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Technical Description

Liquid Cooling of Hubmount TWTAs

Background

Liquid cooling was once the primary method for keeping high power microwave tubes and amplifiers and transmitters from overheating. The necessity to achieve strong uplink signals using the high power, inefficient components available at the time resulted in high heat dissipation. This in turn drove the requirement to use highly effective cooling methods to maintain a reasonable level of reliability, even if they were inconvenient or costly to maintain. Over the following decades, improvements in system satellite design, particularly the introduction of lower noise receivers and antenna design, reduced the need for such high-strength signals. The resulting decrease in prime power usage due to these improvements allowed system designers to use air-cooled amplifiers almost exclusively, leading to major cost savings and requiring less maintenance.

In the last two decades, however, system designers have begun to move uplink equipment, especially higher frequency components, adjacent to or into the transmitting antennae in order to reduce path loss and thereby maximize performance. With physical space at a premium in antenna hubs, air conditioning is often impractical to implement and acoustic noise from fans is often a health and safety problem for employees, and an annoyance for neighboring properties. These modern day requirements have caused engineers to reconsider the quiet, highly efficient liquid cooling methods in their system designs.

Air cooling systems do have design challenges, typically requiring:

- air conditioning, or at a minimum, intake and exhaust venting;
- the use of air ducting to the high power amplifiers (HPAs), using valuable space; and
- sufficient space between HPAs so that heat may be dispersed more efficiently.

Because of the ever increasing value of every bit of physical space in earth stations and the potential for liquid cooling to save some of that space, liquid cooling is now an option that is increasingly considered.

Liquid Cooling Basics

Liquid cooling can be the best option where space is tight and heat is concentrated. Benefits include:

- Flexible locations: liquid cooling system’s heat removal sub-systems can be located either close to the amplifiers or placed further away
- Liquid cooling lines take up less space than traditional air cooling ducts
- Liquid cooling methods can be used over a typical range of ambient temperatures, typically -40°C to +60°C (same as traditional forced air cooling systems)

The main requirement, whether using an air cooled or liquid cooled HPA, is to keep the amplifying devices at a reasonable temperature to ensure optimum performance and to maximize MTBF. In the case of liquid cooled HPAs, minimum liquid flow rates and coolant temperatures need to be maintained to effect reliable cooling of the active devices in an amplifier.

It is important to maintain the temperature of the cooling liquid within a ±10°C range to reduce RF output power drift. In air cooled HPAs, the temperature is typically regulated by managing the air volume via the cooling blower or fan, which in turn is used to cool the heat sink. Regulating the coolant temperature in a liquid cooling system when a recirculating heat exchanger is used requires an active control system to ensure the temperature is kept as constant as possible.

In environments where temperatures reach below freezing, liquid cooling systems require glycol to be added to the coolant to prevent the water from freezing. In extremely cold environments, an additional liquid heater option may be required. Both air and liquid cooling systems require regular maintenance and monitoring.

CPI recommends that system designers review each installation separately, and complete a cost/benefit analysis for the cooling options for each site. This analysis should indicate the return to the user on the possible added cost of a liquid cooled system versus a traditional air cooled system. That cost analysis should include a review of existing infrastructure, since existing liquid cooling infrastructure in many building HVAC systems may be used for liquid cooling of equipment.

Benefits of a liquid cooling system approach

1- As much as a 30% decrease in the required amplifier mounting space can be achieved in a liquid cooled versus an air cooled HPA mounting design, allowing more room for other equipment or more amplifiers.
2- The hub air conditioning requirement and the mounting of air conditioning units at the antenna hub will be greatly reduced, or eliminated.
3- A liquid cooled amplifier will allow the mounting amplifiers to be closer together, possibly reducing RF losses.
4- Properly operating and cooling a liquid cooled amplifier may result in a lower constant operating temperature, resulting in a longer MTBF for the amplifier (due to the overall higher efficiency of liquid cooling).

An air cooled system might be more effective:

1- If a constant, stable-pressure, unlimited source of liquid at a constant temperature is not available requiring the investment in a heat exchanger and the related infrastructure.
2- If operational requirements demand redundant liquid cooling systems or multiple heat exchangers in order to maintain HPA system output and prevent a transmission outage.
3- If the site operator determines that periodic maintenance of the liquid cooling system(s) and related infrastructure would be a considerable burden (financially or otherwise).

CPI LIQUID COOLED HPA's

The following is a partial list of SATCOM commercial amplifiers available with liquid cooling systems, along with their heat dissipation specifications. Full heat exchanger details are at the end of this document.

