length of the board (m)

This results in the following board temperatures:

$\mathbf{T_{board}}$ **= 99.9°C** For the clean filter

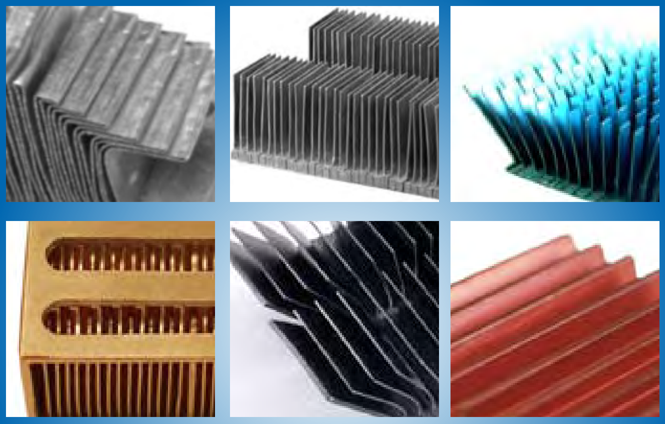
$\mathbf{T_{board}}$ **= 126.3°C** For the old filter

The above analysis allowed us to parametrically analyze the temperatures for a telecom chassis. This analysis showed that the effect of an aged filter can drastically change the temperatures, which in this case increased the board temperature by approximately 27°C. The analytical tool can be used in the same way to analyze different fans and fan trays, and their impact on the system and component temperature.

The power of the analytical tool is that once it is programmed in a program such as MathCAD, it can yield results much faster than by CFD or experimentation. 'What if' scenarios enable engineers to optimize and predict potential problem areas. This will reduce the design duration and establish an independent solution for validating results. ■

References:

1. *Pressure Drop Calculations in a Chassis, Qpedia Thermal eMagazine, Advanced Thermal Solutions, Inc., February 2007.*
2. *Ellison, G., Thermal Computations for Electronic Equipment, Tektronix Computer Science Center, 1984.*



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