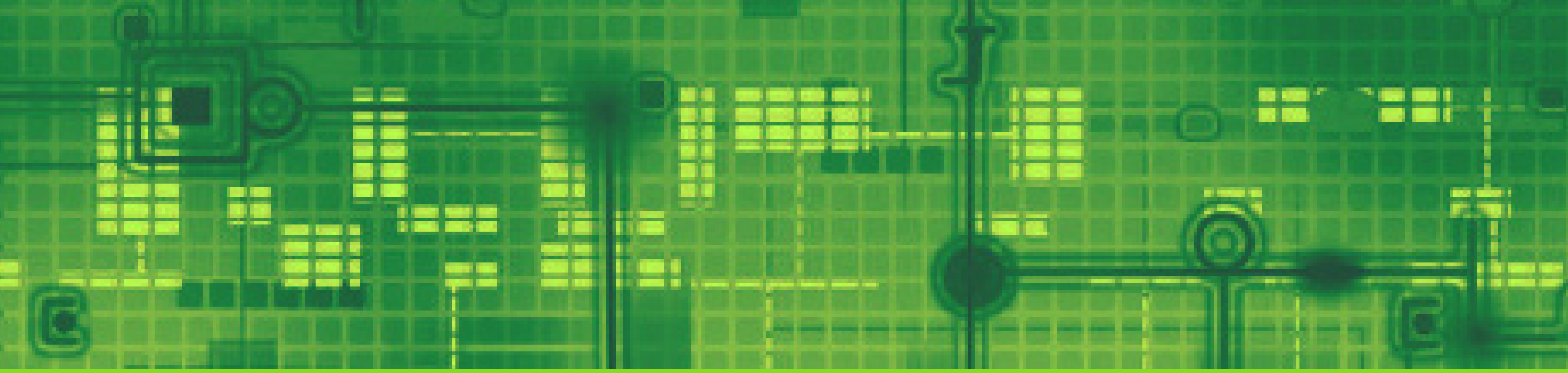

Loop Heat Pipes with a Flat Evaporator

A loop heat pipe (LHP) is a two-phase heat transfer device that uses capillary action to remove heat from a high temperature source and transfers heat to a condenser, where the heat is removed by other cooling methods. LHPs are completely passive and self-driven. They are similar to heat pipes but have the advantage of being able to provide reliable operation over long distance and the ability to operate against gravity, which transports large heat flux with a small temperature difference.

Figure 1 illustrates the basic concept and construction of a LHP. LHPs have an evaporation section, a condenser, tubing for vapor line and liquid line, and working fluid inside the LHP. The evaporation section generally includes an evaporating chamber, wick structure, liquid chamber, and compensation chamber. When heat enters the evaporator chamber, the working fluid boils and vaporizes. The vapor flows to the condenser via the vapor line due to higher pressure. At the condenser, the vapor cools down by external cooling and condenses back to liquid. The liquid moves back to the evaporator through the liquid line. Inside the evaporator, the liquid floods the compensation chamber and is drawn back to the evaporation chamber by the capillary force induced by wick structure. The compensation chamber is designed to operate at a slightly lower temperature than the evaporator. The lower saturation pressure in the compensation chamber draws the condensed liquid from the condenser back to the compensation chamber.

The classic design of a loop heat pipe usually includes a cylindrical shape evaporator like the one shown Figure 1. The heat flux enters the evaporator through the cylinder external wall. This kind of design is well studied and characterized by a well-proven theory. However, many electronic cooling applications require a flat evaporator, which can facilitate better heat spreading and component mounting. In the last decade, the performance and construction of miniature LHP with a flat evaporator have been studied by many researchers numerically and experimentally. However its application in electronics cooling is far from certain. This article discusses the thermal test results of some miniature LHP constructed by researchers in their lab.

