Computer Aided Design, Analysis & Manufacturing Aspects of Brazed Cold Plate for TWT

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Abstract—**this paper presents an optimized cooling solution for electronic component TWT producing 2000W of power which combine both the theoretical &simulation techniques. The high-heat-flux demands on the cooling system cannot be met with air cooling, and advanced liquid cooling solutions are necessary. Designing a vacuum Brazed cold plate is to provide cooling platforms for electronic devices. Different liquid cooling techniques and types of cold plates are surveyed. This design estimates how much quantity of water is required to cool the heat load and maintain the temperature less than 90^0C.To get the minimum thermal resistance and pressure drop parameters of cold plate are estimated for different flow rates. The designed parameters of cold plate are investigated by CFD method using FloEFD software. At 6lpm cold plate has shown the desired temperature with an accepted level of pressure drop &thermal resistance. Manufacturing of the cold plate is followed by CNC programme is generated for creating of flow channels in the cold plate using Master Cam software& vacuum brazing of two half parts of the cold plates.**

Index Terms—**vacuum Brazed cold plate, optimizing cooling solution, TWT, Thermal resistance, pressure drop, Flow rate.**

NOMENCLATURE

Dh	Hydraulic diameter of cold-plate channel.
h	Heat transfer coefficient.
k	Conductivity.
Nu	Nusselt number.
P	Pressure.
q	Heat flux.
Q	Heat transfer rate.
$R_{th,coduc}$	Conduction resistance
$R_{th,conv}$	Convective resistance
t	thickness of the cold plate
A_p	Area of cold plate
L	length of flow channel in the plate Temperature.
Rc	Constriction or spreading resistance
As	Foot print or contact area of the heat source
R_0	Average heat sink thermal resistance.
ΔT	Difference between inlet& outlet fluid temperatures $(T_{fluid,out} - T_{fluid,in})$
$T_{fluid,in}$	Inlet fluid temperature.
$T_{fluid,out}$	Outlet fluid temperature.
T_{max}	Highest temperature of the wall.
$T_{fluid,avg}$	Average fluid temperature.
v	Velocity.
Δp	Pressure drop
f	Friction factor
ρ	Density of the fluid
Re	Reynolds Number

I. INTRODUCTION

The need for new cooling techniques is driven by the continuing increases in power dissipation of electronic parts and systems such low as compared to the utilized energy. The utilized energy is converted into heat energy and it should be dissipated to the atmosphere otherwise the generated heat may reduce the performance of the electronic equipment or it may completely damage system .To avoid the situation, maximum amount of heat should be removed from the system continuously. Electronics cooling using air as medium is not suitable for the heat fluxes are of 100w/cm^2.so inadequate cooing may shorten the life of components. There are several advantages of using liquid cooling over air cooling for thermal management of high power devices. First in applications where power densities exceed the limit of air cooling, liquid cooling is the only practical option. Liquid cooling facilitates a compact design to accommodate in lesser space requirement and serves better control for heat load changes and higher reliability. The objectives in the design of liquid cooling systems are to create a sufficient amount of total flow and to appropriately distribute the flow so as to maintain the electronic component temperatures at the desired level. Liquid cooling eliminates the problems associated with air cooling& suitable for up to 35w/cm^2

A heat sink is a device that transfers thermal energy from a high temperature to lower temperature fluid medium. If the Fluid medium is water then it is **a cold plate.** Consist of fluid flow space that is bounded by metallic walls, contains coolant passage through the channels created in Aluminum base plate. The wall of the cold plate (i.e. the heated surface) can be made using a high conductivity material.

The solution proposed for optimal heat dissipation of TWT (Travelling wave tube) is an electronic device used to amplify radio frequency (RF) signals to high power, usually in an electronic assembly known as a **traveling-wave tub amplifier** (TWTA).Operating frequencies range from 300 MHz to 50 GHz& carries 2Kw output power. Used as amplifiers in satellite transponders, where the input signal is very weak and the output needs to be high power Whose output drives an antenna is a type of transmitter, are used extensively in radar, particularly in airborne fire control radar systems, and in electronic wafer and self-protection systems.

