Old fans – new approach to today's airflow requirements

By Thomas Perazzo

High availability electronic systems require a fault tolerant airflow scheme to ensure no functionality is lost due to overheating. Typically when a fan failure occurs, the system notifies maintenance remotely and several hours, if not days, may go by before a fan module is replaced. The reduced airflow due to the failed fan can cause electronic boards to exceed their thermal limits in less than 30 minutes and fail. Mission critical systems and large electronic infrastructure systems cannot tolerate outages for more than a few seconds per year over the course of several years. In order to meet 5-nines (99.999%) reliability, a fan failure must be expected and the cooling system must provide enough airflow until the system can be repaired. By definition a fault-tolerant airflow system can allow the full system to operate indefinitely with a single fan failure.

If the tough reliability and redundancy requirements are not enough, today's systems dissipate more power than ever and power loads are expected to rise. Figure 1 shows single board power dissipations and maximum device junction temperature forecasts for the next decade. Junction temperatures refer to the silicon die maximum allowable temperature for reliable operation. Experts forecast die temperatures to stabilize at 85° C while more power and functionality is packed into a single silicon chip. Based on Newton's law of cooling, $Q = hA\Delta T$, the only ways to extract the higher heat load, Q, are to: 1) increase the heat transfer coefficient, h, (i.e. more airflow) and 2) increase the surface area, A (i.e. add heat sinks). The ΔT is assumed to be fixed since ambient conditions and junction temperatures are constant. Conventional forced convection techniques are reaching their limitations and new approaches are needed.

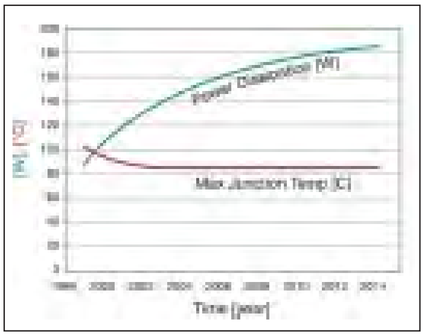

Figure 1: Industry thermal trends for single board devices. SIA roadmap 1999 Edition.

Shortcomings of existing technology

Conventional fan modules or fan trays utilize axial fans or motorized impellers/ blowers to move air through a card cage. The problem arises when the air mover directly above or below a set of cards fails, the corresponding cards fail in a matter of minutes due to the lack of air movement. One approach to achieve redundancy is to use a push-pull configuration, meaning that one set of fans pushes air into the card cage and another set of fans pulls air from the card cage. In the event of a failure, the locked fan introduces higher impedance to airflow, causing airflow to bypass some card slots. The other problem with the push-pull configuration is that high flow rates are difficult to achieve. When two fans are installed in series as in the push-pull configuration, the maximum volume of air is limited to that of a single fan. Two fans installed in parallel have the potential to provide twice the volume of a single fan. The drawbacks to parallel fans are the lack of space available and the loss of redundancy. One might argue that several small fans in parallel could be redundant, however, small fans are not as efficient as large ones and the system will most likely not meet the airflow requirements regardless of a fault.

The new approach

This new approach utilizes a novel technique to arrange large axial fans in a hybrid parallel and series arrangement. Not only is this method more efficient, but it is also inherently fault tolerant. The hybrid parallel and series approach is achieved by staggering the fans in one or two dimensions (see Figure 2). A portion of the airflow from fan 1 goes around fan 2 and the remaining portion goes through fan 2. If either fan 1 or fan 2 fails, air can be pushed or pulled through the open space created by the staggered fan arrangement. Air can bypass the failed fan without the high airflow impedance associated with going directly through a failed fan. High airflow can also be achieved since the airflow is partially additive for each fan in the module. The hybrid or staggered approach can be used for two or more fans.