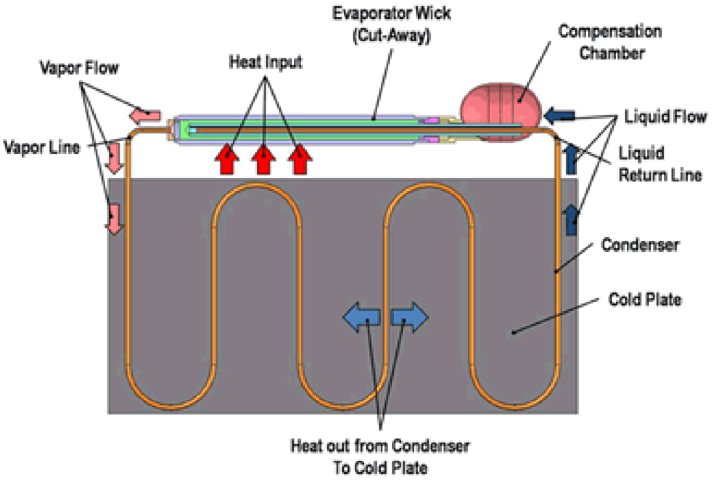

Figure 1. Loop Heat Pipe Concept [1]

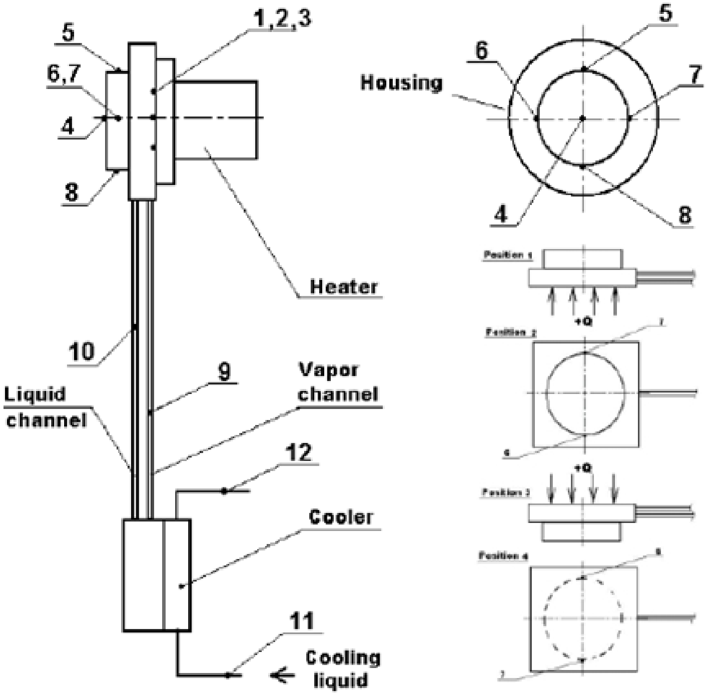

Figure 2. Schematic of LHP Test Setup, Numbers Represent the Thermocouples [2]

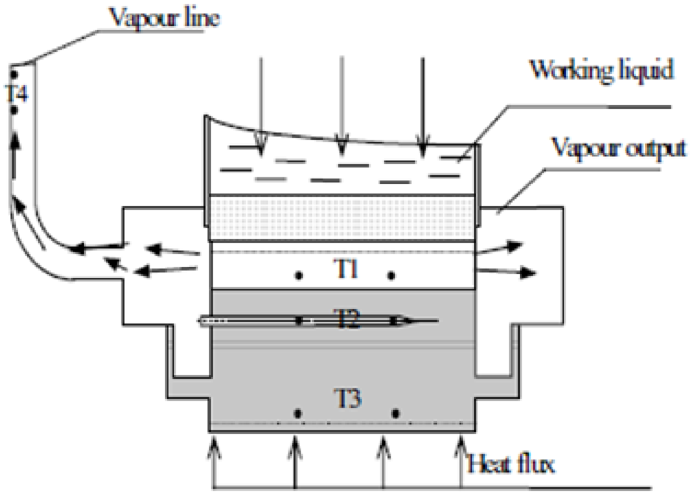

Figure 3. Thermocouple Locations in the Evaporator [2]

Delil et al. [2] studied a miniature LHP performance with different wick structures. The LHP they tested is illustrated in Figure 2. The evaporator has a circular shape and has a heater attached to its base. The condenser is cooled by an outside coolant circulating inside the condenser block. Twelve thermocouples are implemented at various locations on the LHP. The detailed position of thermocouples in the evaporator is shown in Figure 3. Ethanol was chosen as the working fluid. Three different wick structures were tested and their information is listed in Table 1. In the table, the No. 1 wick is fabricated from nickel chromium alloys (X20H80), No. 2 wick is wick fabricated from nickel powder, and No. 3 is wick fabricated from titanium powder.

