Long-Term Deployment of Liquid-Cooled High Frequency (HF) Radar

W. D. Kirkey[1], C. B. Fuller[2], T. O. Ojo[1], and J. S. Bonner[1]
[1]Clarkson University
8 Clarkson Ave., Box 5715
Potsdam, NY 13699 USA
[2]Shoreline Environmental Research Facility
4305 Waldron Rd.
Corpus Christi, TX 78418 USA

Abstract- **A liquid cooling system has been incorporated into a 5 MHz (long-range) SeaSonde HF radar system from CODAR Ocean Sensors. The cooling system consists of commercially available heat exchangers, connected in series and applied to various heat sources within the system. These include the central module within the transmitter chassis, as well as four locations within the receiver chassis. In addition, heat exchangers were also installed on the processor, northbridge, and hard drive of the Apple Mac mini computer used to govern the system. Bench testing showed that these heat exchangers are sufficient to effectively dissipate the roughly 200 W of heat generated by the radar equipment. We also designed and built a cooling reservoir for the dissipation of this heat to the external environment. In order to minimize power consumption, a passive cooling reservoir was developed. Four 55 gallon high-density polyethylene barrels are used to store the water, which is cooled by ambient air and wind. Water is circulated through the system by a single 39 W pump operating off of 24 VDC. This system was field-deployed for one year at Matagorda Island, located in Texas off the coast of the Gulf of Mexico. This is a remote site at which commercial power is unavailable. Instead, the system is powered by a photovoltaic array. Air conditioning at this site would more than double the total power requirements of the installation. In contrast, the water cooling system requires less than 20% of the total electrical power. From August 2008 to August 2009, the system operated with high reliability, producing surface current radial data which was transmitted in near real-time via a cellular signal to the National HF Radar Network and is publically available via the World Wide Web.**

I. INTRODUCTION

High Frequency (HF) radar systems are beginning to find widespread applications in various locations across the globe to monitor water currents in surface waters such as oceans and coastal environments [1]. At present, similar systems are being developed to monitor inland lakes and rivers [2]. Data generated by these systems can be used in such areas as hydrodynamic studies, trajectory tracking in search and rescue operations, and chemical spill response and countermeasures.

HF radar equipment is generally controlled by electronic equipment which must operate in an enclosed, climate controlled environment to avoid overheating. For example, the system used in this work, a CODAR Ocean Sensors SeaSonde, in a standard installation, requires a controlled environment with a temperature in the range of -18ºC to 32ºC and a relative humidity of no greater than 80%. In a warm locale, the need for climate control may more than double the electrical power needed for an HF radar deployment. For a conventional deployment at a site where grid power is readily available, this is not a major concern. However, for a remote location at which grid power is unavailable and an alternative power source is needed, the site design can be greatly complicated due to the need for additional power, as the required space, structure, equipment, and design and installation efforts can increase substantially. Thus, a more directed cooling method that avoids the need for air conditioning could greatly reduce the cost and footprint of remote HF radar deployments. Liquid cooling is an efficient and effective method for cooling electronics, as liquid coolant can be applied directly to heat sources within the electronics. In addition, the cooling capability of air is limited by its low heat capacity; water has a heat capacity over four times that of air. The possibility of a water-cooled HF radar system has only very recently begun to be explored. Researchers at the Southern California Coastal Ocean Observing System have fabricated and tested a cooling block for use with the transmitter chassis of a SeaSonde unit [3].

The Shoreline Environmental Research Facility (SERF) operates several HF radar sites along the Gulf Coast of Texas. One of these sites is on Matagorda Island. This National Wildlife Refuge is accessible only by boat, and there is no commercial electricity available on the island. Prior to August 2008, the SERF HF radar station was powered by a large propane generator which was refilled at regular intervals. In order eliminate the monetary cost and logistical effort associated with propane refills, a photovoltaic power system was constructed at the site during the summer of 2008. During the site redesign, a water-cooling system for the system electronics was designed, tested, and installed to replace the previous building climate control system and thereby vastly reduce the power needs of the system.