TWT

II. BASIC LIQUID COOLING METHODS

A. Heat pipe:

The heat pipe itself is not a heating or cooling device. Heat pipe assemblies are used for moving heat away from the input area (for cooling) or for moving heat into the output area (heating). Heat pipe assemblies provide thermal management solutions in all mediums: liquid, solid, and gas. In most of the current electronic devices some of the interior components will usually have to be designed around the shape of the device because of the compact design. As for heat pipes, one of the reasons that it is so easy to fit inside many different devices without any major redesign is because of its ability to bend around inside a compact area. Heat pipes provide an indirect and passive means of applying liquid cooling.

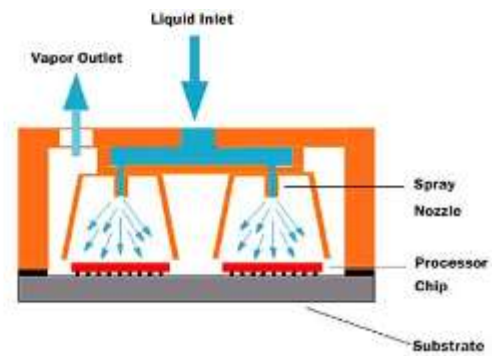
Embedding heat pipes into the cold plate is an effective cooling alternative to greatly enhance the performance of an existing heat sink with minimal design changes. Heat pipes are inserted into the grooves of a cold plate base with epoxy material or by soldering. This technique may reduce a heat sink's thermal resistance by up to 50%& Increases the plate's effective thermal conductivity by several factors without negatively affecting the plate's mass, strength, or corrosion resistance. In general, the performance of a heat pipe embedded Al plate is equivalent to that of the high end specialty composite materials, but cost much less to manufacture.

B. Liquid jet impingement:

Impingement cooling may involve a single jet directed at a single component or an array of electronic components, multiple jets directed at a single component, arrays of jets directed on an array of chips on a common substrate. The jets may be formed by circular slot shaped orifices or nozzles of various cross-sections. The space surrounding the jet may be filled with a gas, leading to a jet with a free surface. Alternately, liquid may occupy the space between the liquid space between the liquid distributor plate and the heated surface, leading to a submerged jet.

C. Spray cooling:

In recent years spray cooling has a means of supporting higher heat flux in electronic cooling applications. Spray cooling breaks up the liquid into fine droplets that impinge individually on the heated wall. Cooling of the surface is achieved through a combination of thermal conduction through the liquid in contact with the surface and evaporation at the liquid-vapor interface. The droplet impingement both enhances the spatial uniformity of heat removal and delays the liquid separation on the wall during vigorous boiling. Spray evaporative cooling with a Fluor inert™ coolant is used to maintain junction temperatures of ASICs on MCMs in the CRAY SV2 system between 70 and 85°C for heat fluxes from 15 to 55 W/cm^2. Spray cooling and jet impingement are often considered competing options for electronic cooling. In general, sprays reduce flow rate requirements but require a higher nozzle pressure drop.



D. Immersion cooling:

Direct liquid or immersion cooling is a well-established method for accommodating high heat flux backed by over thirty years of university and industrial research. With natural convection two-phase flow, generally termed nucleate pool boiling, the critical heat flux using FC-72 is in the range of 5 to 20 W/cm^2. However, much higher heat fluxes up to 100 W/cm^2 can be accommodated with surface enhancement of the heat source. The heat dissipated in the device produces vapor bubbles that are driven by buoyancy forces into the upper region of the container, where the vapor condenses and drips back into the liquid pool.

E. Electro hydrodynamic and electro wetting cooling

As an alternative to a continuous flow set into motion by either temperature differences or by mechanical means, liquid could also be formed and moved in droplets of nano-to-milliliter size by means of electric fields.