No.	Material	Diameter x width	Porosity %	Permeability, m^2	Maximum pore diameter
1	X20 H80	39 x 3.7	35.9	$2.45 \cdot 10^{-13}$	12.0
2	Ni	39 x 7.9	66.0	$2.0 \cdot 10^{-14}$	2.4
3	Ti	39 x 7.3	57.0	$2.0 \cdot 10^{-13}$	10.4

Table 1. Wick Material Information [2]

The measured thermal resistance for X20H80 wick structure is shown in Figure 4. The H in the plot is the height difference between the evaporator and condenser. The measured thermal resistance for Ni wick structure and Ti wick structure are shown in Figures 5 and 6, respectively. The thermal resistance of the LHPs decreases gradually with increase of the heat load. When the heat load is less than 30W, all LHPs perform similar and their thermal resistance are very close. When the heat load is larger than 30W, the LHP with Ti wick has a higher thermal resistance than other two LHPs. The thermal performance of LHP with Ni wick is affected less by the change of the height of anti-gravity due to smaller pore size.

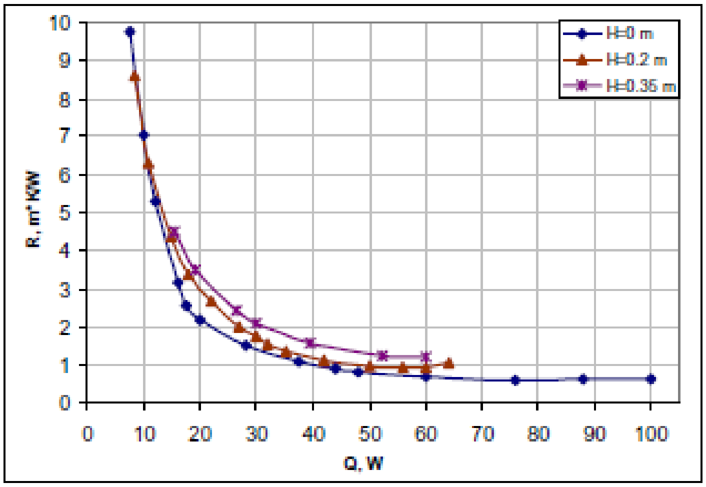

Figure 4. Thermal Resistance vs. Heat Load for X20H80 Wick [2]

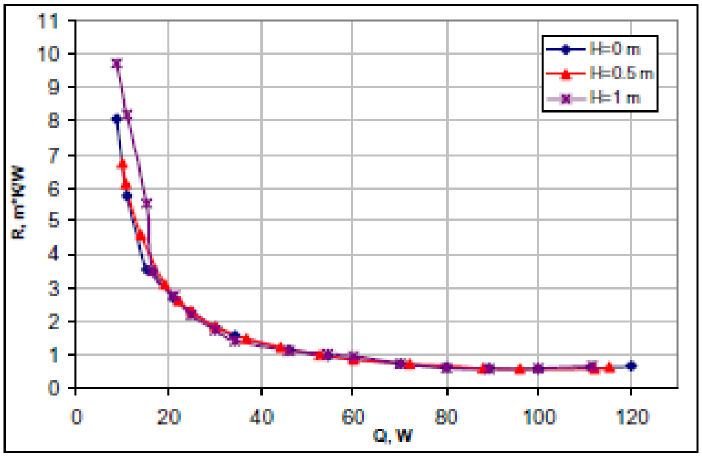

Figure 5. Thermal Resistance vs. Heat Load for Ni Wick [2]

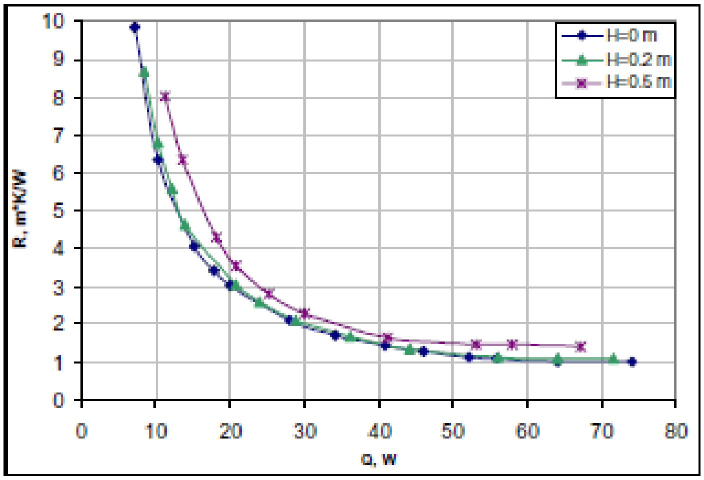

Figure 6. Thermal Resistance vs. Heat Load for Ti Wick [2]