TL05KO heat to coolant = 900W, heat to room = 100W

TL12UO heat to coolant = 1600W, heat to room = 150W

T07UO heat to coolant = 1750W, heat to room = 150W

T07CO heat to coolant = 1750W, heat to room =150W

HPA cooling design

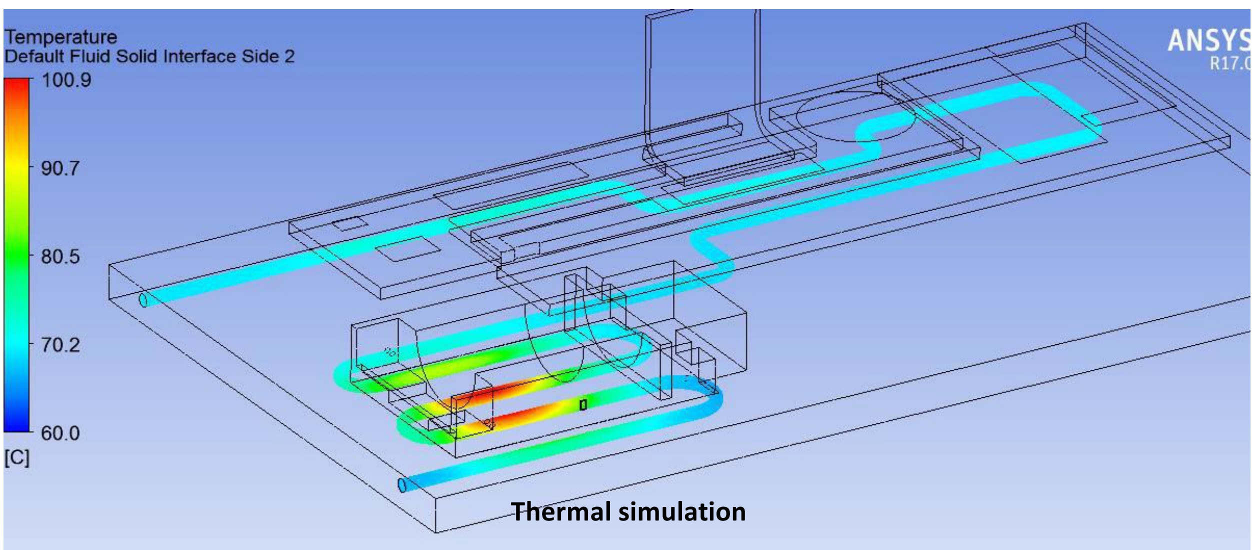
The proprietary design in CPI amplifiers configured for liquid cooling utilizes copper pipes embedded into an aluminum baseplate of the amplifier for transport of the cooling liquid and dissipation of the heat generated by the active components. Using a single type of metal or non- metal components in a cooling system is important to prevent contamination of the cooling fluid in the cooling system. Dissimilar metals can cause galvanic corrosion which can cause the system to fail.

The minimum specified liquid flow rate for liquid cooling of most CPI amplifiers with this option is 1 gallon per minute (GPM) of 60°C liquid. This provides for maintaining the TWT baseplate below the maximum temperature with margin. This is achieved through the fact that typical air cooling keeps the HPA's TWT baseplate operating temperatures at around 45°C for most installations. A liquid temperature of 45°C or less keeps the HPA assembly at a temperature comparable to what is found in a typical air-cooled HPA. Temperatures cooler than 45°C are preferable, though temperature stability is also important. Typically, cooling water from an existing building HVAC system ranges from 40°F to 50°F (4°C to 10°C) and can easily support between 1 GPM of flow to each amplifier. It should be noted that CPI's TWT manufacturing facility successfully use building air conditioning water for cooling water during manufacturing of liquid cooled TWTs.

Some features of CPI's liquid cooled amplifier designs:

- The HPA baseplate includes an insulation layer external to the sealed enclosure to prevent condensation from forming, for applications in which the ambient air temperature is below the dew point.
- A thermistor (for temperature sensing) is always embedded in the hot spot region of the baseplate, in the TWT collector area. For liquid cooling design, this can be used as a monitor or control signal for an external cooling system.
- The HPA has maximum temperature limit shut down. However some external temperature, flow, or other monitor could be connected to the HPA interlock Fault.
- The volume of coolant for each amplifier will vary by model.