II. BACKGROUND

The 5 MHz CODAR system and the computer (Apple Mac mini) together require approximately 250 W (or 6 kWh/day) of electrical power for operation. For the solar-powered continuous operation system, a 24 Vdc CODAR SeaSonde was used. The CODAR unit could thus be powered directly (via a

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load controller) from the 24 V solar battery bank, without the need to utilize power conversion and introduce associated inefficiencies. Similarly, a Carnetix P2140 DC-DC converter was used to power the computer. Based on the historical insolation in east Texas, twelve Kyocera KD-180GX 180W solar panels should provide sufficient power to operate this equipment. For example, from 1961-1990, the minimum solar insolation in Corpus Christi for any month was 2.8 kWh/m^2/day, provided that the solar panel angle is optimized for winter [4]. Since the rated power output for the solar panels is based on 1kW/m^2, one 180 W solar panel would yield a daily average of 180 Wh * 2.8, or 500 Wh, of energy. So 12 solar panels would still be expected to provide the necessary 6000 Wh to operate the system. (Although the solar charging of an actual system would not be perfectly efficient, the residual charge on the batteries would be expected to cover for the slightly insufficient solar charging). However, for a standard installation, climate control would need to be installed to maintain a suitable operating temperature for the (air-cooled) equipment. In a well-insulated enclosure in typical Texas temperatures, with a modern, efficient air conditioner, dissipated the heat generated by the electronics to maintain a safe operating temperature of 27 ºC would more than double the power requirements of the system. As of this writing, the aforementioned solar panels typically cost more than \$600 apiece. Compounding this with the additional cost, effort, and travel time associated with delivery to the site, solar panel mounting structure, wiring, and maintenance, there are tremendous drawbacks associated with conventional climate control at this remote site, which provide the motivation to develop an efficient liquid-cooling system for the electronic equipment.

III. LIQUID COOLING OF EQUIPMENT

Liquid cooling in electronics is a well-established technique. For example, many individuals use water cooling on personal computers in order to reduce fan noise or to increase the speed at which they can operate computer processors without overheating them. Several companies offer small heat exchangers, commonly known as cooling blocks, which are designed for use with various personal computers. In addition, larger heat exchangers, commonly known as cold plates, are utilized for various industrial purposes and thus are also readily available. In this work, cooling solutions for both a Mac mini computer and for the CODAR transmit and receive electronic units were developed using only commercially available heat exchangers.

A. Mac mini computer

Off-the-shelf cooling blocks are generally intended for desktop computers rather than compact computers such as the Mac mini. However, the Koolance CHC-125 cooling block proved to be small enough to be mounted to the motherboard of the Mac mini. Figure 1a shows the Mac mini with cooling blocks installed on both the processor and the northbridge chipset. A Koolance HD-50-L06 cooling pad is attached to the

