Design of system cooling using DC axial fans - Part I

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Cooling has a key role in today`s electronics, as the lifetime expectancy of passive and active components is highly dependent on the way of transferring the heat generated by their electric current towards the surrounding environment. In some cases the properly designed PCB and using a heatsink provides adequate surface to remove the heat emitted by the components, in other cases the system needs active cooling e.g. by forced flow of air. The design of cooling is often not part of the functional design of the electronic devices, however this has to guarantee the reliable primer functionality. Usually a fan used without proper selection may result in oversized mechanical measures, or - in worst case - undersized cooling efficiency. Today`s miniaturization trends make not possible to unnecessarily enlarge enclosure size, while the competition does not allow produce unreliable products. Therefore cooling design cannot be started early enough, just like without proper circuit protection, no electronics device can provide its primer functionality for long time without sufficient cooling. Our article is about some important selection criteria of the proper fan depending on the application conditions.

fig. 1. Exhaust fan: sucking warm air out of the chassis

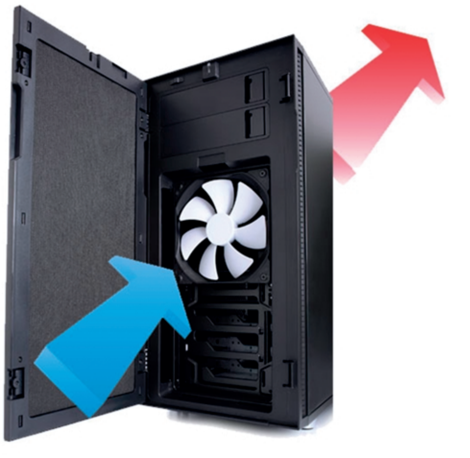


fig. 2. Forced convection by pulling cold air into the chassis

When the heat of a device should be removed, the heat is transferred on one of the three ways:

1. The heat may leave through thermal conduction, when the heat source is in direct contact with another heat conductive material such as the PCB, heatsink or chassis
2. Through radiation, when the generated heat is directly transferred to the environment as an electromagnetic wave.
3. Through convection, when the heat is released by the flow of warming particles of the surrounding medium to the atmosphere.

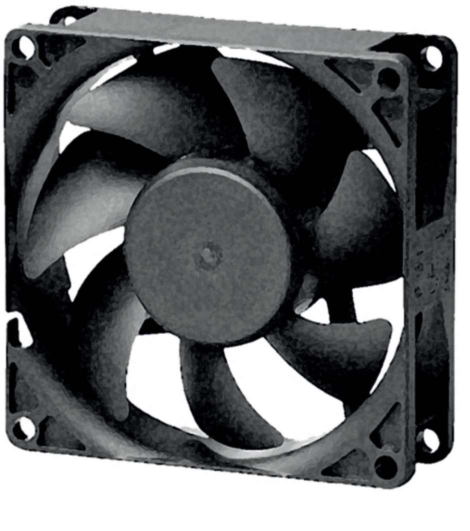
The last way acts the most important role in active cooling of electronics systems. Convection may be natural, when the flow is generated by temperature difference, or forced, when the stream is created by external force such as the rotation of an impeller. Forced convection is extremely effective towards the cooling of electrician devices, either provided by high volume airflow of axial fans or high pressure air of radial blowers.

The most important design aspect is to leave sufficient space for this flow around the most heat-critical parts concerned, the fan and its power supply, paying special attention at least of the proper air-intake and exhaust vents. If these criteria are taken in consideration during functional design, an important step is taken into the direction of reaching the maximum performance of the application and to avoid later stage compromises between functionality and sufficient cooling.

When using forced convection the most of the heat generated by the components leave the system on the following way:

1. Heat generated on the component -> 2. Heat convection from component to surrounding air particles inside the chassis -> 3. Discharge heat with the airflow

(2) may be supported by providing large surface area on the component or increasing the volume of air flow. In former case we have a choice to use a larger component or attach a heatsink, in latter case either reduce component density, using larger air-intake or using more fan or higher speed could be solution.



When applying active air cooling it is possible to suck warm air out of the chassis or blow in cold air to the components. Although in these solutions nearly the same volume of airflow can be used for cooling, both arrangements have their own advantages and disadvantages. Air drawn into the fan flows laminarly providing uniformly distributed particle velocity in the chassis, therefore no hotspots and stagnant air are present. The air exhausted by the fan becomes turbulent, which offers twice as better heat dissipation than in laminar flow with the same volumetric flow rate. But this turbulent zone is concentrated near the exhaust of the fan and due to possible recirculation a huge loss in airflow may happen inside the chassis if the air velocity profile is not well defined and the air flow path is not developed by using huge vents and air bafflers. During design it is advisable to use the natural convection as well, warm components should be placed above cool ones, huge components should not block the airflow from small ones.

The exhaust fan sucks the warm air out of the chassis, which reduces the air pressure of the enclosure, causing dust drawn into the housing with the air going in through of the vents and holes. This may be accumulated and deposited on the components causing reduced convection and prevents effective cooling. If exclusion of dust is required, it is better to use a fan pushing cold air into the chassis, where an inlet filter may offer good protection against dust. As in this arrangement there will be slightly higher pressure inside the enclosure, which prevents airborne dust to penetrate through holes and vents. The filters should be replaced time to time to avoid dust accumulation, which may prevent airflow, therefore causing even bigger problem than the dust would create inside the enclosure. The other advantage of this arrangement is that the room temperature air does not stress the bearings as much as the warm air at exhaust types of fans, which results in 2-3 times higher lifetime. Some small drawback is caused by the own heat dissipation of the fan motor, which slowly warms up the incoming air and therefore reducing the cooling efficiency. For the same reason it is the best to place the most heat critical components near the inlet and the highest temperature ones near the outlets.

Before going deeper in required air flow calculations, it is very important to decide about the geometry of the used fan. When requiring high volumetric airflow, it is advised to use an axial fan, in case we have to overcome a high static pressure a radial blower can be used. As this article is about axial DC fans, we do not detail the selection of radial blowers, in case it is necessary to increase the pressure, we choose other methods such as e.g. using multiply axial fans in serial arrangement.

Although the proper fan selection depends on many factors, at first stage in designing a forced air cooling system is to determine the required air flow volume. This is primarily defined by the total heat generation of the system, and the allowed maximum temperature rise.

In order to calculate the required airflow Q [m^3/min] we need to obtain the following values:

- The power dissipated within the system (worst-case estimation) : P_{loss} [W]
- The k constant describing the packing density of the components that prevent the free flow of air (k=80-95 rare placement, k=60 dense components)
- The maximum allowed temperature rise that is defined by the operating temperature range of the used components (DT)

$$Q = \frac{P_{loss}}{c_P \cdot \rho \cdot \Delta T} \cdot k$$

Where,
Q: required airflow [m^3/min]
c_p: heat capacity of the air at constant air pressure: 1007 J/(kgK)
r: air density: 1.2 kg/m^3 @ 25 C°

Taking the usual experimental values of the constants in consideration the formula of the required airflow may be simplified like this:

$$Q = \frac{P_{loss}}{\Delta T} \cdot 0.05 \qquad [m^3/min]$$

In practice this means that a system dissipating 200W requires 0.5 m3 airflow a minute to keep at maximum 20 Co of temperature rise. Although this theoretical calculation provides exact volumetric airflow requirement, it does not give adequate answer for the practical problem, whether the selected fan will provide this airflow or not, since it does not hold enough information about the interaction between the fan and the system to be cooled.

This will be discussed in the second part of the article series...

To be continued...

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