F. Cooling fluid selection: Plain water is the optimum cooling choice and will be used only in controlled environments, laboratory conditions, or requested solutions. Tap water may contain active ions or other impurities, which will attack the inside of aluminum flow channels. Given time, those aluminum channels will corrode, causing a leak path and ultimately equipment failure. That is why copper in tube or channel form is the preferred solution with water and other liquids.

More often an ethylene glycol–water solution of a given percentage is specified, since it lowers the freezing point and raises the boiling point. Corrosion inhibitors must be used if any aluminum is in the flow path, such as piping, tubes, manifolds, tanks, fittings, or cold plates. Fluids are polyolefin, gasoline, kerosene, mineral oil, transmission fluid, JP-5, seawater, etc. Matching or optimizing the available fluid to the target temperature of the heat sink is the challenge.

III. COLD PLATE CLASSIFICATION

The substrate and the fluid flow channels can be arranged in several different configurations depending on the device size and power dissipation requirement. These cold plate configurations are classified into four major types as described next.

A. Formed tube cold plate (ftc)

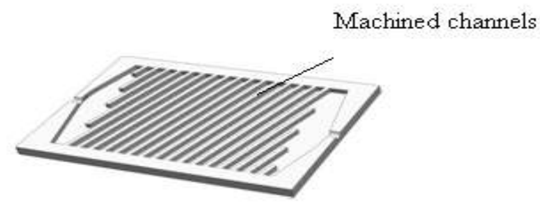
The coolant tubes are attached to the cold plate substrate by soldering or using a thermal epoxy. In this design, shown in Figure 1, copper plate is generally used, although aluminum is sometimes employed in low power applications. This is one of the simplest cold plate designs, but its performance is rather poor, limiting its use in the low-power applications.

B. Deep drilled cold plate (ddcp)

In this design, Deep holes are drilled in the plane of the substrate plate, generally made of copper. These holes are then configured with end caps (or plugs) to create coolant flow paths through the substrate. The placement of the electronic devices often influences the coolant passage layout. It is not uncommon to implement two or more parallel paths for the coolant flow to meet the pressure drop, coolant distribution, or temperature rise considerations.

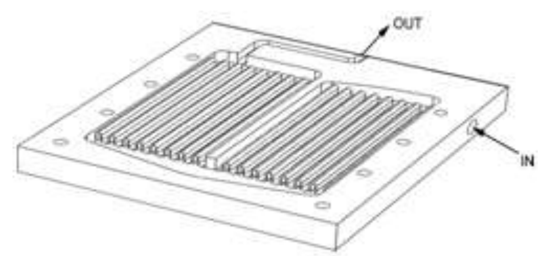
C. Machined channel cold plates (mccp)

Channels are machine-cut into the base plate and a cover is soldered in place to form the flow passages. Depending on the thermal performance desired, these channels can be several millimeters wide or as small as 200 µm wide micro channels for extremely high heat flux applications (over 100 W/cm2). Cross-rib patterns, shown in Figure or other enhancement features may be incorporated in the channels, depending on the performance requirements.



D. Pocketed folded-fin cold plates (pfcp)

The local heat transfer coefficient, as well as the surface area in the coolant passages, can be enhanced by implementing fins in the coolant passages. In this design, recessed pockets are machined to accept various folded fin inserts, which are soldered inside the passages. Similar to MCCP, a cover plate is soldered in place to form the enhanced flow channels.



Other designs include straight fins with square edges, straight fins with rounded edges, herringbone, ruffled, lazy ruffled, lanced, offset, lanced and offset, perforated, and triangular in all the designs just described, appropriate provisions are made for coolant inlet and outlet locations. Depending on the heat flux, total heat removed, and available pressure drop, a specific design may be selected. The cost is an important factor.

E. Brazed

There are three common types of brazed plates, Vacuum, Dip and Controlled Atmosphere. All internal fluid path cold plates need to be carefully pressure tested to make sure that parts are completely sealed. Internal fluid leakage from one cooling path to another inside the cold plate usually cannot be detected and some level of internal leakage should be allowed on the thermal design.