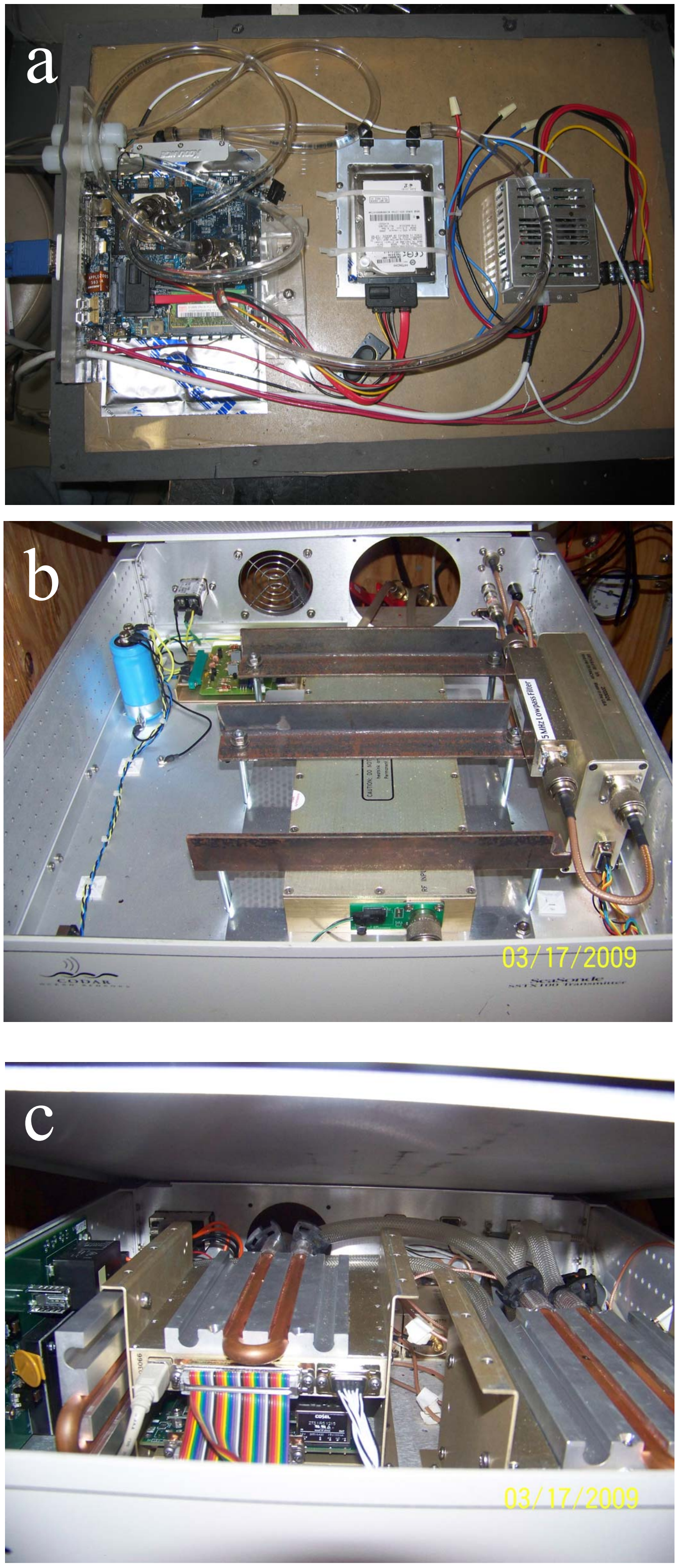

Figure 1. a) Liquid cooling system installed on a dismantled Apple Mac mini computer. At right is the Carnetix DC-DC power converter. b) SeaSonde transmitter chassis with Lytron CP30 cold plate installed. The amplifier temperature sensor is located on the small circuit board at the front of the module. c) SeaSonde receiver chassis with Lytron CP10 cold plates installed.

hard drive. The water-cooled computer was tested in the laboratory. Temperature Monitor, a free program from Marcel Bresink Software-Systeme, was used to monitor the computer's built-in temperatures. With water temperatures greater than 40 ºC and ambient temperatures above 70 ºC, the microprocessor temperatures remained at safe levels.

B. CODAR transmitter amplifier and chassis

The largest source of heat in the entire electronics system is the transmitter module. In the original configuration, this module is fixed to the bottom of the chassis, and an air-cooled heat sink covers the entire top of the module. The chassis shown in Figure 1b has been modified. In this case, a Lytron CP30 cold plate is positioned at the bottom of the chassis, and the module has been turned upside down and clamped down onto the cold plate. Based on temperatures regularly seen during standard SeaSonde deployments, it was presumed that the system would operate relatively safely as long as the temperature sensor installed on the module maintained did not exceed 45ºC and would likely handle higher temperatures as well. System testing at 32ºC ambient temperatures with 29 ºC water yielded an amplifier temperature reading of 30 ºC, suggesting that the unit would rarely (if ever) reach the 45ºC level during the deployment.

C. CODAR receiver modules and chassis

The receiver chassis contains three modules and one circuit board that each generate moderate amounts of heat. It was determined that some cooling may be necessary to protect this equipment. Four Lytron CP10 cold plates were installed in the vicinity of the modules, as shown in Figure 1c. For the three modules, the center portion of each module cover was removed and replaced with the cooling block. It was estimated that the receiver unit would be acceptable if the temperature sensor mounted near the receiver chassis did not exceed about 50 ºC. This reading remained below 45 ºC with cooling water at 30 ºC and ambient temperatures outside the chassis of about 50 ºC.

