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Design of Cold Plate for the Thermal Management of Electronic Equipment

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Abstract: For cooling of electronic equipment various techniques are used. They are mainly divided as air cooling and liquid cooling. Liquid cooling is more efficient than that of conventional air cooling. Cold plate is a type of liquid cooling technique, which is used to remove heat from electronic devices. This work presents thermal design and analysis of cold plate for Travelling Wave Tube (TWT). Basically, TWT is used amplify input Radio Frequency (RF) to high power in electronic systems. The designed cold plate dissipates heat approximately 100 watts. 3-D model of cold plate is designed using CATIA V5R16. Design analysis is done using ANSYS Fluent software. In this study we used theoretical and numerical approach to predict performance of cold plate.

Keywords: Cold Plate, Travelling Wave tube, Cooling performance.

Introduction

In general, high temperatures are reached in operating conditions in heavy electronic equipment. Any electronic device can work securely at a temperature of 90 degrees Celsius. As a result, exceeding this temperature limit has a negative influence on the gadget, which can cause it to malfunction. This will result in reduction of equipment's life. The maximum operational temperature of the equipment must be less than 90°C to keep it safe, thus we must lower the temperature. As there is convective heat transfer, liquid cooling is more successful in solving this problem.

A cold plate is just a plate with grooves in various directions. The plate is constructed of copper and aluminium and is positioned beneath the electronic gadget on the surface. The coolant (water, ethylene glycol, etc.) flows at a set pace from the grooves. Cooling is accomplished by transferring heat from circuit's lower surface to coolant and raising the coolant's temperature. There are various types of cold plates based on application, size, shape and orientation.

a) Formed Tube Cold Plate [FTCP]
b) Deep Drilled Cold Plate [DDCP]
c) Machined Channel Cold Plate [MCCP]

The current project uses a Formed Tube Cold Plate. Coolant is 25°C running water. The temperature of water at the exit is calculated theoretically. For validation, the theoretical results are compared to CFD findings. The temperature of the plate surface is 80 °C. If compared to an equal mass of air, liquid cooling systems exchanges heat four times faster. This results in a smaller system with improved cooling performance. A closed loop liquid cooling system consists of four basic components: cold plate, heat exchanger, a water reservoir, and a pump. The cold plate is usually composed of aluminium or copper and affixed to the item that needs to be cooled. Internal fins on the plate normally transfer heat to the coolant, which is flowing through it. This fluid then flows from the cold plate to the heat exchanger, where it is forced convectively transmitted to the ambient air. The pump, which propels fluid through the cooling loop, is the final component of cooling loop.