After machining two halves of the cold plate, they are assembled by the following procedure of vacuum brazing process.

F. Vacuum brazing

This process follows mainly three steps. Initially the two halves of the parts are joined together with the filler metal processed with in a heat controlled high vacuum chamber. The vacuum means that no air pockets or contaminants will be trapped and a solid metallurgical joint is made. Parts can be very thin-walled and this is good in applications where weight is important, such as aircraft parts. The big drawback is that this is a very expensive process

IV. PROBLEM DESCRIPTION

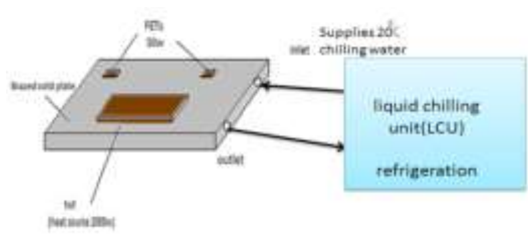
Our cold plate design is a compact in size which has with dimensions 570mmx396mm and height of 16mm.The proposed cooling system will combine the simplicity and Compactness of the heat sink method with the large heat dissipation that is achieved through liquid flow channels in the cold plate.Water+20%ethyleneglycol is taken as the cooling fluid with desired properties. Two heat sources TWT& two FETs with dimensions of 282x80x16mm 25x25mm carrying 2000W&50W each FET, attached directly on to the top cold plate and cooled using forced convection. The heat sink that will circulate the fluid throughout the structure.

TABLE: Summary of design model dimensions& heat fluxes

Elements	Dimensions Mm	Heat source W	Heat flux w/cm^2
Cold plate	590x396x16	-	-
TWT	282x80x5	2000	88.65
2 FETs	25x25	50	16

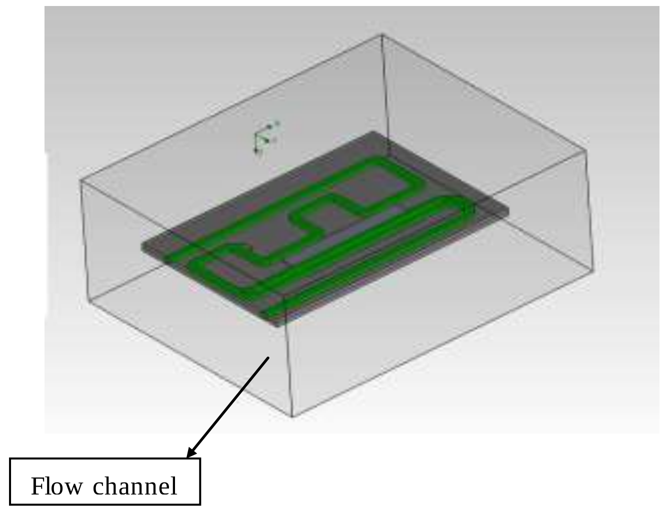
Overview of design approach

To design a liquid cold plate, type of liquid, fluid and system pressure, fluid flow, inlet temperature, cold plate weight, type of material, and the allowable or desired pressure drop are major factors in the cooling system design. The first challenge is to decide on the required flow rate and to fix the pump characteristic. The liquid cooling system consists of a cold plate, Liquid chilling unit (LCU), & water pipeline which supplies the chilling water at 20 c to inlet and receives the hot water from the outlet of the cold plate. LCU contains a Refrigeration unit to chill the hot water from outlet. Here the work scope is design the vacuum brazed cold plate by considering the water at 20^{o}c.The cold plate cooling capabilities depend primarily on the heat transfer coefficient (h) of the fluid flow boundary layer, which exists at the inner wall of the cooling passages.



