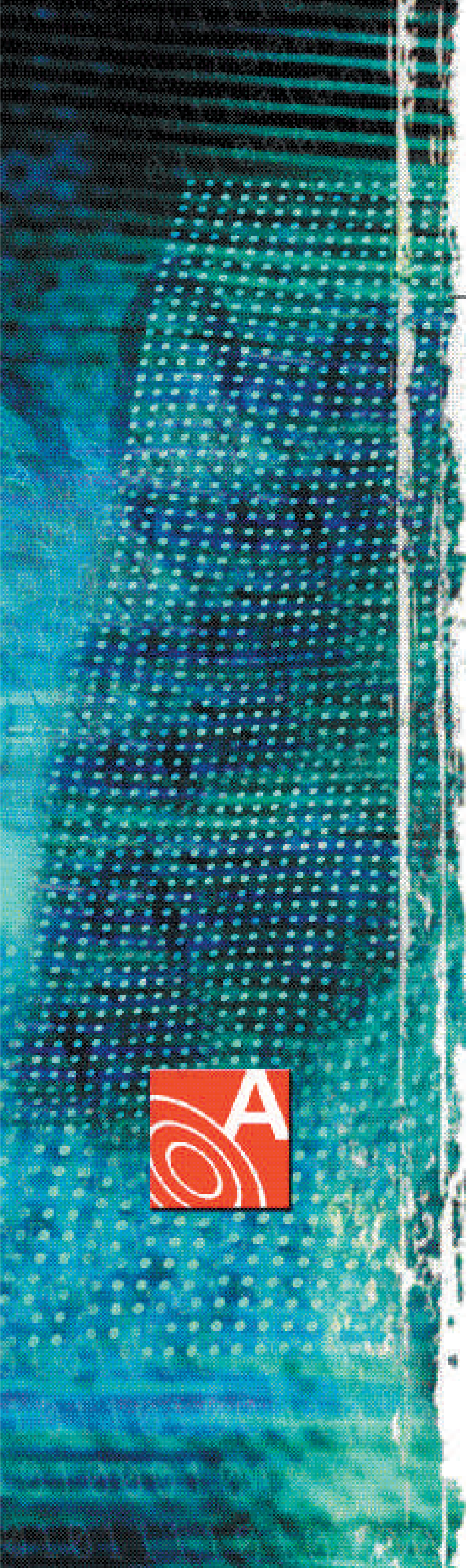

TechNotes

Technical Reference for the RF Engineer from the RF Experts

No. 11 August 2002

Thermal Considerations for RF Transmitters

Introduction

When designing transmitter products, special attention must be given to the thermal aspects of the design process in order to ensure a highly dependable and reliable product. In order to achieve this goal, many physical challenges must be considered, including environmental impact, device power and size constraints, time to market, price constraints, customer expectations, and maintenance. This paper will explore the various thermal solutions present in RF transmitter products, explain each type, and describe the methodology used for implementing each solution.

Industry Trends

Historically, passive thermal design methods were used for determining product cooling requirements. In some cases, designers would add fans and/or heat sinks where they would fit, many times after the discovery of a particular hot spot. This philosophy has changed with the ever-increasing need for higher power, more reliable transmitter products. This demand has increased heat dissipation levels in a highly competitive market, making it a challenging effort to balance thermal solutions and cost while ensuring that customers' expectations for reliability and dependability are met.

Recent industry trends have been geared toward trying to minimize the costs of operating and maintaining transmitters. Transmitter designers have looked at ways to reduce the ever-increasing energy costs by keeping the internal components temperatures at their upper limits by reducing airflow and/or fluid flow through the unit. This philosophy not only introduces higher stresses on heat sources, but can also cause unexpected or premature failures in surrounding components. While this would seem like a lower cost, more efficient means of cooling a transmitter, it has the potential be just the opposite if component failures force significant transmitter downtime. Reliability of electronic components is highly dependent on operating temperatures. For silicon devices, and other electronic components such as electrolytic capacitors, life expectancy doubles for every 10° C reduction in temperature. With this in mind, it is easy to understand the importance of a good cooling system and why it should not be overlooked or compromised during the design process.