Most enclosure systems require air intake in the front and exhaust in the rear (see Figure 3). This requirement forces air to flow in a S-shaped pattern making 90 degree bends in the bottom and top. Thermodynamic work is required to change the direction of airflow, which results in irreversible losses. The hybrid parallel and serial approach utilizes multiple fans to direct the airflow in a 90-degree bend without the need for additional steering devices such as baffles. This is achieved by angling the front fan and relying on the others to pull the air through the module. See Figure 3 for fan placement. The angle and location of each fan can be optimized for a given chassis layout.

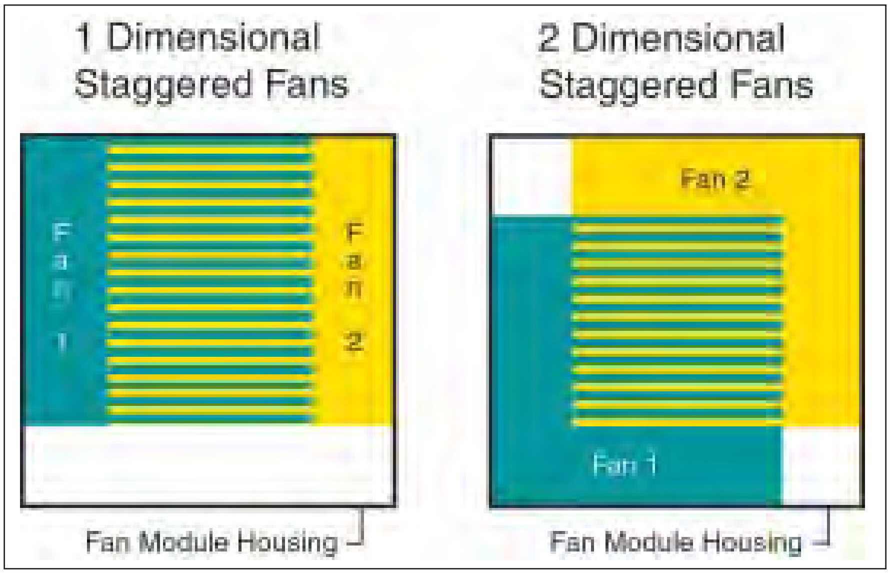

Figure 2. Schematic of parallel-series fan arrangement

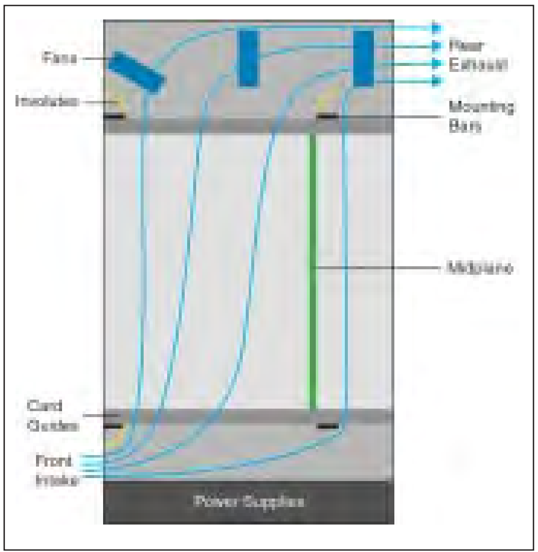

Figure 3. Side view – shows airflow path of new approach

Higher efficiency occurs in this fan arrangement because the air intake is the entire bottom of the fan module, whereas conventional fan trays are limited to the cross sectional area of one fan per module.

Fan manufacturers and textbooks strongly recommend the use of baffles on the perimeter of the fan to avoid recirculation (see Figure 4).