liquid cooling system

The cooling ability of cold plate is based primarily on conductive and convective heat transfer, with radiation playing minimal role. Heat is conducted through the semiconductor or electronic device to the heat sink interface. It is then transferred by conduction from the inner wall of the heat sink cooling passages through a boundary layer of semi-stagnant fluid layer into the main bulk of moving fluid. The heat is carried away with the moving fluid. The conductive properties of the cold plate material dictate its temperature rise as heat is transferred into the moving fluid. Fig shows the half part of cold plate with rectangular flow channel



Input parameters of the cold plate:

Density (ρ): 1017Kg/m^3
Kinematic viscosity (c_p): 1.16x10 $^{-6}$m^2/s
Thermal conductivity of plate (k): 180W/mk
Thermal conductivity of fluid (k): 0.53W/mk
Prandtl number: 17.1

Consider the schematic arrangement shown in Figure 6a where all devices are placed on a cold plate with the coolant serving them in plate. By considering the inlet flow volume from 2, 4, 6&8, 10 Lpm. The basic heat transfer/fluid flow relations take the following form.

Determining the heat transfer Coefficient:

Type of the flow can be calculated the from the given flow rate by using the following formula

$$Re = v\, d/v$$

Nusselt number:

$$Nu = 0.023\ Re^{0.8}\, Pr^{0.4} = h\, D/k$$

Thermal resistances:

The temperature difference between an electronic component and a cooling fluid (air or other gas or **liquid)** is determined by the thermal resistance between its surface and the cooling fluid passing through or past a cold plate heat sink attached to it. This resistance is due to three factors, the conduction resistance associated with the finite thermal conductivity of the heat sink, the convective resistance at the heat sink-cooling fluid interface, and spreading resistances or constructional resistance is used to describe the case where heat flows out of a narrow region into a larger cross sectional area.

$$R_t = \frac{(T_{max} - T_{fluid,avg})}{Q/A} = R_{th,coduc} + R_{th,conv} + R_c$$

$$= \frac{t}{A_p k} + \frac{1}{h \pi D L} + R_c$$

Where,

$$R_c = \frac{\sqrt{A_p} - \sqrt{A_s}}{k\sqrt{\pi A_p A_s}} \times \frac{\lambda k A_p R_0 + \tanh(\lambda t)}{1 + \lambda k A_p R_0 \tanh(\lambda t)}$$

$$\lambda = \frac{\pi^{3/2}}{\sqrt{A_p}} + \frac{1}{\sqrt{A_s}}$$

Newton's law of cooling for temperature of fluid,

$$Q = m\, c_p\, \Delta T$$

Since the coolant outlet temperature is the highest near the exit, it is important to check if the maximum allowable device temperatures near the exit are exceeded.

$$\Delta T = T_{fluid,out} - T_{fluid,in}$$

And, $Q = (T_{max} - T_{fluid,avg}) / R_{total}$

The total pressure drop with an equivalent fluid flow resistance in the coolant passages from the inlet to exit is given by:

$$\Delta p = v^2 \text{ x f x L} x \rho \text{ / (2 D)}$$

Pressure drop at the bends, $\Delta p = 1/2 \, x \rho x v^2$

V. SIMULATION METHOD

The detailed flow field and heat transfer characteristics inside the cold-plate for 6lpm as the inlet flow rate is investigated by computational fluid dynamics using FloEFD software, it analyze a wide range of complex problems including: 2D and 3D analyses, External and Internal flows, Steady-state and Transient flows, Heat transfer in solids only (no fluid exists in the analysis). FloEFD provides accurate results regardless of the model complexity. The heat source generated at constant power 104.65 W/cm^2 with a thickness of 5mm is placed over the cold plate. Boundary conditions such as the ambient temperature 55^{0}c, environmental pressure at out let of the fluid flow channel are applied to the model. The inlet temperature of the water is fixed and the flow analysis automatically generates the mesh.

