CONCEPT DEVELOPMENT FOR THE THERMAL MANAGEMENT OF THE RUSSIAN AMERICAN OBSERVATIONAL SATELLITES (RAMOS)

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Abstract

For the past several years, cryogenically cooled sensors have become an increasingly popular method of observation and study for both space-based and ground-based operations. Accordingly, various cooling techniques have been developed to accommodate this group of sensors. Because of rising performance standards and escalating cost limitations, cryocoolers have become an impressive cooling technique to consider. This report focuses on the use of a mechanical cryocooler in conjunction with the Russian American Observational Satellites (RAMOS), a future pair of earth-imaging satellites which will fly infrared radiometers.

The RAMOS program consists of mapping the earth's surface in stereo using two co-orbital satellites. The American Observational Satellite (AOS) will utilize an infrared radiometer with the telescope focal plane assembly (FPA) operating at approximately 60 K. The FPA will be cooled using a multiple cryocooler configuration. The use of multiple coolers introduces redundancy into the cooling system—a redundancy which has been absent from many previously flown satellites. In addition, the cooling system will incorporate various other new technologies, such as thermal disconnects, a thermal storage unit, low-resistance flexible thermal links, etc., to meet the overall system objectives and requirements. Thermal storage units are discussed as a means of eliminating cryocooler self-induced vibration and passively controlling FPA temperatures. Incorporating thermal switches and thermal storage units into a cooling system design can alleviate the concerns of cryocooler vibration and parasitic heat loads. An understanding of these concepts and configurations will assist in the design of similar optical instruments for both space-based and ground-based exploration campaigns.

Introduction and Background

During the early 1990's, the United States government began exploring the idea of joint space research and exploration with Russian scientists and engineers. The Russian American Observational Satellites (RAMOS) program is a direct result of this venture. RAMOS is a space research program that involves "an innovative measurement technique, simultaneous stereo-optical imaging (that) addresses the twin concerns of target detection and background suppression. The simultaneous stereo measurement technique also offers the potential for significant improvement in environmental monitoring[1]."

Pseudo-stereo imaging is a process that has long been used to map terrain and other such stationary objects from space. This process, however, is usually performed by a single satellite taking pictures of a fixed target at various times during its orbit. The stereo-imaging technique employed by RAMOS has the potential to map not only stationary objects, but high-speed moving targets with images obtained simultaneously from two different orbital positions.

The AOS satellite will consist of an infrared radiometer operating at approximately 60 K over a mission lifetime of 2 years. This paper examines various cooling options as well as several cryogenic technologies for use with the RAMOS sensor. As a result of this examination, a conceptual thermal management scheme is presented.

Objectives and Requirements

The objectives and preliminary requirements for the RAMOS sensor are listed in Table 1.

Table 1. Preliminary sensor thermal requirements for RAMOS.

Objectives

- Determine the instrument thermal requirements and constraints
- Develop alternative thermal management options that meet requirements
- Perform trade-off studies
- Formulate an initial thermal management conceptual design
- Devise a passive thermal disconnect mechanism pending the selection of a cryocooler system.
- Develop "Vibration Free" Environment
- Ensure thermal system compatibility
- Refine and optimize the design
- Obtain, build, and test certain critical components of the design solution
- Finalize the design

Instrument Requirement	**Specification**
Lifetime	> 2 year
Total Mass Limit	< 50 kg
Approximate System Envelope	36x44x48 cm
Maximum Heat Loads (FPA)	
Launch Pad	< 1.5 W
On-Orbit	< 1.3 W
Maximum Heat Loads (Telescope)	
Launch Pad	< 10.0 W
On-Orbit	< 8.0 W
Approximate Telescope Temp	< 220 K
System Thermal Link Temperature	55 K
Maximum Input Power	< 200 W
Maximum Environmental Temps	
Launch Pad	300 K
On-Orbit	250 K
Spectrometer Temperature Reqs.	
Optical Bench Temperature	59 ± 2 K
Focal Plane Array Temperatures	60 ± 1 K
FPA Thermal Drift Requirement	<0.5K/15 mn
Maximum Sensor Operation Period	~15 min
System Readiness Level	High
Flight Proven	Yes
Maximum Vibration Levels	
Sensor Operating	Minimal
Sensor Dormant	< 1.0 N

An Encompassing Cooling Solution

The main components and functions of the RAMOS cooling system are summarized in Table 2. In addition, a breadboard layout of the system is shown in Figure 1. The selection as well as the details of each component are discussed in the following sections.