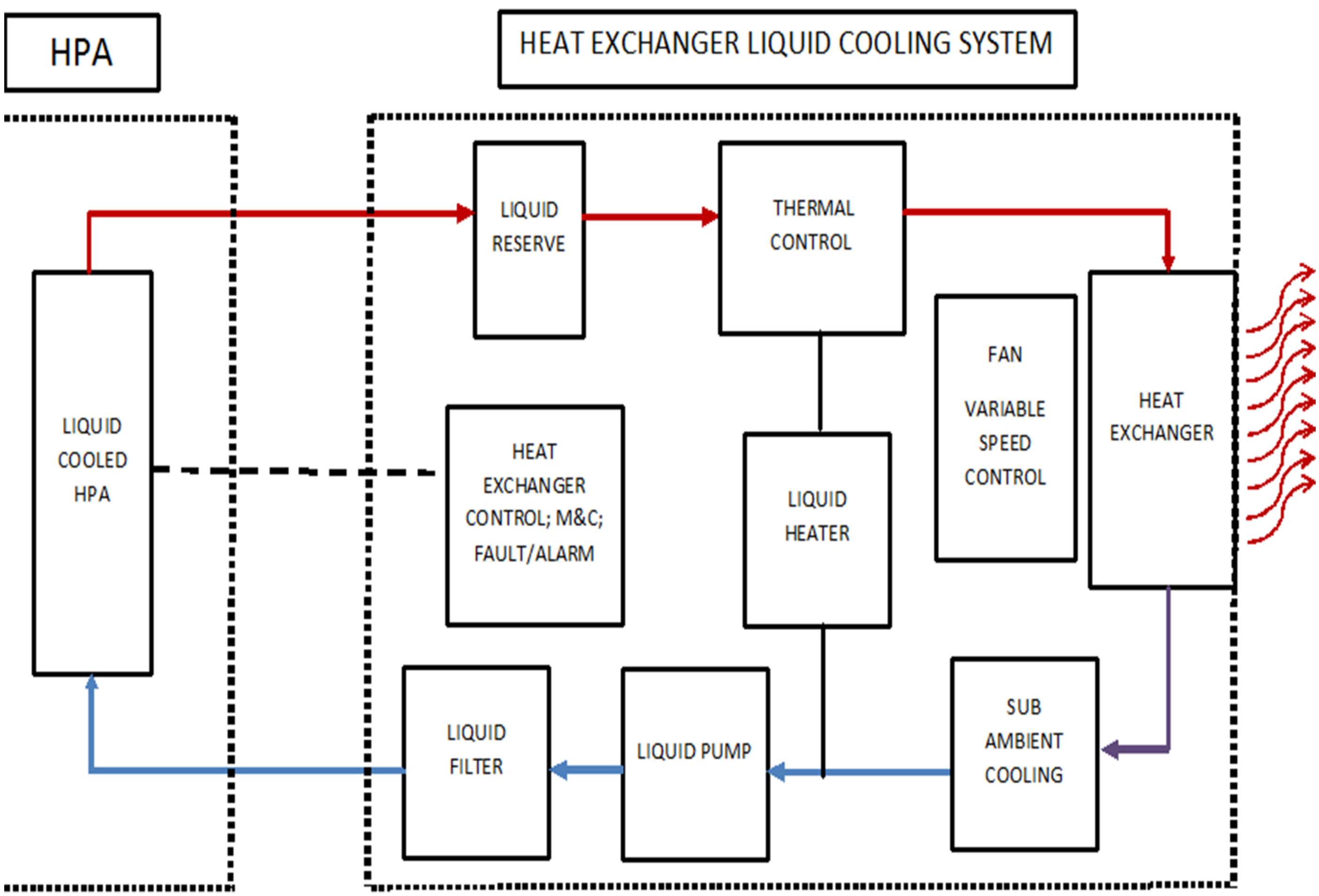
The figure below shows the path of the copper pipes and the hot spots situated under the power supply modules and the TWT collector, with the fluid inlet on the power supply side and fluid outlet on the TWT/RF side.



Cooling system and HPA interlock

The HPA has an external interlock that will disable or fault out the HPA power supply in a condition where the cooling water is interrupted and no cooling water is available. It is highly recommended that this be used in conjunction with some sort of flow monitor to interlock the HPA and the liquid cooling system. Failure to do this could result in overheating and possible damage to the HPA and TWT. It is more likely damage would occur in a situation where the flow is reduced vs a complete failure or stoppage of water flow. A degraded flow rate can overheat or cause the HPA to operate at the thermal limit.

Liquid Cooling Systems



EXCHANGER BLOCK DIAGRAM

Considerations for liquid cooling of your HPAs

An amplifier liquid cooling approach may be a good idea if:

1- The amplifier is going to be used in an antenna hub and space for all the required equipment is limited and the use of an air cooled system is not possible.
2- A multiple redundant/high frequency amplifier system requires minimal space and minimal distance between amplifiers to reduce RF loss.
3- There is already installed a reliable, stable pressure, liquid source (water or water/Glycol) at a constant temperature (filtering and pressure regulation may still be required).
4- The HPA will be exposed to an environment where the ambient temperature requires a sub-ambient cooling system.

Technical specifications (for liquid cooling systems) to be considered:

NOTE: Keep in mind that acceptable generic systems as well as custom systems are available, with costs appropriate to either selection.