The hybrid approach violates this industry practice for good reason. The influence of the other staggered fans prohibits air from recirculating. In the hybrid approach a fan baffle is not needed because the other fans force airflow in the open area next to the fan. The momentum of airflow in this open area is larger than the tendency for air to recirculate. This is only true for high flow and low backpressure designs. If the exhaust of the fan module is highly restrictive then the backpressure may be significant enough to cause recirculation. Therefore this new approach requires a low-impedance exhaust. Low impedance is achieved by using large open area ratios in the rear of the module. The exhaust design attenuates ElectroMagnetic Interference (EMI) and protects the operator's fingers from the rotating fans. One material that serves the purpose is a honeycomb structure. The cell size is chosen such that a finger hazard is avoided. The depth of the cell is chosen such that the wave-guide below cut-off condition is met and the shielding effectiveness (SE) is greater than 30 dB for the system frequency limit. For example a cell size of 0.25 inches with a depth of 0.625 inches has a theoretical SE of 80 dB in the far field. Typical honeycomb structures have an open area ratio of greater than 98 percent and provide superior airflow performance over stamped sheet metal perforations of only 67 percent open area ratio. Similar structures using other geometric shapes are adequate as long as the area ratio is better than 95 percent.

The best location for the fan module is on top of the card cage for two reasons: 1) The intake side of the fan experiences more uniform airflow than the exhaust. After air is sliced by the fan blades, the flow becomes highly turbulent and directional. The highest velocities are near the perimeter of the fan while almost no airflow is present near the fan hub. This lack of uniformity makes the board design unpredictable. 2) The backpressure of the fan module is lower since air can be exhausted directly to the ambient. As mentioned before, if the backpressure is significant then recirculation may occur. For instance, if a hybrid fan arrangement was installed underneath the card cage in a push configuration, the flow impedance of the card cage will reduce the efficiency of the hybrid approach.

Since high airflow is desired for cooling efficiency the entire system impedance shall be minimized. Area changes, sharp corners, porous media, and bends all contribute to airflow loss. Historically enclosures are made from sheet metal bent at 90 degrees with a minimum bend radius. Large bend radii are preferred to control airflow and minimize impedance losses. Figure 3 shows how involutes placed in the card cage area are used. As air flows around a corner the velocity of air increases on the inside bend. The larger the inside radius, the smaller the eddy zone, as seen in Figure 5. Eddy zones are undesirable since the air currents circulate with low speed and they restrict the area for bulk airflow.

The outside radius is also important, but since the air speed is lower on the outside, the benefits are not as great. The radius placed near the intake of the chassis minimizes the eddy zone in the front of each card and provides much more balanced airflow from front to rear.

Test results of the new approach

A single module was tested first and then the entire enclosure. Each module tested measured 11.6 inches deep x 5.6 inches wide x 4.0 inches tall. Three Mechatronics G9232X fans were placed according to Figure 3. The volumetric airflow was measured in accordance with AMCA 210-85. Air streamers were used to visualize the airflow direction while hot wire anemometers were used to measure air speed. Various angles and positions of the fans were investigated to yield the best airflow volume; 115 CFM per module. A small baffle was required to eliminate a recirculation region near the front of the module. Due to the complex airflow patterns generated by each fan and the close

