Design Of An Air Duct Cooling System In A Medium Voltage MMC Phase Leg

Min Lin[1], Ruirui Chen[1], Dingrui Li[1], Leon Tolbert[1], Fred Wang[1,2]
[1] The University of Tennessee, Knoxville [2] Oak Ridge National Laboratory

Motivation:

- An efficient cooling system to dissipate the heat generated by SiC devices
- Promote the implementation of high voltage SiC in medium voltage converter application
- Detailed numerical calculation and FEM simulation to guide future cooling design

Challenges:

- Sufficient isolation between low voltage cooling system and high voltage SiC devices
- Compact cooling design that does not compromise converter power density
- Uniform flow rate for individual submodules to prevent overheating

Crisscross shape airduct:

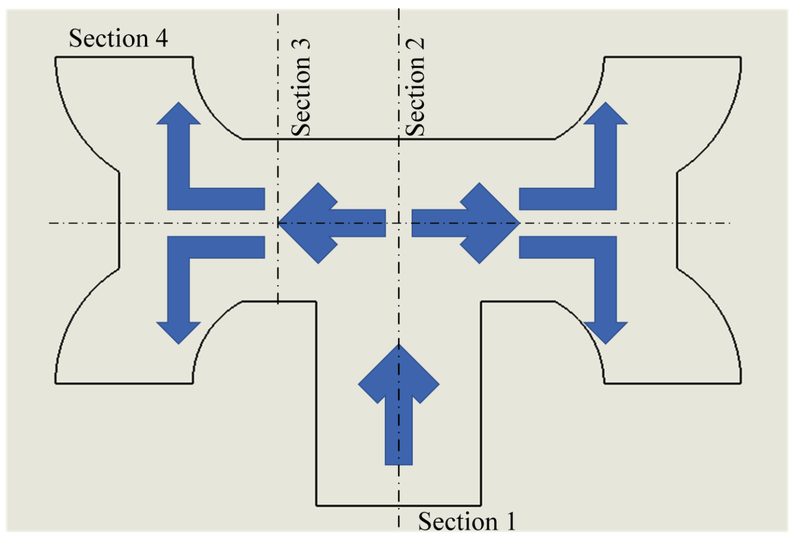
Fan situated at section where the air flows in, and the air passes through a T-type fitting and then a 90° bend to four outlets.

- Major loss is caused by friction within a pipe:

$$\Delta P_{major} = \sum f \times \frac{L}{D} \times \frac{1}{2}\rho V^2$$

- Minor loss occurs at the change of section, valve, bend:

$$\Delta P_{minor} = \sum k \times \frac{1}{2}\rho V^2$$



Crisscross shape airduct

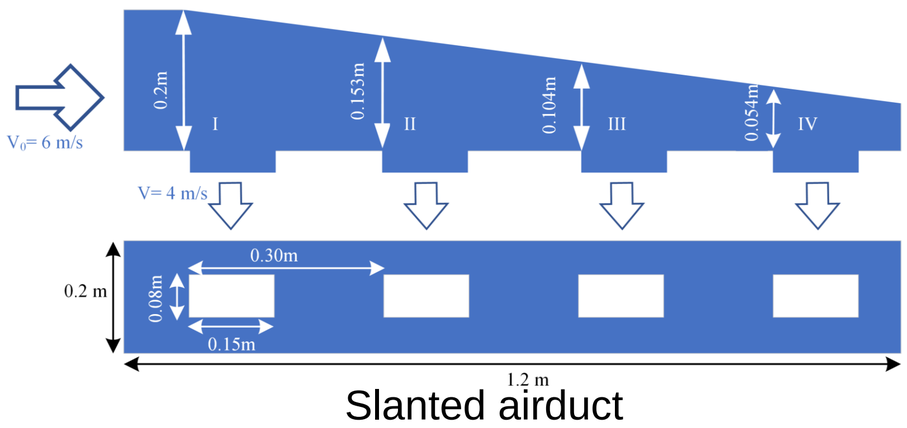
TABLE I - FLOW RATE IN CRISSCROSS AIRDUCT

Section	Volume flow rate (m3/s)	Width×Height (m×m)	Actual flow rate (m/s)	Minor loss (Pa)	Minor loss coefficient
1-2	0.188	0.12x0.1	15.67	147.27	1
2-3	0.094	0.12x0.1	7.83	36.82	1
3-4	0.047	0.1x0.1	4.70	19.88	1.5