Keeping the temperature of the cooling liquid low allows the heat exchanger to operate over a wider temperature range. Maintaining the liquid temperature at a high temperature requires much more heat exchanger thermal capacity to remove the heat from the coolant.

A typical heat exchanger that will operate over an ambient temperature range of -10°C to +50°C will need to have its liquid operating temperature centered at 20 to 28°C.

- When considering a liquid cooling system, the user will have to consider
  - If in an outdoor environment: Protection from direct rain and dirt, dust and sun, and the costs of such a shelter versus investing in a fully environmentally sealed heat exchanger
  - Ambient or sub-ambient cooling

    The HPA thermal load of all the HPAs in the system should be considered when determining the operational temperature of the coolant prime power

    The availability and reliability of single phase or multi-phase power and its impact on the liquid cooling system

Pressure requirements

- Pressure drops in the cooling system. The cooling system needs to be designed to overcome the pressure drop of connections, valves, and manifolds; as well as piping type and distance.
  - Flow
- Flow requirements for single or multiple HPAs
  - Temperature regulation
- Required regulation to maintain output RF stability

- Control and monitoring system (local/remote)
- Reservoir volume
  - How much buffer is required for cooling fluid stability?
    When a leak occurs how much time will pass depends on the reservoir's volume before the backup cooling system needs to kick in redundancy
  - Multiple HPAs with one heat exchangers per HPA?
  - Standby or redundant heat exchanger?
- Maintenance
  - Filter replacement, radiator cleaning, and leak-inspection should be performed at regular intervals
  - De-Ionized water is possibly an option to maintain water purity to reduce maintenance intervals

Water cooled system maintenance

Whether air or liquid cooling, all parts of the cooling system must be maintained to minimize any heat transfer resistance. Blocked fins, blocked radiators, resistance in the cooling air path, poorly maintained cooling liquid, contaminated cooling lines or various other issues can degrade the efficiency and performance of the cooling system. Once the system cost is justified and purchased, maintenance of the system will become an on-ongoing requirement.

Maintenance cost for liquid versus air may be slightly more for liquid due to liquid system filters. Periodic cooling system cleaning is required in an air cooled system as well as in a liquid cooled system.

Having someone that knows how to maintain a liquid cooling system might be difficult. Maintenance of a water cooling system may require some special training.

Conclusion

As described above there some considerations on the need to use liquid cooling over air must be established. Once a CPI HPA product is chosen then some advice and applications information for use of that specific product can be acquired from CPI sales and the CPI applications group. Each amplifier is unique in its flow and power dissipation requirements.

Typical heat exchanger specification data sheet:

Description: Closed loop self-contained sub-ambient air-to-water temperature-regulated system. System sized for one TL12UO liquid cooled outdoor HPA

Cooling system specifications		
Specification	Spec limits	Comments
Cooling media	100% water or 50/50 water/glycol	
Reservoir volume	Minimum 2 gallons	Designed to maintain thermal control
System coolant operating temperature range	+25°C	
Temperature stability	+/- 10°C; set to 25°C nominal operating temperature	
Heat exchanger capacity	2 kW @ 8°C rise between inlet and outlet coolant ports	
Flow rate	1.8 gallons per minute (6.8 liters per minute)	
Connections	Output and input quick disconnect	The amplifier connector types (and mating connector) detail can be found on the outline drawings of the various models that have liquid cooling.
Pressure	50 psi (3.4 bar)	
Over pressure limit valve	60 psi (4.1 bar)	

Mechanical and environmental specifications		
Heat exchanger Operating ambient air temperature in a covered outdoor environment	-10°C to +50°C	
Humidity	Outdoor environment 100% condensing	
Altitude	Sea level to 10,000 feet (3 km)	
Electrical	208/240 volt AC ±10% single phase, 50/60 Hz	
Dimensions	TBD	

Control and monitoring specifications	**UNITS**	**LOCAL OR REMOTE CONTROL AND MONITOR**
Serial or Ethernet M&C	PROTOCOL	
Liquid Temperature	DEG	Remote
Temperature limits set	High and low	Remote
Temperature limit fault	Indicator / sum fault	Local indicator
Coolant temperature set	Set in degrees C	Remote
Low Flow fault	Indicator / sum fault	Local indicator and remote status bit
Loss of pressure fault	INDICATOR / sum fault	Local indicator and remote status bit
Summary fault	INDICATOR	Local indicator, dry contact, remote status bit
Over pressure indicator	Indicator / sum fault	Local indicator remote status bit
Over pressure valve	MECHANICALLY FIXED	
Water level low indicator	Indicator / sum fault	Local indicator and remote status bit

Maintenance specifications		
Removable / replaceable water filter		
Accessible Drain and fill		
Removable and replaceable DI filter (if option exists)		
Replaceable exchanger air filters		