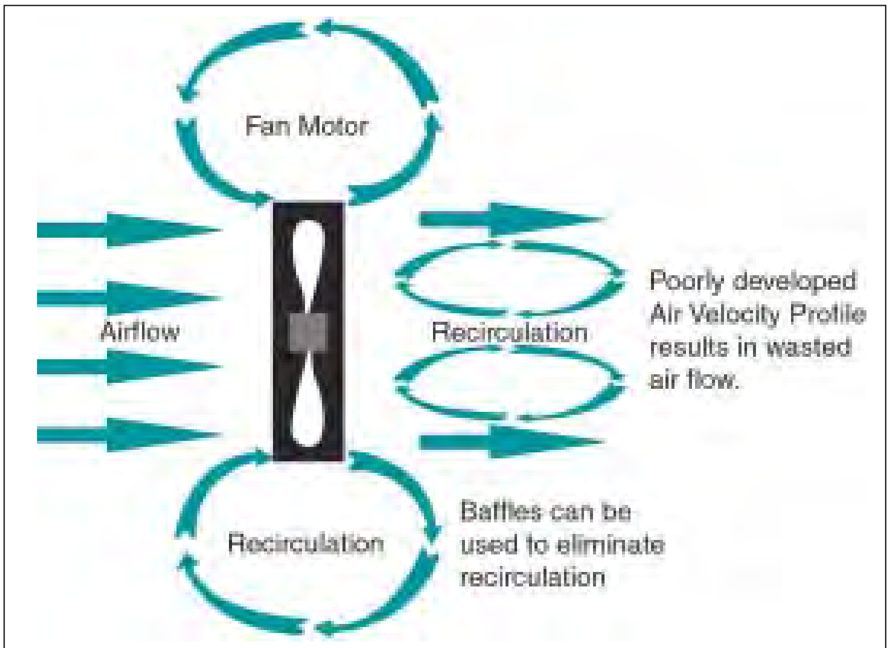

Figure 4. A single fan tends to recirculate air unless baffles are used around its perimeter

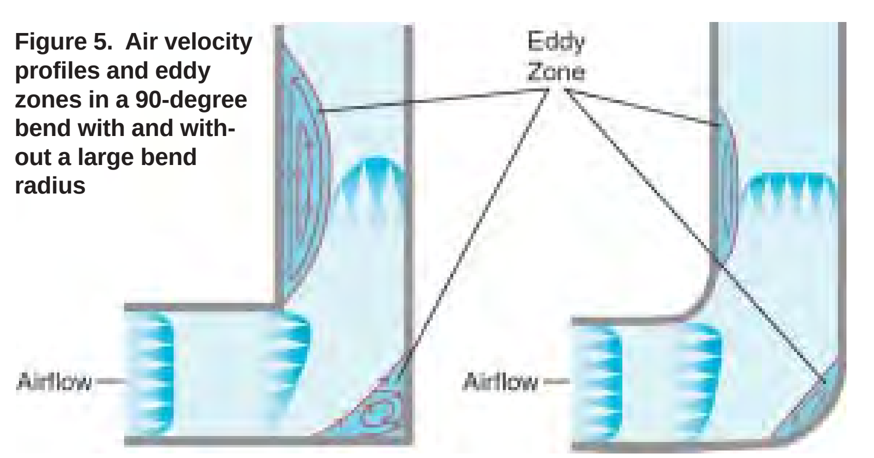

Figure 5. Air velocity profiles and eddy zones in a 90-degree bend with and without a large bend radius

proximity of the fans to each other, empirical data is preferred to study the airflow. In this case computational fluid dynamics would require very detailed models, therefore necessitating a considerable amount of time and money. Knowledge of air velocities and pressure gradients in the module is not mandatory since the goal is to provide uniform airflow to the cards.

Next, three modules were installed in an 6U x 160mm Eurocard enclosure, measuring 19.25 inches tall x 11.6 inches deep x 17 inches wide. Each module contained three fans, therefore nine fans were present in the chassis. Three velocity probes were mounted 1 inch from the bottom of one test card. The instrumented card and all other cards contained a simulated component blockage of 65 percent. The same instrumented test card was stepped through the card cage to provide the data below. Each data point shown on the chart is an average of 200 measurements and the bar averages all three probes.

Total airflow was measured at 215 CFM and 190 CFM with one fan fault, respectively. Air velocity data is shown under normal operation and with a worst-case fan fault (see Figure 6).

The plots show that a 12 percent reduction in airflow was measured with the worst-case fan fault. If the system is designed with this amount of airflow in mind, no loss of performance will be noticed. Fan speed control can be used to reduce the airflow if need be.

For comparison a conventional fan tray and enclosure was measured. The results below were taken from a chassis with three 92 x 25 mm fans located below the card cage and three 92 x 25 mm fans located at the rear exhaust. Large variance occurs when fans are placed below the card cage, due to the distinct airflow pattern that exits each fan. Also the volume and speed of the air is substantially less than the new approach, although only six fans were present instead of nine (see Figure 7).