Cooling System Types

There are generally two main cooling methods for transmitters that keep heat source junction temperatures within their operating range. The designer's objective is to choose the best approach for each particular case while keeping in mind all possible obstacles at the reasonable cost to the customer. These methods are air-cooling and liquid-cooling, both of which have specific benefits. Air-cooled systems are the preferred method unless conditions exist in which air-cooled units no longer provide sufficient cooling capacity, such as in the highest power transmitter applications. Solid state transmitters generally use air-cooling methods (with a few exceptions), while tube transmitters use both air and liquid-cooling methods.

An air-cooled system usually consists of a fan or blower that moves air via ducting through the system across heat sinks and removes the heat from the product. This type of system generally is lower in cost, less complex, and usually it can be sized within a smaller area than that of liquid-cooled systems. Air-cooled systems can be configured as closed or open loop systems that re-circulate air or allow fresh air into the system. Additionally, while a leak in a liquid-cooled system is likely to cause a system shutdown, a well-designed air-cooled system will usually continue to operate even if leaks are introduced into the system.

A liquid-cooled system offers an advantage over an air-cooled system in terms of heat transfer coefficients (its ability to remove heat), but it is generally more complex and expensive. Liquid-cooled systems generally consist of a pump moving water, a water-glycol mixture, or oil across the heat source(s) in order to remove the heat. The heated liquid is then transported through a heat exchanger that dissipates the heat into the surrounding air. Liquid-cooled systems use a closed loop architecture.

There are also differences between liquid types. Pure water provides the best heat transfer coefficient followed by water-glycol and oil. Water-glycol mixtures are used in climates where the potential for freezing is present because of its low freezing point characteristics. Special oil and de-ionized water are occasionally used in applications where electrical conductivity is a concern due to their insulating properties. The reasons for using each should be considered in the system design process.

Theory

One of the first tasks for designing a cooling system is to determine the appropriate operating conditions for the heat source components that will ensure a dependable and reliable product. Component manufacturers can supply the necessary information such as power dissipation, thermal resistance, maximum temperatures, and flow rates in order to design the system. From this information, a designer can determine the heat transfer from the heat source to the air. These principles can be derived from the following basic equations for conduction and convection heat transfer:

1 $$Q = (T_2 - T_1) / R_{th}$$

When

Q	Heat Flow
$(T_2\text{-}T_1)$	Thermal Potential Difference
R_{th}	Thermal Resistance

2 $$Q = H \times A(T_w - T_a)$$

When

Q	Heat Flow
H	Convection Heat Transfer Coefficient
A	Surface Area
$(T_w\text{-}T_a)$	Thermal potential difference between heatsink wall and air

Another step is sizing the blower(s), fan(s), or pump(s). The designer must determine the correct flow rate of the fluid that will keep the heat sources at its predetermined desired temperature. In addition, the designer must calculate the total dynamic head through the system and size accordingly.

3 $$(P_1/\gamma) + (V_1^2/2g) + z_1 = (P_2/\gamma) + (V_2^2/2_g) + z_2 + h_L$$

Where

P	Pressure
γ	Specific Weight
V	Fluid Velocity
g	Acceleration of Gravity
z	Vertical Elevation
h_L	Head Loss in Ducting, Fittings, Filter, etc.

This head loss can be determined using the energy equation:

Proper Installation

Air-Cooled Systems

As discussed in the previous section, when designing an air-cooled system one must first determine the appropriate operating junction temperature of the devices at the expected extreme environmental conditions and determine the appropriate airflow that is required to achieve this goal. High ambient temperatures and altitudes must be considered due to physical changes in air properties that change the mass flow of the air and reduce its capability to transfer heat. Ducting sizes and lengths as well as filter selection must be considered as they will impact the system pressure drop and potentially impact the blower or fan sizing.