Singh et al. [3] proposed a miniature LHP with flat evaporator design for electronic component cooling and tested it with different heat loads. The schematic of their LHP design is shown in Figure 7. The LHP device has a copper evaporator with a characteristic diameter of 30 mm and thickness of 10 mm. The flat face of the evaporator was contacted directly with the heat load simulator. Fifteen channels with rectangular cross-section of 1mm depth and 0.5mm width were machined on the inner surface of the evaporator. These channels work as evaporating surface and vapor removal passages. A 3mm thick, 75% porous nickel disk

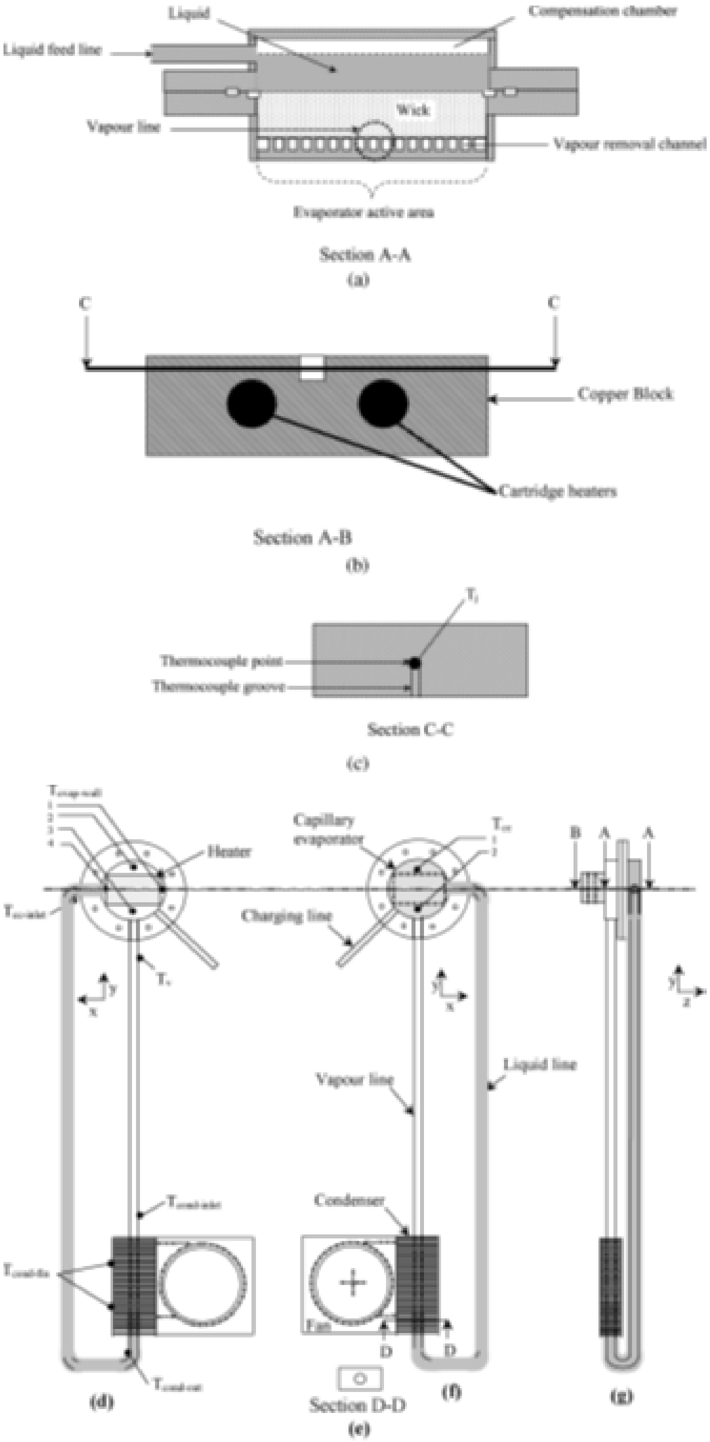

Figure 7. Schematic of the LHP: (a) Evaporator Cross-section; (b) Heater Block Cross-section; (c) Sectional View of the Heater and Thermocouple Location; (d) Device Bottom View; (e) Condenser Cross-section; (f) Device Top View; and (g) Device Side View [3]

with 4µm mean pore radius is used as the wick structure. It provides capillary pressure for moving the working fluid from compensation chamber to the channels in evaporation section. The wick structure also functions as a thermal and hydraulic lock to inhibit back conduction of heat and prevent any back flow of vapor from the evaporation section to the compensation chamber. The vapor line and liquid line are also made of copper. Water was selected as the working fluid. The condenser of the LHP was cooled using a combination of fins and a fan. The temperature of various locations of the LHP was monitored and recorded in the test.