IV. LIQUID COOLING RESERVOIR DESIGN

The chief concern for the design of the Matagorda liquid cooling system was to minimize electrical power consumption while providing adequate cooling capability. The size of the reservoir was not an issue. Thus, a large outdoor cooling reservoir which would be passively cooled by the surrounding ambient air was deemed a suitable setup. High-density polyethylene (HDPE) drums were chosen as the reservoir walls. This choice was driven by the ready availability of such drums, the fact that these plastic drums would not corrode in the coastal environment, and the reasonably large (relative to plastics in general) thermal conductivity of HDPE (approximately 0.5 W/mK). In estimating the cooling capability of this system, the overall heat transfer coefficient U from between the water inside the reservoir and the ambient wind outside was crudely estimated to be 8 W/m^{2}K. The rate of heat transfer, dQ/dt, out of the reservoir is governed by the equation

$$dQ/dt = UA\left(T_w(t) - T_a(t)\right), \tag{1}$$

where $T_w(t)$ and $T_a(t)$ are the temperatures of the water in the reservoir and the ambient air, respectively, and A is the surface area of the reservoir available for heat transfer.

To ensure adequate sizing of the cooling reservoir, calculations regarding the estimated water temperature were based on the assumption that all heat power P generated by the CODAR equipment and the Mac Mini would be dissipated to the water. Under this assumption, along with the definition of heat capacity, the following expression can be obtained:

$$dT_w(t) = \frac{\left(P - UA\left[T_w(t) - T_a(t)\right]\right)}{c_w m_w} dt, \tag{2}$$

where c_w is the heat capacity of water (4.18 J/gK) and m_w is the total mass of water in the system.

Equation (2) was used to estimate the needed reservoir size. Because reservoir size was not a major concern, conservative estimates were used for the field conditions. P was presumed to be 250 W, which equals the entire electrical power draw of the system electronics. U was estimated to be 8 W/m^{2}K. The ambient temperature was simulated as a sinusoidal function with temperatures ranging from 38ºC to 32 ºC, representing extremely warm conditions. Figure 2 shows the resulting estimated water temperature for a reservoir consisting of four 55-gallon HDPE barrels filled with water, such that the total water mass is 832 kg. An initial water temperature of 35 ºC was used. The available area A was estimated to be 7.2 m^2, which would be equivalent to the case where all but one end of each barrel is available for heat transfer. The estimated water temperature for the four-barrel reservoir peaks at 40 ºC. Based on the preliminary testing, this was deemed an acceptable water temperature for the field deployment.

Thus, a cooling system consisting of four such barrels was implemented. A small amount of antifreeze (approximately 5% by volume) was added to the cooling water to aid in inhibiting corrosion. The water is circulated by a single 24 Vdc pump (Iwaki America RD-05H) which consumes only 39W of

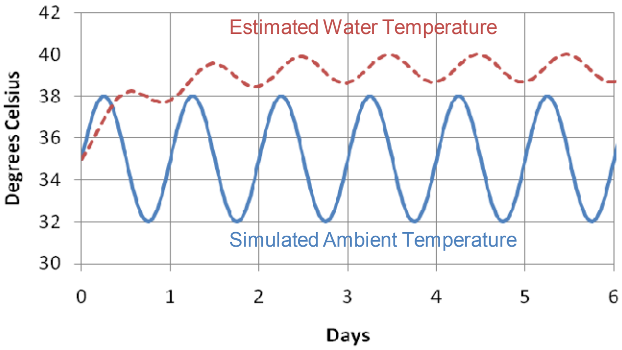

Figure 2. Estimated temperature of water in four barrel reservoir under extremely high ambient temperatures.


Figure 3. Water cooling reservoir installed at Matagorda Island site.

electrical power. The cooling reservoir installed at the Matagorda site is pictured in Figure 3.

V. RESULTS AND DISCUSSION

The HF Radar system at Matagorda Island ran continuously with minimal interruption from September 2008 to August 2009. As expected, twelve 180 W solar panels proved sufficient to power the system. Radial data from the site can be accessed from the National HF Radar Network at http://cordc.ucsd.edu/projects/mapping/. Total surface current vectors can be obtained by combining the data from Matagorda Island with that from the Sargent Beach radar site, which harbored a conventional 5 MHz SeaSonde system.

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