VI. RESULTS AND DISCUSSIONS

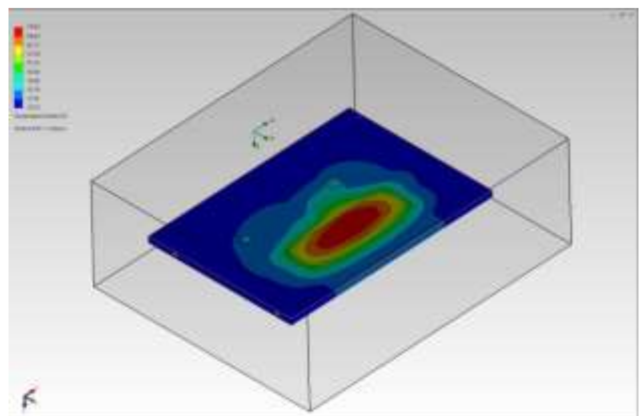
Calculated results for various inlet flow rates, 6lpm has the shown the optimizing cooling solutions for the electronic component TWT is shown in table. For the flow rate of 6 lpm, the designed parameters are shown in simulation process. The temperature decrease with the increase in flow rate and causes the rapid increases in pressure drop.

Table: summary of calculated results for various inlet flow rates.

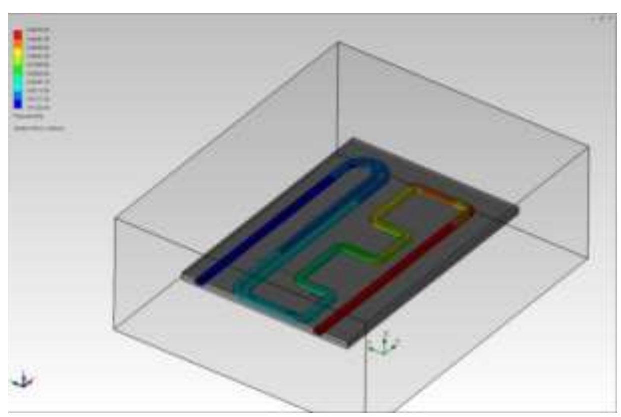
Liquid flow rate(lpm)	Velocity m/s	Resistances °c /w	T_{max} °c	Pressure drop (Δp) pa
2	0.26	0.0364	100.3	1237.3
4	0.518	0.027	79	2504
6	**0.8**	**0.023**	**69**	**3567**
8	1.036	0.020	62.16	5762.65
10	1.3	0.0176	56.82	9476.62

Simulation results for inlet flow rate 6lpm:

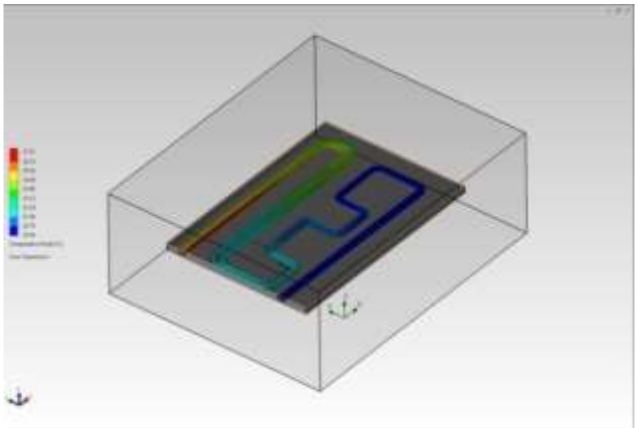
Maximum temperature in solid 74.93^{0}c



Pressure drop: 3554 pa.



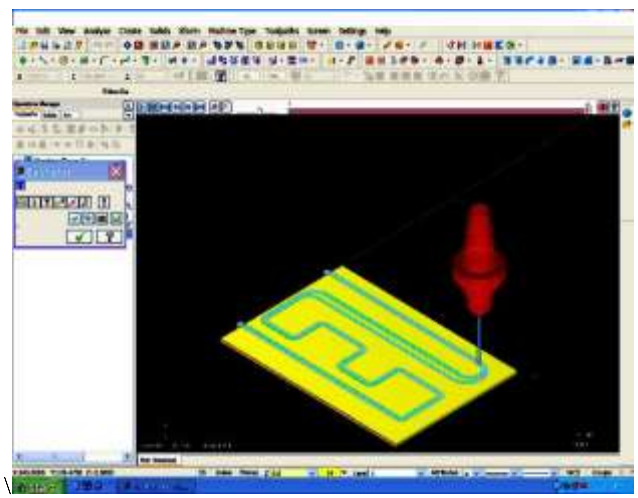
Temperature of the fluid: 27^{0}c



MANUFACTURING OF VACUUM BRAZED COLD PLATE:

Raw material Aluminum alloy- 6063

The modeling of the designed part is done in solid works software, now the part is exported in master cam software to create flow channels in cold plate on CNC vertical milling machine as shown in fig.,



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VACUUM BRAZING: After machining the two parts, this process follows mainly three steps:

Initially the two halves of the parts are joined together with the filler metal processed with in a heat controlled high vacuum chamber of 10 torr with temperature of 521℃ for 20 minutes,after finishing the first process, temperature should be maintained with 590 ℃ for 10 minutes in second step. In the last operation 150 ℃ temperature & parts are kept in high vacuum for 8 hours. This completes the total fabrication of cold plate.

VII. CONCLUSION

The flow and heat transfer characteristics for the cold-plate is simulated in this study. Vacuum Brazed cold plate is to provide cooling platforms for an electronic device TWT. Different liquid cooling techniques and types of cold plates are studied. This design estimate the required quantity cool the heat load and maintain the temperature less than 90^0C.To get the minimum thermal resistance and pressure drop parameters of cold plate are estimated for different flow rates. The designed parameters of cold plate are investigated by CFD method using FloEFD software. At 6lpm cold plate has shown the desired temperature with an accepted level of pressure drop &thermal resistance. Manufacturing of the cold plate is followed by CNC programme is generated for creating of flow channels in the cold plate using Master Cam software& vacuum brazing of two half parts of the cold plates.

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N376 G1 X66.5
N378 G3 X58.975 Y98.6 R7.525
N380 G1 Y65.2
N382 G2 X54.5 Y60.725 R4.475
N384 G1 X15.
N386 G2 X10.525 Y65.2 R4.475
N388 G1 Y121.5
N390 G2 X23. Y133.975 R12.475
N392 G1 X245.
N394 G3 Y179.525 R22.775
N396 G1 X0.
N398 X-4.525
N400 Y176.475
N402 X0.
N404 X245.
N406 G0 Z1.
N408 X23. Y144.975
N410 Z.5
N412 G1 Z-.75 F10.
N414 G3 X8.675 Y132.577 R14.475 F350.
N416 X12.961 Y130.564 R2.475
N418 G2 X23. Y135.025 R13.525
N420 G1 X245.
N422 G3 X266.16 Y161.672 R21.725
N424 X261.275 Y161.129 R2.475
N426 G2 X245. Y144.975 R16.275
N428 G1 X23.
N430 X32.218 Y146.025
N432 X245.
N434 G3 X256.221 Y171.541 R15.225
N436 G1 X258.87 Y171.843
N438 X260.45 Y169.368
N440 X261.887 Y165.655
N442 X263.397 Y165.903
N444 X261.407 Y169.12
N446 X258.87 Y171.843