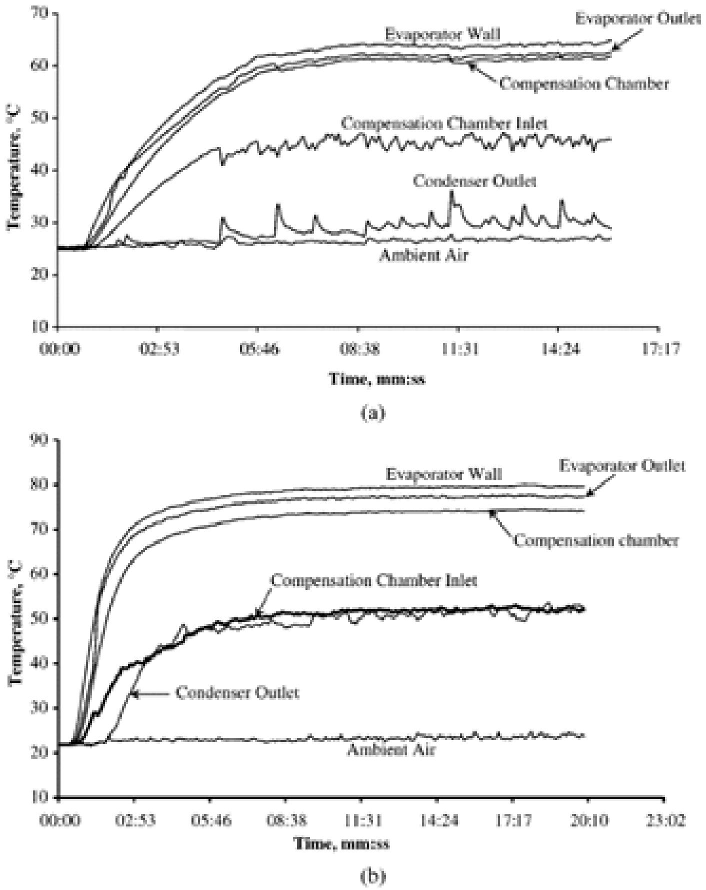

Figure 8. LHP Startup Test under Different Heat Loads: (a) Power=20W and (b) Power=50W [3]

Singh et al. first performed startup test for the LHP at different heat loads. The results for heat loads of 20W and 50W are plotted in Figure 8. The device showed reliable startup under low as well as high heat loads and achieved steady state without any problem. The capillary evaporator does not show any symptoms of wick depriming like overshoot of evaporator temperature or back vapor flow from evaporator to compensation chamber for high heat load.

Figure 9 shows the measured evaporator surface temperature at different heat loads. When input power is less than 30W, variable conductance mode is observed. In this case one can observe that the same value of temperature may correspond to different heat loads. This is because the mass flow rate of the working fluid is small at low heat load; therefore the compensation chamber and the condenser are partially filled with the liquid. When the input power is larger than 30W, a constant conductance mode is realized. The evaporator surface temperature increases linearly with increase of heat load.

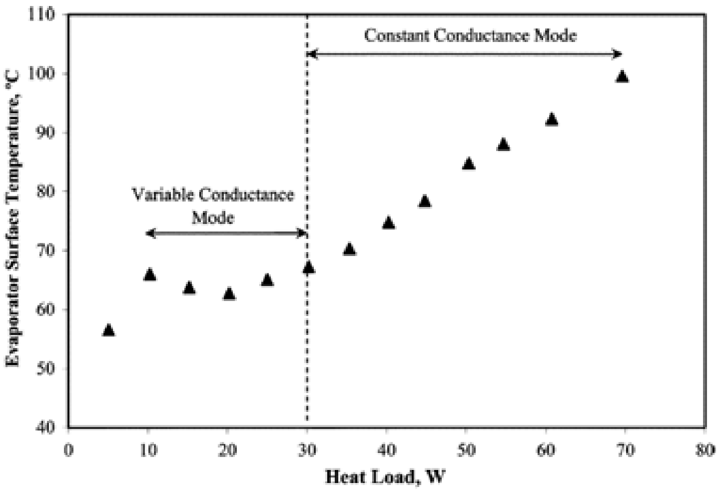

Figure 9. Evaporator Temperature vs. Heat Loads [3]