Acoustic measurements were also taken from the front and rear at a distance of 1 meter. The lab measured 60 dB and 66 dB from front and rear of the hybrid chassis respectively. This value is consider-

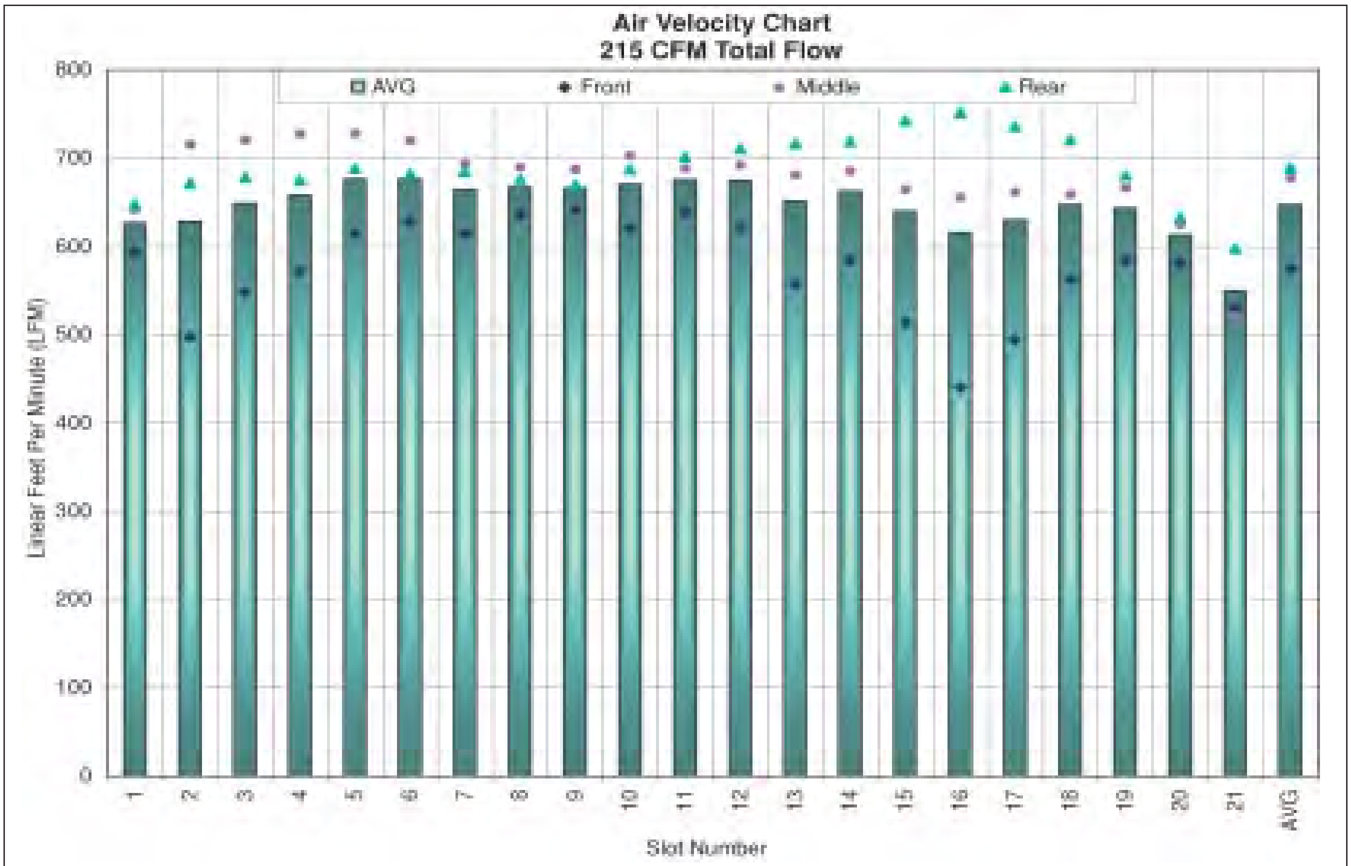

Figure 6 Before
Test results of new fan approach before and after a fan fault

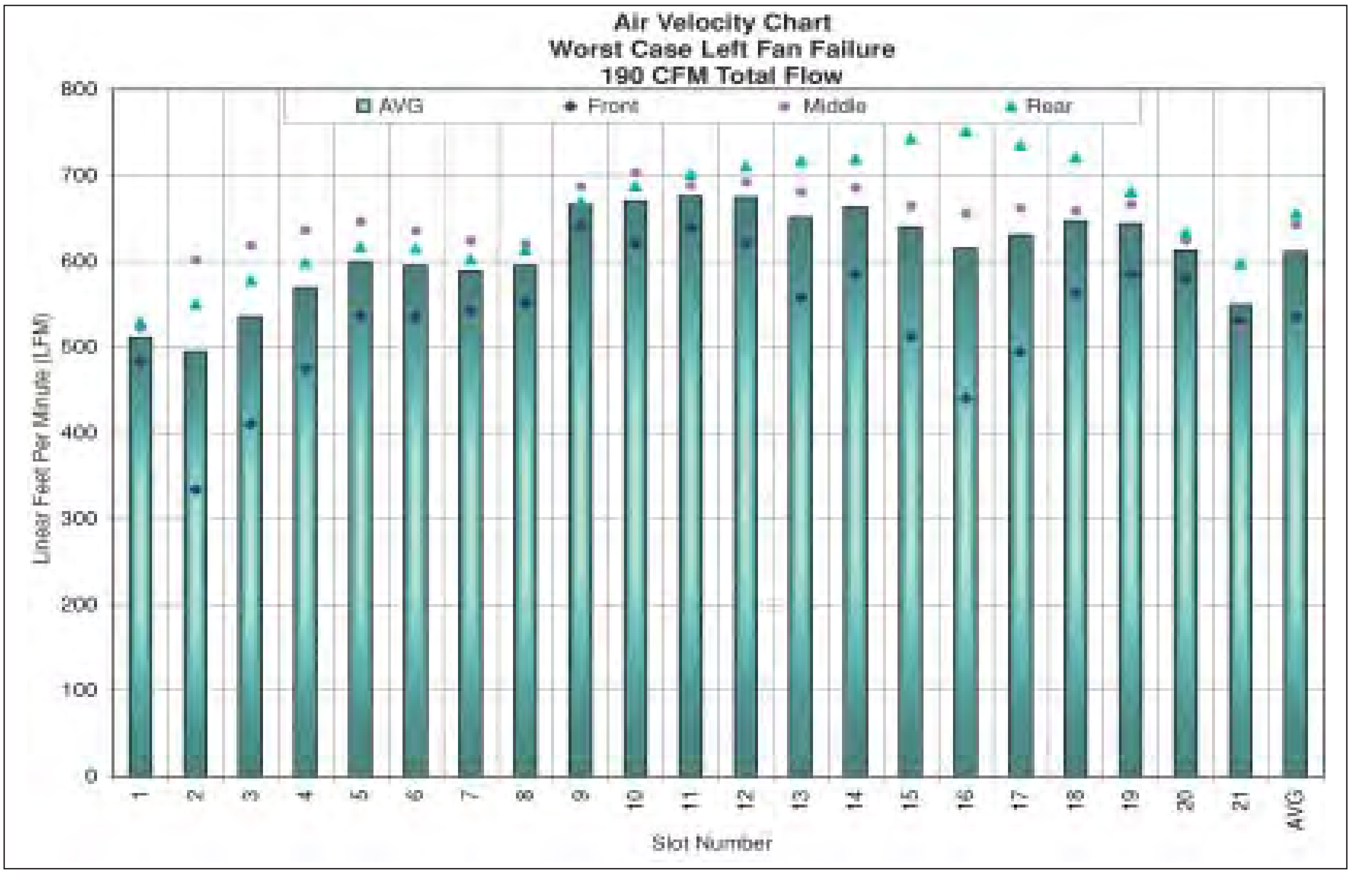

Figure 6 After

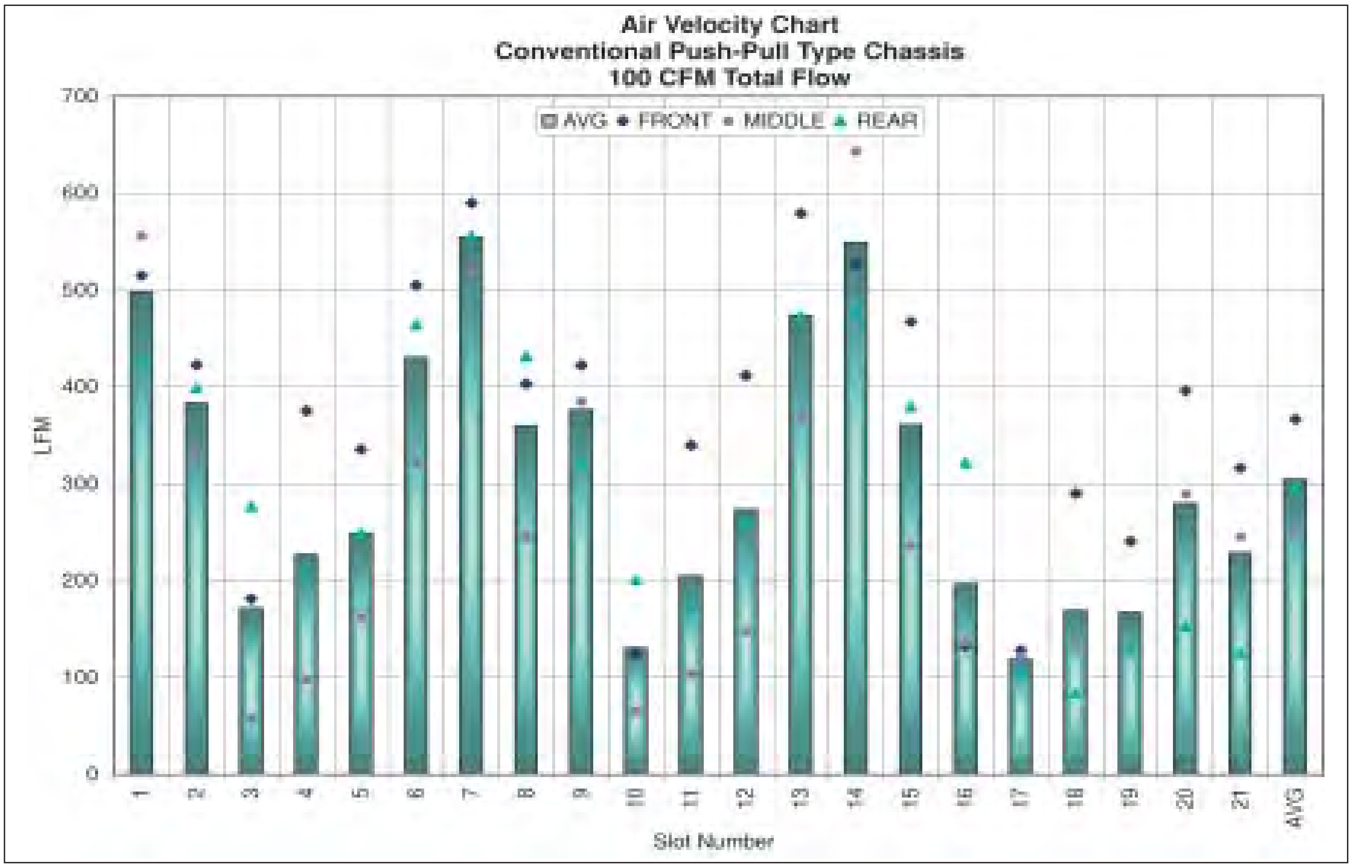

Figure 7. Airflow distribution of conventional push-pull fan arrangement

ably less than some systems that use reverse impellers and the new approach generates more airflow, thus providing better cooling.