Table 2. Main RAMOS cooling system components and function summary

Component	Function
Primary Cryocooler(s)	Provide < 1.3 W of cooling to FPA
Secondary Cryocooler(s)	Provide < 1.3 of cooling to FPA in event of primary failure
Thermal Disconnect	Link cooler to FPA; Disconnect cooler during failure
Thermal Storage Unit	Control FPA loading fluctuations; allow for cooler shut-off
Flexible Thermal Link	Attach cooler to FPA, minimize cooler operation vibration
Primary Radiator	Remove Cryocooler, Sensor input power
Secondary Radiator	Provide radiative cooling for telescope housing.
Thermal Insulation and Isolation	Blanket telescope and cooling link; reduce heat loads

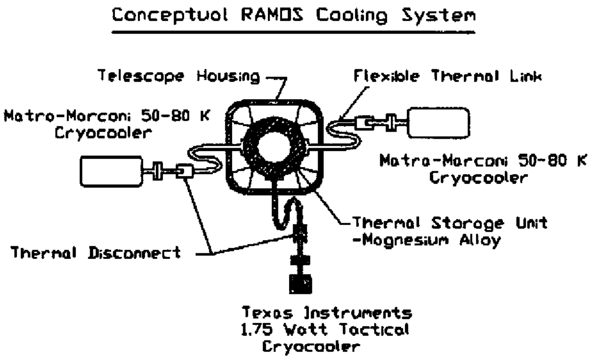

Figure 1. Main components and breadboard layout of the cooling system.

Estimated Heat Loads

The preliminary RAMOS sensor heat loads were estimated from a previous SDL project, SPAS III^2. The "Pad" values are based on a telescope enclosure of 300 K with the optical bench operating at 59 K. The "Orbit" values are based on the radiative cooling of the telescope to 220 K. A summary of the estimated heat loads is shown in Table 3 with a general heat path diagram of the system shown in Figure 2. The heat load total values listed include a 10 percent adjustment factor to accommodate for any generalized inaccuracies.

The cryocooler on-orbit heat load was calculated to be approximately 0.765 W with an additional 10 percent. This value exceeds the maximum cooling capacity of one MMS cooler. With this loading confirmed, 2 MMS cryocoolers would be used with a TI tactical cooler as a backup (discussed in more detail later).

It is important to note that the major source of heat loading on the sensor (and ultimately, the cryocooler) is the MLI blanketing. This heat path accounts for approximately 33 percent of the on-orbit loading. The heat transfer through the blankets was calculated using the Lockheed MLI equation[3] with a perforation factor of four. The accuracy of this value, however, depends heavily on the preparation and installation of the blanketing. Poor blanket preparation can not only increase the heat load, but also cause outgassing problems for the sensor. Proper blanket preparation and installation, however, can greatly improve the effectiveness of MLI blanketing. This aspect of the design will be closely monitored when the cooling system is integrated into the spacecraft.

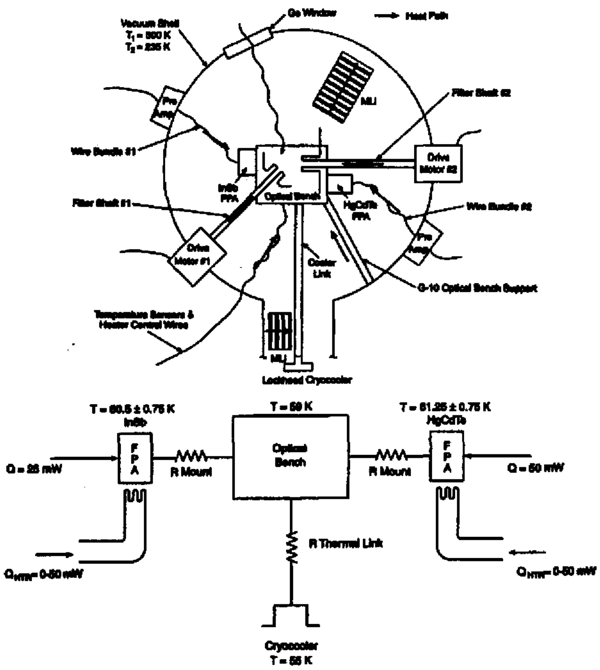

Figure 2. RAMOS Thermal schematics derived from SPAS III[2].