The total thermal resistance of the LHP is defined as,

$$R_{hp} = \frac{T_e - T_c}{q}$$

Where T_e is the external temperature of the evaporator active zone which was measured by averaging the temperatures of the thermocouples fixed on the evaporator heating face (position 1, 2, 3, 4); T_c is the condenser temperature which is measured at the condenser inlet.

The evaporator thermal resistance of the LHP is defined as,

$$R_e = \frac{T_e - T_v}{q}$$

Where T_v is the vapor temperature which is measured at the evaporator outlet.

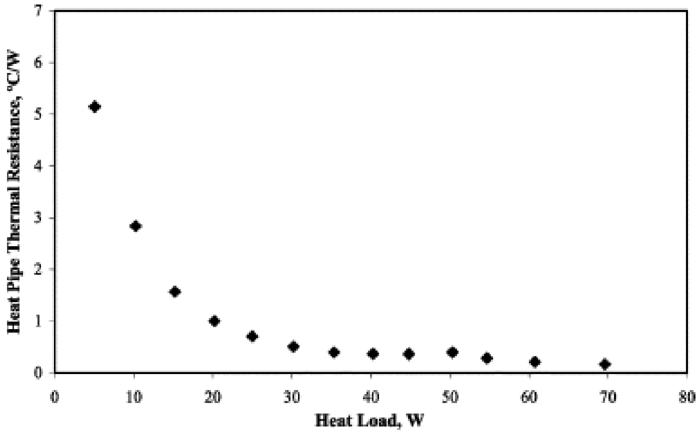

Figure 10. LHP Heat Pipe Thermal Resistance vs. Heat Loads [3]

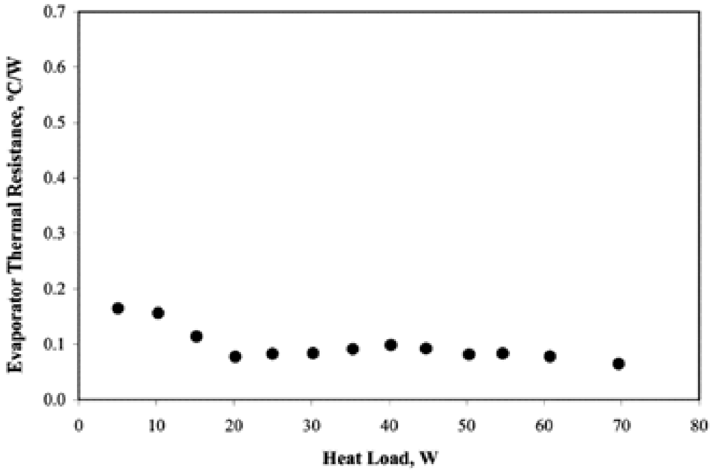

Figure 11. LHP Evaporator Thermal Resistance vs. Heat Loads [3]

The measured heat pipe thermal resistance of the LHP is shown in Figure 10. The heat pipe thermal resistance of the LHP decreases steadily with increase of input power. The minimum value of the heat pipe thermal resistance is 0.17 °C/W at 70W. The evaporator thermal resistance of the LHP is shown in Figure 11. Due to very low spreading and conductive resistance offered by the evaporator active zone made from copper, very low values of R_e were obtained in the LHP evaporator, with the minimum value of 0.06 °C/W at 70 W.

The experimental works of the LHP done by Delil et al. [2] and Singh et al. [3] show that the design of reliable, low thermal resistance LHPs with a flat evaporator is feasible. Both of their LHPs have no startup issue and perform well at low and high heat loads. At a low heat load, the LHP generally has large thermal resistance due to low liquid flow rate and incomplete wetting of the compensation chamber. The LHP thermal resistance gets smaller when heat load increases, which proves that the LHP with a flat evaporator can suit the electronics cooling application for high power chips.