Heat sink design is also vital in reducing the junction temperatures of heat source devices. A heat sink is a device, commonly made from aluminum, that increases the surface area between solid to air. Generally, the transfer of heat by means of convection is the least efficient. The increased surface area increases the amount of heat removed from the device, making the components run cooler and more reliably. This is achieved in a relatively small volume by creating closely spaced fins that allow air to flow between them. To ensure proper conduction of heat between the power device and heat sink, thermal compound is

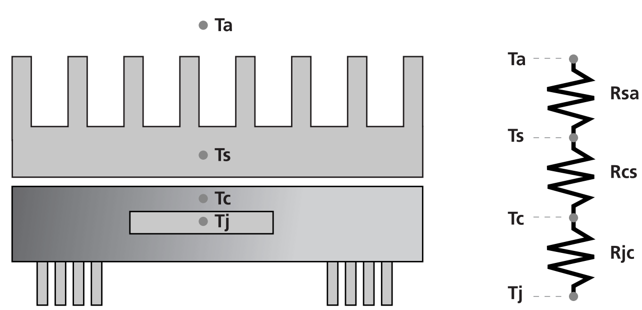

Figure 1 *Thermal Resistance Circuit*

typically used between the mounting surfaces. The heat source locations should be optimized to ensure an even distribution of the heat and to reduce the amount of heat that is absorbed by neighboring components. As discussed in the previous section, the heat transfer from the heat source component to the air can be calculated. Consider a typical example of this as illustrated in Figure 1.

Here, a heat sink is mounted on a device package that is the heat source. Using the concept of thermal resistance, a simplified thermal circuit can be drawn. Heat flows serially from the junction to the case, then across the interface into the heat sink and is dissipated from the heat sink to the air. From equation

$$(T_J - T_A) = Q(R_{JC} + R_{CS} + R_{SA})$$

(1), the temperature drop is:

In order to ensure operational longevity, the heat sink(s) must be sized with enough surface area to allow the heat to be removed by the air flowing across them. In the case of a RF power amplifier module, a well-designed unit should feel no more than warm to the touch. This demonstrates that the heat is being transferred from the devices mounted to the heat sink and the airflow is dissipating that heat. If a module feels hot, the system most likely has improper airflow or inadequate heat sinks. As mentioned earlier, a hot module will not only stress the components mounted to the heat sink, but also the surrounding components as the heat will continue to build within the module, thereby reducing component life and reliability.

Liquid-Cooled System

When designing a liquid-cooled system, the designer must again determine the appropriate operating junction temperature of the devices at the expected extreme environmental conditions and determine the appropriate flow rate that is required to achieve this goal. High ambient temperatures must be considered to ensure reliability at these extreme locations. High ambient temperatures must also be considered for the air-liquid heat exchange of the dry cooler.

Before sizing a pump to handle the flow capacity, the designer must consider pipe sizing, liquid mixture type, product pressure drop, and heat exchanger pressure drop. Pipe sizing, length of runs, and elevation from input-output have a direct impact on the pressure drop of the system and drive the pump selection process. Liquid type must also be considered due to physical changes in the properties of the liquid that can reduce its capacity to remove heat. For example, a water-glycol mixture of 50% has different physical properties than pure water. In order to maintain the same cooling capacity as the pure water, the water-glycol flow rate must be increased by about 14%.

When selecting a heat exchanger (dry cooler), the designer must consider the required heat capacity, altitude above sea level, entering air temperature (highest ambient), fluid type, fluid flow, and the entering fluid temperature (into the heat exchanger). This information is then used to select the correct heat exchanger for the application.

Product Maintenance

Probably one of the most overlooked aspects of thermal design and its reliability is proper maintenance technique. This is important for both air-cooled and liquid-cooled systems to ensure that the design will efficiently work through the life of the product.
In air-cooled systems it is important to regularly inspect and clean ducts, blower(s) or fan(s), and filter(s). Maintenance intervals for cleaning or replacing filters are typically recommended every 90 days or as environmental conditions require. A dirty air filter or ductwork can increase the pressure drop and potentially trip pressure or temperature sensors that are designed to protect the product from heat overload. Cleaning and preventive maintenance (lubrication of parts) of the blower(s)/fan(s) will assure reliability of those units for the life of the product.