LITERATURE REVIEW

1) Satish G. Kandlikar and Clifford N. Hayner grouped the cold plates into four kinds viz, shaped cylinder cold plate, profound bored cold plate, machined channel cold plate and stashed collapsed balance cold plate. In this article they examined choice of cold plate type and channel arrangement and a portion of the pertinent assembling issues, for example, general plan issues, coolant issues, fabricating issues and so forth It was suggested that the warm architect be engaged with the beginning phases during the electrical plan and design of the gadgets.
2) Ephraim M. Sparrow, John P. Abraham, and Paul W. Chevalier introduced concentrate on The Plan of Cold Plates for the thermal Administration of Electronic Hardware. In this work they manage the liquid stream and heat move in cool plates in which both the liquid stream and heat move experience intermittent varieties in the stream savvy course and their attention was on the improvement of a plan strategy for upgrading the heat move execution of cold plates. In such manner, thought was given to assembling issues just as to thermal and liquid stream issue
3) Pratik N. Raut, Prof. Mahendra, P. Nawathe. introduced concentrate on plan and examination of fluid cooled cold plates utilizing computer aided design displaying for cooling of electronic gear having high force dissemination rate, In this work the advancement is accomplished by looking at the thermal attributes of three kinds of cold plates at same workplace and proposed the best technique that can be embraced in various mechanical hardware for safe condition.
4) P. Sivakumar, P. Srihari, Prof. N. HariBabu et al. performed enhancement of liquid cold plates utilizing computational fluid dynamics. The goal of work was contrasting 3 distinct profiles of cooling plates to keep up the hardware in safe temperature condition. In this investigation, assessment of 3 distinct kinds of cooling plates through CFD examination by fixing the widths of channel and outlet partitions were kept steady. The plan of cooling plate put upon 8 IGBT's and the investigation of stream by utilizing solid workflow simulation programming. Looking at these three changed cooling plates for example the Structure tube, Machined channel and Profound penetrated cold plate and Enhancement is finished by considering weight of the cold plate and better temperature circulation.
5) Karin Dietl, Jens Vasel, Gerhard Schmitz, Wilson Casas, Christian Mehrkens et all., introduced concentrate on Demonstrating of Cold Plates for Force Electronic cooling. Cold plates are utilized to cool parts with heat motions of around 100 W/cm2. The force electronic cooling library contains models for cold plates and heat scattering models for some force electronic parts. The planned mathematical models can be utilized to pre-plan cold plates utilizing various designs and finned regions to have the option to arrive at the necessary intersection temperature. In this paper reproduction results are contrasted and test rig information. The test rig is intended to examine cold plates utilizing various coolants at changing heat transitions, liquid mass flow rates and inlet temperatures.

Design and Analysis

Let fluid is flow through the pipe, from one end to another end. Heat is coming to the pipe from device. By applying first law thermodynamics to the control volume.

Heat balance is given by,

The rate of heat convected by of the plate = Heat acquired by the water.

$$H.\ A.\ (T_s - T_f) = m.\ cp.\ (T_o - T_i)$$

The assumptions considered for finding out the maximum temperature are

a) Steady state conditions.

b) Specific heat of fluid is constant.

c) No leakage in the flow path.

Resistances are conveniently evaluated:

1. Conductive Resistance: In cold plate, two modes of heat transfer are involved. First one is heat conducted through the electronic device surface to the surface of the plate. Conductive resistance is calculated by,

$$R_c = \frac{t}{k.\ Ab}$$

2. Spreading Resistance: The variation in the cross section of electronic device foot print size $L_s \times W_s$ mm dimension and cold plate base size of L×W mm.

Presence of spreading resistance involves in heat path. The distance between electronic device and cold plate is assumed to be negligible and considered on one side of electronic device. Collective area as a foot print area of heat source. Spreading resistance as per Seri Lee is calculated by the relation of,

$$R_{sp} = \frac{\psi \max}{k.R1.\sqrt{\pi}}$$

Where,

ψ_{max} = constant

R1 = equivalent radius of rectangular source

3. Convective Resistance

Heat flows from cold plate to the water is convective mode of heat transfer. The cold plate performance is estimated for different flow rate.

The temp. raise of water solution is calculated as,

$$\Delta T_f = \frac{Q}{[\rho .\ Cp.\ Ac.V]}$$

Where, Q is total heat load, ρ is the density, C_p is the specific heat of the coolant, Ac is the cross-sectional area of flow channel and V is the velocity of the flowing coolant.

$$Re = \frac{V.\ \rho .\ Dh}{\mu}$$

Where, Dh is the hydraulic diameter of the channel and μ dynamic viscosity of the coolant.

For the internal flows, which is having Re>3000, Nusselt Number (Nu) is given by Dittus-Boelter equation. The Prandtl Number (Pr) and other properties are evaluated at the bulk mean solution temperature.

$$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$$

heat transfer coefficient (h)

$$h = Nu\ \frac{K}{Dh}$$

convective resistance

$$R_{conv} = \frac{1}{h.\ As}$$

The total thermal resistance (R_t)

$$R_t = R_c + R_s + R_{conv}$$

The temperature raise of surface ΔT_s is evaluated using following equation by considering the total heat dissipation (Q) of the equipment.