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N452 G2 Y146.025 R15.225
N454 G1 X23.
N456 G3 X7.475 Y130.5 R15.525
N458 G1 Y65.2
N460 G3 X15. Y57.675 R7.525
N462 G1 X54.5
N464 G3 X62.025 Y65.2 R7.525
N466 G1 Y98.6
N468 G2 X66.5 Y103.075 R4.475
N470 G1 X127.5
N472 G2 X131.975 Y98.6 R4.475
N474 G1 Y65.2
N476 G3 X139.5 Y57.675 R7.525
N478 G1 X179.5
N480 G3 X187.025 Y65.2 R7.525
N482 G1 Y98.6
N484 G2 X191.5 Y103.075 R4.475
N486 G1 X252.5
N488 G2 X256.975 Y98.6 R4.475
N490 G1 Y42.5
N492 G2 X252.5 Y38.025 R4.475
N494 G1 X0.
N496 X-4.525
N498 Y34.975
N500 X0.
N502 X252.5
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N508 G3 X252.5 Y106.125 R7.525
N510 G1 X191.5
N512 G3 X183.975 Y98.6 R7.525
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N526 G1 X66.5
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N538 G1 Y121.5
N540 G2 X23. Y133.975 R12.475
N542 G1 X245.
N544 G3 Y179.525 R22.775
N546 G1 X0.
N548 X-4.525
N550 Y176.475
N552 X0.
N554 X245.
N556 G0 Z1.
N558 X23. Y144.975
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N562 G1 Z-1. F10.
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N570 G1 X245.
N572 G3 X266.16 Y161.672 R21.725
N574 X261.275 Y161.129 R2.475
N576 G2 X245. Y144.975 R16.275
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N592 X263.397 Y165.903
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N596 X258.87 Y171.843
N598 X254.149 Y173.419
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N602 G2 Y146.025 R15.225
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N608 G1 Y65.2
N610 G3 X15. Y57.675 R7.525
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N614 G3 X62.025 Y65.2 R7.525
N616 G1 Y98.6
N618 G2 X66.5 Y103.075 R4.475
N620 G1 X127.5
N622 G2 X131.975 Y98.6 R4.475
N624 G1 Y65.2
N626 G3 X139.5 Y57.675 R7.525
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N638 G2 X256.975 Y98.6 R4.475
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N642 G2 X252.5 Y38.025 R4.475
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N646 X-4.525
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N792 G2 X252.5 Y38.025 R4.475
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N802 X252.5
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N806 G1 Y98.6
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N854 X245.

N856 G0 Z1.

N858 X23. Y144.975

N860 Z-.25

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N866 X12.961 Y130.564 R2.475

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N874 X261.275 Y161.129 R2.475

N876 G2 X245. Y144.975 R16.275

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N896 X258.87 Y171.843

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N902 G2 Y146.025 R15.225

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N906 G3 X7.475 Y130.5 R15.525

N908 G1 Y65.2

N910 G3 X15. Y57.675 R7.525

N912 G1 X54.5

N914 G3 X62.025 Y65.2 R7.525

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N918 G2 X66.5 Y103.075 R4.475

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N928 G1 X179.5

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N942 G2 X252.5 Y38.025 R4.475

N944 G1 X0.

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N950 X0.

N952 X252.5

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N956 G1 Y98.6

N958 G3 X252.5 Y106.125 R7.525

N960 G1 X191.5

N962 G3 X183.975 Y98.6 R7.525

N964 G1 Y65.2

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N980 G1 Y65.2

N982 G2 X54.5 Y60.725 R4.475

N984 G1 X15.

N986 G2 X10.525 Y65.2 R4.475

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N998 X-4.525
N1000 Y176.475
N1002 X0.
N1004 X245.
N1006 G0 Z1.
N1008 X23. Y144.975
N1010 Z-.5
N1012 G1 Z-1.75 F10.
N1014 G3 X8.675 Y132.577 R14.475 F350.
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N1064 G3 X62.025 Y65.2 R7.525
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N1068 G2 X66.5 Y103.075 R4.475
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N1072 G2 X131.975 Y98.6 R4.475
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N1124 G3 X127.5 Y106.125 R7.525
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N1140 G2 X23. Y133.975 R12.475
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N1156 G0 Z1.
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N1164 G3 X8.675 Y132.577 R14.475 F350.
N1166 X12.961 Y130.564 R2.475
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N1262 G3 X183.975 Y98.6 R7.525
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N1284 G1 X15.
N1286 G2 X10.525 Y65.2 R4.475
N1288 G1 Y121.5
N1290 G2 X23. Y133.975 R12.475
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