Table 3. RAMOS sensor heat loads estimated from SPAS III heat loads and configuration

Heat Path	Orbit (mW)**	Pad (mW)*
Window	73	218
MLI	231	663
Filter Shafts	98	147
Optical Bench Supports	59	89
Wires	79	119
FPA	75	75
Link (to Cooler)	60	172
Trim Heater	20	20
TOTAL †	765	1653

* Based on a pad temperature of 300 K and an optical bench temperature of 59 K.

** Based on a orbit temperature of 220 K and an optical bench temperature of 59 K.

† Total values contain 10% adjustment factor.

Multiple Cryocoolers

The mission lifetime and initial heat load predictions constituted the use of a lightweight and

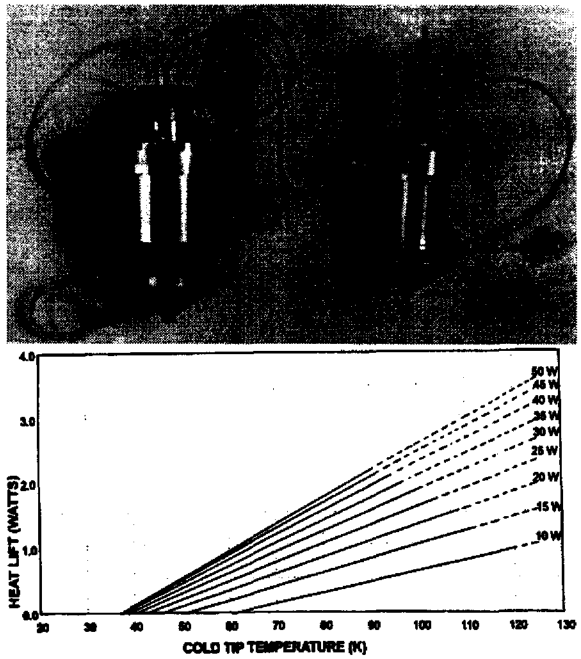

Figure 3. Diagram and cooling performance curves for the MMS 50-80 K cryocooler[4].

compact cryocooler over a more massive cryogen to cool the RAMOS sensor. This selection, however, introduced vibration and mechanical disadvantages into the system. The self-induced vibration compensation is performed by using a thermal storage unit (TSU) in conjunction with the sensor on-orbit scenarios (discussed in more detail later). In addition, to enhance the reliability of the RAMOS cooling system, redundant cryocoolers are necessary. This notion has several advantages. The main advantage lies in reducing the system risk factor and increasing confidence in the system. This confidence is extremely important to ensure when designing a system in which a single point failure (SPF) of one component is fatal to the mission. This is the case with the RAMOS IR radiometer. If, for any reason, a single cryocooler were to fail, a redundant cryocooler would be available to prolong the mission. In this type of system, the benefits of redundancy outweigh the necessary costs associated with an additional cooler.