$$\Delta T_s = Q * R_t$$

Size of Plate & Pipe:

Length (L) = 200mm

Width (W) = 150mm

Thickness (T) = 20mm

Diameter of pipe (D) = 10mm

Properties of Plate & Pipe:

Material for plate = aluminium alloy

Thermal conductivity of plate (k) = 154 W/mK

Material for pipe = copper

Thermal conductivity of pipe (k) = 154 W/mK

Heat Load:

For travelling wave tube heat load is around 100 W

Q = 100 W

Size of Travelling Wave Tube:

Length = 90mm

Width = 30mm

Thickness = 30mm

Temp. of device (T_S) = 90 °C

Properties of Ethylene Glycol Solution with Water Mixed 50%:

Density (ρ) = 1077 kg / m3

Dynamic viscosity = 2.8 centipoise

Freezing point = - 36.8 °C

Thermal conductivity (K) = 0.433 w / mK

Specific heat (C_p) = 3411.6 J / kg.K

Inlet temp. of solution (T_i) = 20 °C

Atmospheric temp. (T_{atm}) = 25 °C

Calculation of Thermal Resistance:

1. Conductive Resistance

$$R_c = \frac{t}{k.\,Ab}$$

R_c = 0.004329 W/K

2. Spreading Resistance

$$R1 = \sqrt{\frac{ls\,.ws}{\pi}} \qquad R2 = \sqrt{\frac{l\,.w}{\pi}}$$

R1 = 0.02931 R2 = 0.0977

$$\epsilon = \frac{R1}{R2} = 0.2998$$

$$r = \frac{tp}{R2} = \frac{0.02}{0.0977} = 0.2047$$

$$Bi = \frac{heff\ .\ R2}{K}$$

h_{eff} is calculated by following process,

$$Nu = \frac{heff\ .\ l}{k} = c\ (Gr\,.\,pr)^n$$

Properties if air at 25℃ are,

Density (ρ) = 1.1845 Kg / m^3

Dynamic viscosity (μ) = 1.8444 * 10^{-5} Kg / m.s

Specific heat (C_p) = 1007 J / Kg. k

Thermal Conductivity (K) = 0.02551w / m .K

$$Pr = \frac{Cp\ .\ \mu}{k} = \frac{1007 * 1.8444 * 10^{-5}}{0.02551} = 0.7296$$

β = 0.0341 1/k

L = 0.2 m

$\Delta Ts = (Ts - Ta) = 75 - 25$

ΔTs = 50°C

$\frac{heff\ .\ l}{k} = c\left(\frac{\rho^2\ .\ g\ .\ \beta\ .\ Cp\ .\ \Delta T\ .\ l^3}{\mu^2} \cdot \frac{\mu}{Cp\ .\ k}\right)^n$

= 75 W/K

Bi = $\frac{heff\ .\ R2}{K}$ = 0.0336

$\lambda = \pi + \frac{1}{0.2998\ \sqrt{\pi}}$ = 5.0233

$\phi = \frac{\tan h\ (\lambda.r) + \frac{\lambda}{Bi}}{1+\frac{\lambda}{Bi}\tan h\ (\lambda.r)}$ = 1.287

$\psi = \frac{\epsilon.\ r}{\sqrt{\pi}} + \frac{(1-\epsilon)\ \phi}{\sqrt{\pi}}$ = 0.5429

$R_s = \frac{\psi}{k.r1.\sqrt{\pi}}$ = 0.0678

3. Convective Resistance

$R_{conv} = \frac{1}{h.As}$

Nu = 0.023 $Re^{0.8}$ $Pr^{0.4}$

But, Re = 3500

Pr = $\frac{\mu * Cp}{k} = \frac{0.0028 * 3411.6}{398}$ = 0.024

Nu = 3.5401

h =3.5401 × $\frac{398}{0.01}$ = 140912.298 W/m.K

As = $\pi * D * L$ = $\pi * 0.01 * 1.5$ =0.0471 m^2

$R_{conv} = \frac{1}{h.As}$ = 0.00015059

Total Resistance = $R_t = R_c + R_s + R_{conv}$

R_t = 0.004329 + 0.0678 + 0.0001505

R_t = 0.07227

$\Delta T_s = Q \times R_t$

ΔT_s = 100 × 0.07227

ΔT_s = 8 °C

Modelling

Modelling is done by using CATIA V5. Material selected for plate is Aluminium and for tube is Copper.