Slanted airduct:

- Tapered shape to ensure equal flow rate at each outlet
- Static pressure in the airduct stays the same
- Dynamic pressure loss from the beginning to the end of the duct is equal to the total pressure loss of the whole air duct

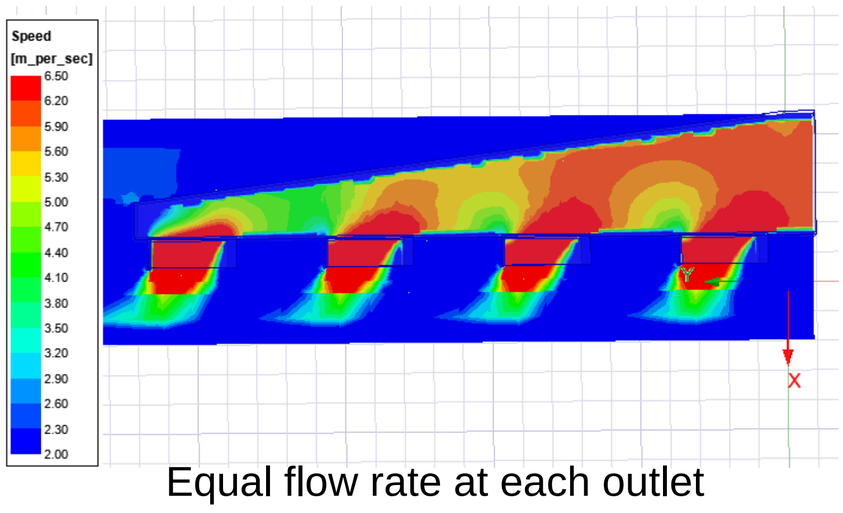
$$\frac{\rho}{2}(V_0^2 - V^2) = \sum(\Delta p_m l + \Delta P_i)$$



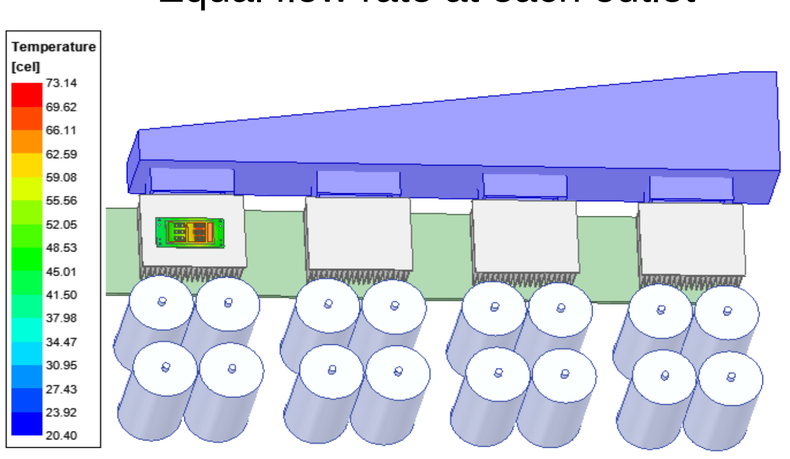
Slanted airduct

TABLE II - FLOW RATE IN SLANTED AIRDUCT

Cross section No	Volume flow rate $L(m^3/h)$	Dynamic pressure $P_d(Pa)$	Static pressure $P_i(Pa)$	Air flow velocity $V(m/s)$	Cross section area $A(m^2)$
1	866.3	21.6	46.1	6	0.04
2	649.7	20.85	46.1	5.88	0.0306
3	433.2	20.03	46.1	5.78	0.0208
4	216.6	19.03	46.1	5.64	0.0107
Cross section No	Width×Height (m×m)	Hydraulic diameter D_m	Airduct	Average pressure loss $p_m(Pa/m)$	Pressure loss $P_m(Pa)$
1	0.2x0.2	0.1953	1-2	2.384	0.7152
2	0.1912x0.2	0.1743	2-3	2.6456	0.7937
3	0.1302x0.2	0.1435	3-4	3.218	0.9654
4	0.0668x0.2	0.0942	4-5	5.100	1.5301



Equal flow rate at each outlet



Power module temperature distribution