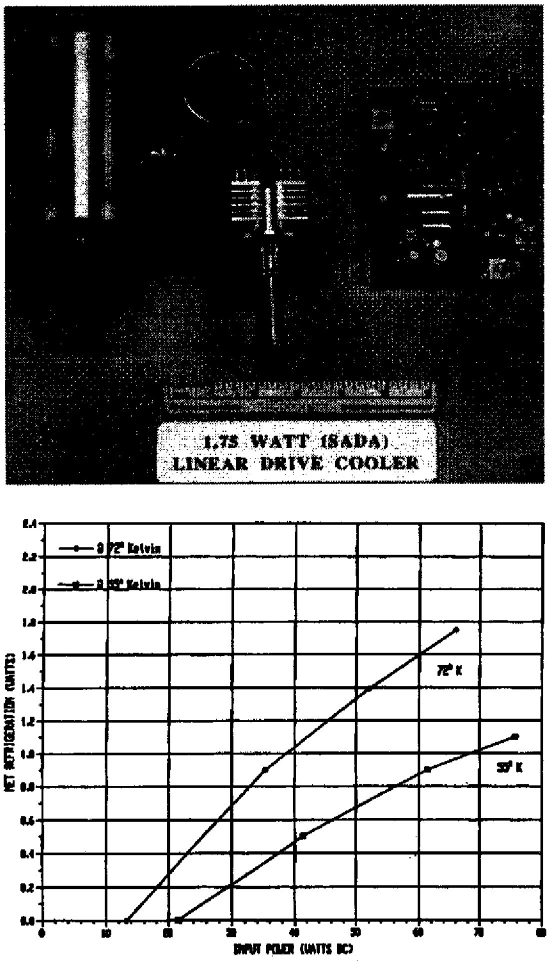

Figure 4. Diagram and cooling curves for the Texas Instruments 1.75 W tactical cryocooler[5].

Based on the system requirements and predicted heat loads, two Matra-Marconi Space (MMS) 50-80 K cryocoolers (Figure 3) were chosen with a tactical 1.75 W Texas Instruments cryocooler (Figure 4) as a backup. The MMS coolers were chosen based on their compact size, past flight history, and cooling capacity relative to the RAMOS heat loads. The TI cooler was chosen as an inexpensive backup to the system. A complete comparison of the two coolers is found in Table 4.

This configuration is very flexible and has several advantages. The MMS coolers provide approximately 0.75 W of cooling capacity at 55 K with 50 W of input power, which is low for a space qualified cryocooler. The MMS coolers, mounted head-to-head, also reduce the ensuing operation vibration. In addition, both coolers can be operated at lower duty cycles, increasing their lifetime and reliability. In the case, however, of a single point failure, the TI cryocooler is on hand to provide sufficient cooling and prolong the mission.

Thermal Disconnect Development

"In applications where redundant cryocoolers are required to enhance reliability, the non-operating standby cooler presents an added parasitic load to the operating cooler. The nonoperating cooler needs to be thermally isolated from the focal plane array, while the active cooler is thermally connected to the system[6]." This is accomplished by inserting a thermal disconnect or switch into the cooling path between the cooler and the FPA.

A thermal disconnect or thermal switch is simply a device which acts as both a thermal link and isolation mechanism. In the "on" position, the switch has a low thermal resistance and heat may freely flow across the connection. In the "off" position, the switch literally disconnects the heat path, creating a high resistance to heat transfer. The thermal disconnect requirements for RAMOS are listed in Table 5 and are based on the performance of JPL's switch. In an effort to meet these requirements, four disconnect concepts were considered: JPL's Hydrogen Sorption Bed, a cryogenic CPL, a linear stepper motor, and thermal expansion bimetal.

One idea for a thermal switch for use in cooling an IR focal plane has been previously undertaken by Johnson and Wu of the Jet Propulsion Laboratory (JPL) to be used on a candidate Space Missile Tracking System (SMTS)[6]. This switch, based on the desorption and absorption of hydrogen within a zirconium-nickel matrix, is currently under development and is scheduled for flight testing, Fall 1998. In addition to JPL's switch, a cryogenic heat pipe or CPL was investigated because of its inherent diode characteristics. This idea, however, was not feasible for RAMOS because of the FPA operating temperature. There was not a known CPL working fluid capable of operating between 55 K and 59 K.

In addition to the two existing switches, two alternative concepts were explored. The first involves a linear stepper motor and precision lead screw (See Figure 5). To achieve the on position, the motor simply steps and locks into place the thermal contact points. A forcing spring is also used to ensure contact and prevent the lead screw from backing out due to slip and vibration. The assembly also consists of various G-10 standoffs and mounting supports to minimize the heat leak into the cooling link in the on position. In the off position, the main heat leak across the switch is limited to radiation heat transfer which can be small if the contact points are very low emissivity surfaces. Control of the motor can be performed by a thermostat or other temperature sensing device, or even the control electronics of a cryocooler in the event that such a configuration is available.