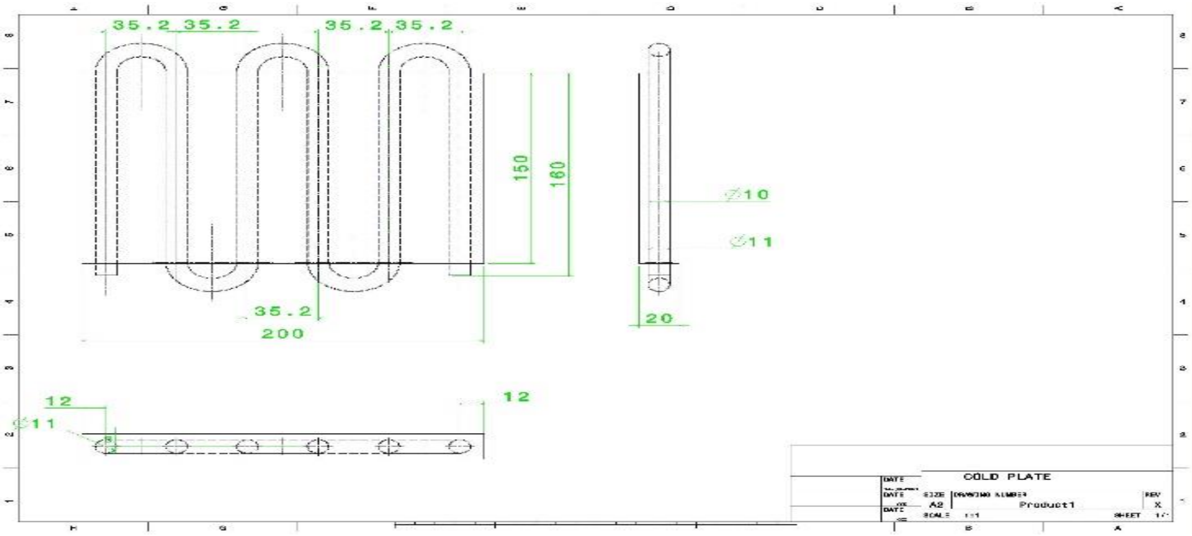


Fig. Drafting Drawing

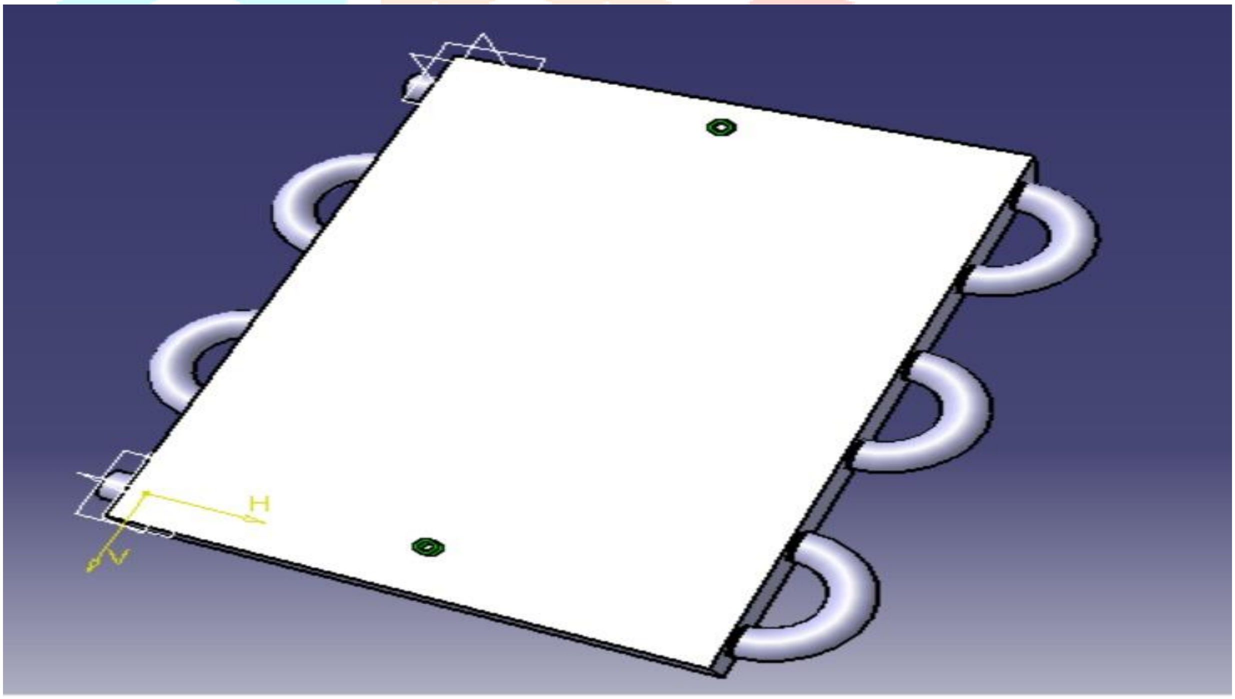
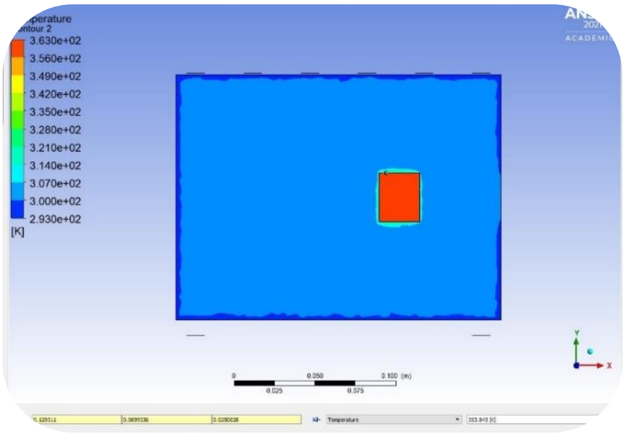


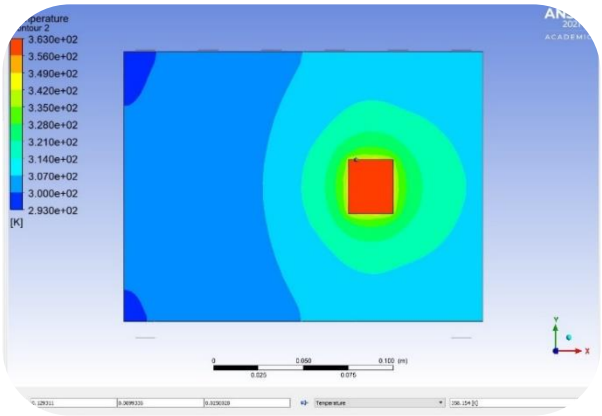
Fig. Catia Design

For analysis purpose geometric model is imported in ANSYS Fluent solver and core temperature is maintained at 90℃ and heat flux applied on plate surface is 100 W/m^2. The inlet temperature of cooling fluid id maintained at 20℃ .