In water-cooled systems it is important to inspect the water-glycol mixture, heat exchanger, and pumps. The water-glycol mixture should be flushed or changed periodically when visibly dirty to reduce corrosion of the piping circuit and minimize pressure increase in the piping circuit. Strainers should be cleaned, filters should be changed, and water hoses should be inspected and replaced when visibly worn. The heat exchanger coils and fins should be free and clear of obstructions to reduce the risk of airflow blockage. Pumps should be inspected periodically and cleaned to ensure reliability.

Table 1 (back) compares various aspects of the different cooling methods.

Conclusion

Proper thermal design is essential to ensuring that a RF transmitter meets or exceeds customers' expectations for reliability and dependability. This applies to both the design of the transmitter itself, as well as the proper installation and environmental/site considerations. The selected technique of air or liquid cooling, thermal design optimization, and proper system maintenance are key steps to providing a quality product to the customer.

References

J.P. Holman, *Heat Transfer*, Seventh Edition, pg. 27-59, 281-320, McGraw-Hill Inc., New York, 1990.

B.R. Munson, D.F. Young, T.H. Okiishi, *Fundamentals of Fluid Mechanics*, pg. 465-532, John Wiley & Sons, New York, 1990.

Marconi Communications, *Thermal Management Challenges,* pg. 1-2, Marconi Communications, Irving, TX, 2000.

Seri Lee, Aavid Thermal Technologies, *How to Select a Heat Sink,* pg. 1-2, Electronics Cooling Online, 1995-2000

Aavid Thermalloy, *Thermal Management of Electrolytic Capacitors,* pg. 2, Aavid Thermalloy, LLC, 2002

Table 1 Cooling Method Comparison

	Air	Water	Water-Glycol	Oil
Complexity	**Low** Compact Design. Open or closed loop.	**Medium to High** In climates where freezing may occur, pure water systems require dual-loop heat exchangers	**Medium** Single loop system adequate in freezing climates.	**High** Dual loop heat exchanger required
Environmental Impact	**Low** No environmental impact.	**Low to Medium** Pure water has no restrictions. Dual loop systems use glycol which must be handled per EPA requirements	**Medium** Glycol must be handled per EPA requirements	**High** Oil must be handled per EPA requirements
Cost	**Low** Low design complexity, installation and maintenance. Design relatively inexpensive.	**Medium** Medium to high design complexity, installation, and maintenance. Design relatively more expensive than air.	**High** High design complexity, installation and maintenance. Design relatively more expensive than air and pure water.	**High** High design complexity, installation and maintenance. Design relatively more expensive than air and pure water.
Maintenance	**Medium** Inspect/change filter. Periodic inspection of air ducts, blower/fans.	**High** Periodic flush and change of water. Periodic inspection of heat exchanger coils, pumps, strainers, pipes and hoses.	**High** Periodic flush and change of water-glycol. Periodic inspection of heat exchanger coils, pumps, strainers, pipes and hoses.	**High** Periodic flush and change of water-glycol, oil, oil filter. Periodic inspection of heat exchanger coils, pumps, strainers, pipes and hoses.
Efficiency	**Low** Air has a low heat transfer coefficient	**High** Pure water has a high heat transfer coefficient.	**Medium** Water-glycol heat transfer coefficient reduced from pure water. Higher coefficient than air.	**Medium** Oil heat transfer coefficient lower than pure water. Higher coefficient than air.
Configuration	Open/closed loop. Blower/fan ductwork, filter & heat sinks.	Closed loop Pump, piping, strainer, heat exchanger, & reservoir	Closed loop Pump, piping, strainer, heat exchanger, & reservoir	Closed loop Pump, piping, strainer, heat exchanger, & reservoir

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