Table 4. MMS 50-80 K cryocooler and TI tactical cooler characteristics summary

Component	MMS Specs	TI Specs
Type	Space	Tactical
Cooler Function	Primary	Secondary
Model Number	50-80 K	1.75 W
Cycle	Stirling	Stirling
Stages	1	1
Cooling Capacity	0.75	1.0
Cooling Temperature	55	55
Reject Temperature	298 K	298
Reject Range	263-313 K	219-344 K
Input Power	50 W	70 W
Off-State Parasitics	< 250 mW	-
Cooler Mass	4.9 kg	2.0 kg
Compressor Envelope	23.8x12.0D cm	13.9x 7.7D cm
Displacer Envelope	22.0x7.8D cm	9.0x5.5D cm
Electronics Mass	4.3 kg	1.2 kg
Electronics Envelope	29x22x11 cm	12x15x4 cm
Estimated Lifetime	10 +	4500 hrs
Mechanical Reliability	0.9879 (3 yrs)	-
Self Induced Vibration	0.044 Nrms	2.0 Nrms
Natural Frequency	44 Hz	-

Table 5. Thermal disconnect performance requirements

Requirements	
Temp Range	50 - 300 K
Mass	< 1 kg
Envelope	< 250 cc
ON Resistance	< 2.0 K/W
OFF Resistance	> 1000 K/W
Power Req'd	< 1.0 W
Time to Connect	< 10 min
Time to Disconnect	< 10 min
Gravity Functionality	0-G, 1-G
Switching Cycles	1
Est. Lifetime	> 2 years

The main advantages of a stepper motor thermal switch are the size and speed of operation. These motors are very small (1-3 in. long, 0.5-2 in. diameter) with extremely accurate step increments (0.0005 in.-0.008 in.). In addition, connection times can be less than 1 minute for short lead distances. Also, in instances where a large cooling source exists, the off-line configuration, shown in Figure 5, may be favorable since the bulk of the parasitic heat load occurs during cooler operation. Disadvantages would be input power, control and operation temperature. The necessity of external power and control to the motor provides an additional complexity to the system--a complexity which is often discouraged in simple applications. Passive systems are almost always preferred. In addition, certain actuators have an operating temperature range. This range limits the motor to temperatures above 250 K. This could complicate mounting and placement of the stepper motor and also require a strip heater for temperature control.

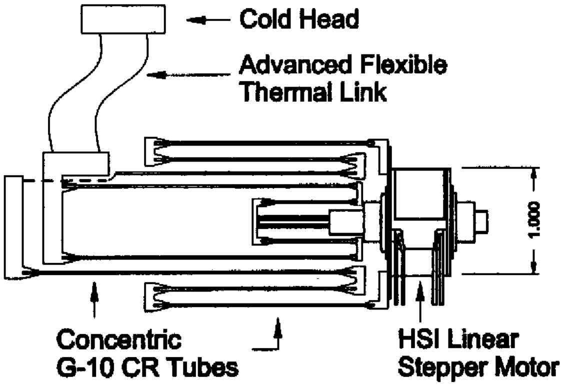

Figure 5. Layout of a possible linear stepper motor thermal disconnect concept.

The final concept considered was a passive thermal disconnect bimetal switch. Bimetals or thermostat metals, by definition, are combinations of two materials having different coefficients of thermal expansion (CTE). When the material is exposed to a temperature change, one material deforms more than the other, causing movement, force, or a combination of both. The driving mechanism is temperature. The amount of deflection or force achieved by a given bimetal depends on the temperature change, materials, and bimetal geometry. For example, the amount of deflection that can be achieved from a simply supported beam is given by

$$\text{Thermal Deflection:} \quad B = \frac{F(T_2 - T_1)L^2}{4t}, \qquad (1)$$

where L is the active beam length, t is the thickness, T_1 and T_2 represent the temperature boundaries and F is a material property known as the specific deflection—a unique mechanical characteristic of each bimetal strip. Similarly, the force produced by a simply supported beam can be calculated by using either the mechanical force or thermal force (P) equations in which

$$\text{Mechanical Force:} \quad P = \frac{4EBwt^3}{L^3}, \qquad (2)$$

$$\text{Thermal Force:} \quad P = \frac{EF(T_2 - T_1)wt^2}{L}, \qquad (3)$$

where E is the bimetal modulus of elasticity and w is the beam width[7]. Using these equations, a bimetal work curve may be established which approximates the maximum work which can be done for a given bimetal and geometry. An example of a work curve is shown in Figure 6 along with the material properties of two Texas Instruments Truflex bimetals in Table 6.