The new fan approach enables higher power boards to operate safely and reliably despite a single fan failure. With the airflow demonstrated, APW Electronic Solutions calculates that about 1200 watts can be dissipated in the card cage with 55° C ambient conditions. This technology is scalable to platforms of all shapes and sizes. The airflow performance can be tailored to each unique system. For instance, a system with a dense card cage or stringent air filter requirements would require that the fans be arranged in a more serial manner. For sparse card cages the fans may be arranged in a more parallel manner. If more airflow is required, four or more fans could be used in each module although the depth of the chassis may need to increase.

The hybrid parallel-serial approach utilizes existing axial fan technology in a new way that improves performance and efficiency. The use of nine or more fans is a cost-effective solution due to their low cost. Reverse impeller blowers are five times more expensive than axial fans.

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APW'S ANSWER TO THE COOLING CHALLENGE

There is a high demand for superior cooling and reliable components in telecommunications systems. The challenge is to provide a fault-tolerant system design while achieving the cooling requirements of today – 30 to 60 watts, and of tomorrow – 60 to 80+ watts. Systems are being designed today with these new requirements. APW Electronic Solutions services these requirements by providing design, manufacturing, and compliance testing for CompactPCI-based systems. The company's new Ventus Chassis provides a non-traditional way of cooling redundancy with common, economical components. The unique fan arrangement combines different airflow techniques to provide very high CFM results for high-power boards. Dimensions and 21-slot CompactPCI/cPSB backplane architecture can be customized for various OEM applications. All Ventus chassis are designed to be NEBS compliant with Safety and Regulatory Compliance Certifications.

Thermal Management

Company/Model	Web site/Product	Airflow Access	Blowers/Fans	Conduction Cooling	Fire Suppression	Redundant N+1	Spray Cooling	Thermal Monitoring	Thermoelectric Cooling	Ruggedized	Custom Design
APW Electronic Solutions	**www.apw.com**										
CCA-134-CG	Conduction-cooled assemblies			x							x
CCK-KIT-ZA	VITA 1.6 conduction-cooled keying			x							x
Dage Group	**www.dage-group.com**										
N/A	Custom designs	x	x	x	x	x	x	x	x		
DegreeC	**www.degreec.com**										
1	Fan tray and controller	x	x	x				x			
N/A	Thermal services	x	x					x			
Donghae Systems	**www.donghaesystem.com**										
1122xx-DBx series	cPCI systems	x	x	x		x		x			
Electrografics International	**www.electrografics.com**										
AAC-140B-4XT	400 BTU, 120/220V, lightweight thermoelectric air conditioner								x		
AAC-140B-T-E	400 BTU, 120/240 VAC thermoelectric air conditioner								x		x
AAC-141-T-E	8000 BTU, 120/240V, NEMA 12 thermoelectric air conditioner								x		
Hoffman	**www.ehoffman.com**										
N/A	Blowers and fans		x								
I-Bus/Phoenix	**www.ibus.com**										
PSU-DCx	Input supply					x					
Inova Computers	**www.inova-computers.com**										
FP-80MM-FAN-RIO	80mm fan module w/rear I/O		x								
Kaparel	**www.kaparel.com**										
PS3900 Series	Thermal development system and software										
Knurr USA	**www.knurr.com**										
Dart Lufter Family	Dart fan unit	x	x	x				x		x	x
Dart Lufter Family	Dart fan unit with equable air distribution	x	x					x			
N/A	Custom development services										
Miltron/Maktron Systems	**www.maktron.co.uk**										
Air baffle module	Air baffle module									x	
One Stop Systems	**www.onestopsystems.com**										
OSS-SYSMON	6U cPCI system monitor board							x			
PCI Automation	**www.pcisystems.com**										
600-500	Conduction-cooled ruggedized enclosure w/available water cooling			x		x		x		x	x
Pentair Electronic Packaging	**www.pentair-ep.com**										
10827-custom	Custom cPCI chassis, NEBS, high availability, shielded	x	x			x		x			
Rittal Rigac	**www.rigac.com**										
Model PP	RiCool SuperCooled MPS System	x	x	x	x	x	x	x	x		x
Triple E	**www.tripleease.com**										
MaxAir 10	CPCI chassis	x	x			x		x			