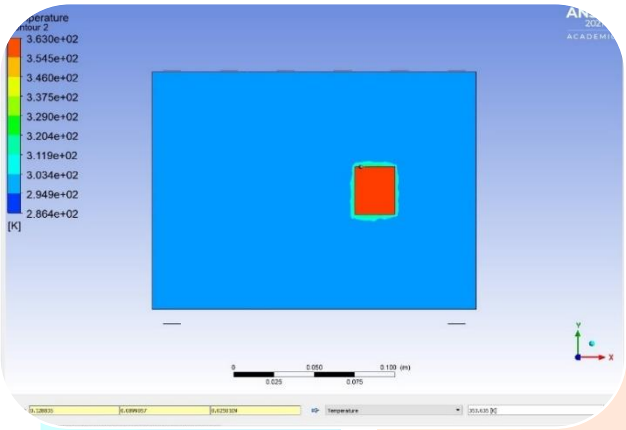
The figures below show the results of analysis for varying mass flow rate and with two difference cooling fluids.



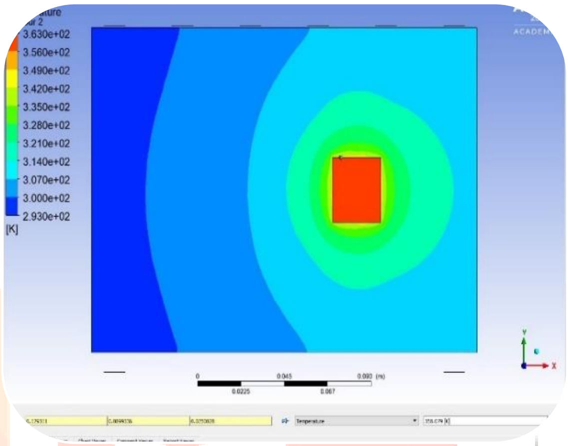
Ethylene glycol flow rate at 4lpm



Water flow rate at 4lpm



Ethylene glycol flow rate at 8lpm



Water flow rate at 8lpm

Result and Discussion:

Chart 1: Ethylene Glycol Solution (50% concentration)

SR.NO.	Discharge in (lpm)	Velocity in (m/s)	Temperature of core (k)	Drop in temperature (k)
1	2	0.67	354	8.97
2	4	1.33	353.8	9.15
3	6	2	353.65	9.36
4	8	2.7	353.6	9.36
5	10	3.33	353.5	9.5

Chart 2: Water

SR.NO.	Discharge in (lpm)	Velocity in (m/s)	Temperature of core (k)	Drop in temperature (k)
1	2	0.67	358.2	4.8
2	4	1.33	358.15	4.84
3	6	2	358.12	4.88
4	8	2.7	358	4.92
5	10	3.33	357.5	5.15

Computational Results

Considering, the heat flux load and core temperature of electronic device, comparative study of two cooling fluids that is ethylene glycol and water at various flow rates are simulated in ANSYS software.

For ethylene glycol (50% concentration) solution heat transfer rate is more as compare to water temperature of core of device decreases with increasing flow rate of cooling fluid. In case of ethylene glycol solution temperature of core decreases from 90℃ to 81℃ for flow rate of 2 lpm and it further reduces to 80.6℃ in case of 10lpm flow rate.

For water solution heat transfer rate is lesser as compare to ethylene glycol solution. Temperature of core decreases from 90℃ to 85℃ for flow rate of 2 lpm and it further reduces to 84℃ for flow rate of 10 lpm. Maximum decrease in core temperature is achieved 9℃ for ethylene glycol solution and 5℃ for water solution.

CONCLUSION

In this project, comparative study of the temperature and velocity distribution is done within the cold plate used. For decreasing the hot junction temperature of Travelling Wave Tube using both theoretical and approach as well as through simulation approach by using ANSYS R21. Some closing remarks can be made as follows,

1) By theoretical approach, decrease in temperature in hot junction is achieved about 8℃, while by numerical analysis result, the decrease in temperature is about 6℃. Which is desirable since life expectancy of electronic devices increases by every 10℃ decreases in junction temperature.

2) Ethylene glycol (50% concentration) shows higher thermal and cooling properties than water. Hence, ethylene glycol is more preferred for cooling application in cold plate.

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