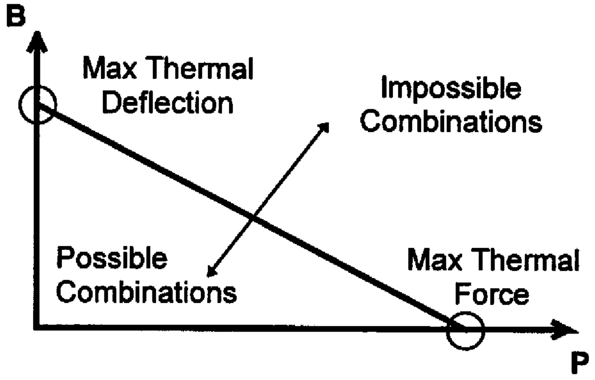

Figure 6. Approximate bimetal work curve.

Table 6. TI thermostat metal properties[7]

Properties (Truflex)		F20R	P30R
Specific Deflection @220 K (10^{-5})	K	1.09	1.29
Modulus of Elasticity (10^5)	N/mm^2	1.38	1.38
Density	g/cm^3	8.58	8.30
Thermal Conductivity (300 K)	W/mK	221.8	146.4
Jk Factor (10^{-5})	W/m	241.8	188.9

The area bounded by the work curve and the axis represents all possible combinations of force and deflection that can be achieved with a given bimetal and geometry. As an approximation to the optimum combination, it is common to use half of the driving temperature change to produce a deflection and the other half to produce a force.

The thermostat metal switch concept is to use the temperature conditions surrounding the bimetal to produce a deflection and a force. These conditions dictate the deflection or contraction of the metals and ultimately the joining or disjoining of the thermal path. Figure 7 shows a conceptual layout and main components of a bimetallic thermal disconnect (The dimensions shown are bigger than the predicted final configuration for simplicity in testing). The system basically consists of aluminum end-pieces for thermal and structural support. Two thermostat metals are mounted back-to-back and are cantilevered off one of the aluminum end-pieces. When the cantilever end-piece is cooled, the bimetals deflect outward. The heat path from one end of the disconnect to the other is joined through the bimetal motion, which forces the endcaps of two advanced flexible thermal links[8] to contact the aluminum housing. When a temperature difference exists across the link, the bimetals contract, severing the heat path. The G-10CR stand-offs are used to minimize the parasitic heat leak in the off position as well as for structural support.

Bimetal thermostats have been used on spacecraft and in innumerable other ground-based applications in the past. Their popularity stems from the fact that they are simple, passive devices that only need to be calibrated once for operation. This simple, passive performance is the main advantage of a thermostat metal switch. In addition, it is estimated that the disconnect can achieve high levels of resistance in the off-state and low levels of resistance in the on-state similar to those obtained by JPL's hydrogen sorption switch.

The main disadvantage of thermostat metals lies at low temperatures. Most, if not all bimetals have been used in applications where the minimum temperature was approximately 200 K. The cyclic performance and material flexibility are generally unknown at temperatures below this. Therefore, the success of a cryogenic bimetallic thermal disconnect depends heavily on the performance of various bimetals at low temperatures

Table 7. Thermal disconnect concept comparison

Specs		Stepper Motor	Hydrogen Sorbent Bed[6]	Bimetal Strips
Type		Active	Active	Passive
Temp Range		Variable	Variable	? - 800 K
Mass	g	300	< 295	< 500
Envelope	cc	250	< 160	< 300
ON Resistance	K/W	< 1.6	0.9 - 1.2	2.0
OFF Resistance	K/W	> 1500	660	1000-1500
Power Req'd	W	3 - 4	0.3	None
Time to Connect	min	< 0.15	5	< 10
Time to Discon.	min	< 0.15	< 12	< 10
Switching Cycles		TBD	> 124	TBD
Est. Lifetime		TBD	N/A	TBD
History		None	JPL SMTS	None
Main Restr.		Power and Control Requirements	Hydride Heat Sk. 288-301 K. H_2 Ops.	Bimetals @ Low Temp

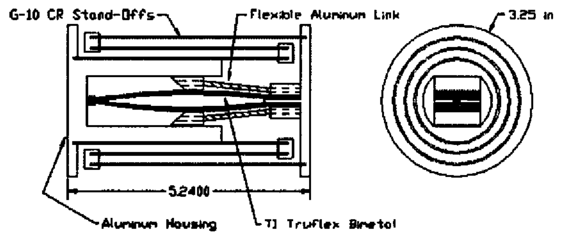

Figure 7. Concept design and layout of a bimetal thermal disconnect.