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2. **Delil, A. A. M., Baturkin, V., Friedrichson, Yu., Khmelev, Yu., and Zhuk, S., "Experimental Results on Heat Transfer Phenomena in A Miniature Loop Heat Pipe with A Flat Evaporator", National Aerospace Laboratory NLR Report NLR-TP-2002-273, 2002.**

3. **Singh, R., Akbarzadeh, A., Dixon, C., Mochizuki, M., and Riehl, R. R., "Miniature Loop Heat Pipe With Flat Evaporator for Cooling Computer CPU", IEEE Transactions on Components and Packaging Technologies, Vol. 30, No. 1, March 2007.**

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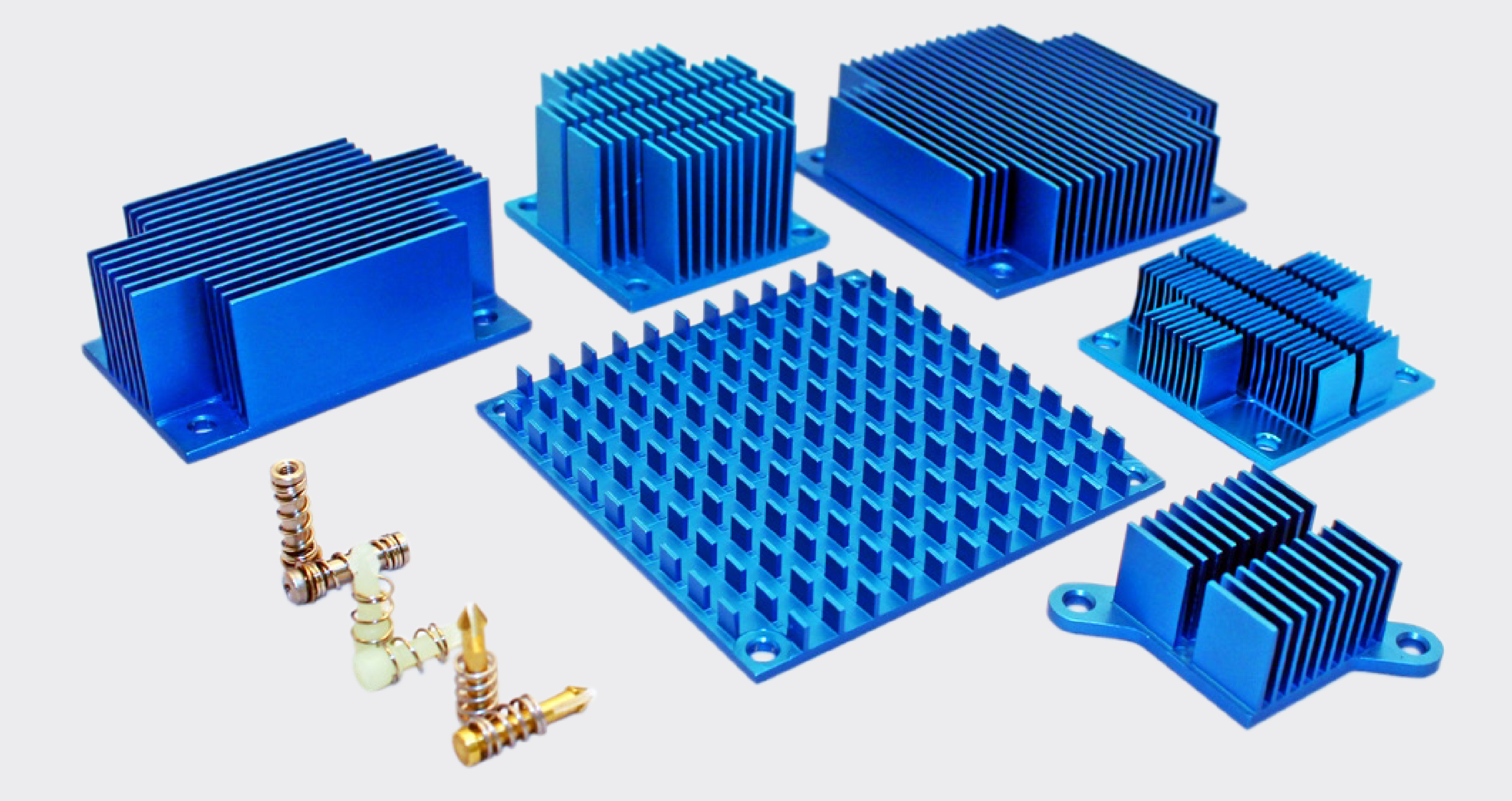

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