Table 7 compares three of the thermal disconnect concepts discussed in this chapter, including JPL's Hydrogen Sorption Bed. It is important to note the values listed are calculated approximations based on switch operation at cryogenic temperatures to meet the requirements of the FPA cooling problem that was discussed previously.

From the information listed in Table 7, a bimetal thermal disconnect was selected for RAMOS. Although this option requires significant testing and optimization, it is simple, compact, and has the potential of being a very effective component.

Thermal Storage Unit

The thermal drift rates and vibration requirements of the FPA are the driving forces in the need for a thermal storage system. Currently, the FPA can tolerate a maximum change in temperature of 0.5 K over a 15-minute period. The sensor vibration requirements stipulate minimal vibration during sensor operation. To meet each of the specifications with a cryocooler assembly, a thermal storage unit (TSU) is necessary. The existence of a TSU allows the cryocooler to be dormant while the sensor operates, eliminating any transmissible vibration. The TSU then stores the FPA heat load and any parasitic loads for a maximum period of 15 minutes while maintaining the FPA within 0.5 K. Once data acquisition is completed, the cooler resumes operation. As with thermal disconnect technology, this concept is also necessary to the RAMOS sensor in order to minimize cryocooler self-induced vibration.

TSUs have many benefits when used in conjunction with an IR sensor and cryocooler configuration[9]. The first is thermal load leveling. TSUs allow the cryocooler to be sized for the average focal plane heat load rather than the maximum heat load. This advantage can result in a smaller cryocooler and better FPA temperature stability, and can eliminate focal plane heaters altogether. A second advantage that TSUs provide is the ability to temporarily turn off a cryocooler. This allows the sensor to operate in a vibration-free environment. It also can extend the cryocooler lifetime, which is a main concern with tactical coolers. These TSU benefits translate directly into advantages for the overall cooling system. A more accurately sized cryocooler can improve the overall system performance and lifetime while reducing the system mass and cost[9].

There are generally two types of thermal storage units: sensible heat devices (SHDs) such as aluminum or copper, and phase change materials (PCMs). Although PCM TSUs have a larger storage capacity compared with SHDs, they presented a problem for RAMOS. Once again, a working fluid was lacking within the 55-59 K temperature range. Both Swales Aerospace and the AFRL reported on the use of Nitrogen Trifluoride (NF_3) as a possible PCM at 57 K[9]. The existence, however, of supercooling phenomena forced them to resort back to nitrogen as a working fluid at 63 K. Thus, a PCM is currently not feasible for use on RAMOS.

Sensible heat devices or high specific heat materials were then investigated. After gathering data on various materials (See Figure 8 and Table 8), Magnesium alloy AZ80a was chosen having a specific heat of approximately 560 J/kgK at 55 K. For RAMOS, approximately 2.4 kg of AZ80a will be needed (Figure 9). The exact amount will be determined following sample testing to ensure the thermal characteristics of the material.

The main disadvantage of AZ80a is its thermal conductivity. The limited thermal conductivity, however, can be improved in various ways. This can be done by swaging wafers of magnesium with wafers of high conductivity aluminum or copper, by encasing the magnesium in a high conductivity container, or by adding molten Mg AZ80a (melting point, 763 K) to an aluminum mesh (melting point, 933 K). Other methods such as sizing may also be employed to reduce the thermal impedance (from Fourier's Law) of the TSU in the cooling link. In short, it is easier to decrease the thermal resistance of the TSU than to improve its storage capacity at low temperatures.

Other Components

Additional components of the cooling system would include MLI blanketing, wire shielding, radiative cooling surfaces, flexible thermal links and possible fiber support technology. Flexible thermal links and fiber support technology are two popular areas of spacecraft thermal research. Flexible links involve various methods of thermally joining two components with a low resistance path. The flexible characteristic helps, not only in connecting offset components, but to mechanically isolate vibrating systems, such as cryocoolers, from a FPA.

Fiber support technology (FiST) is a means of isolating a component using high-strength, low-conductivity composite strands. This technique, currently being developed for the SABER

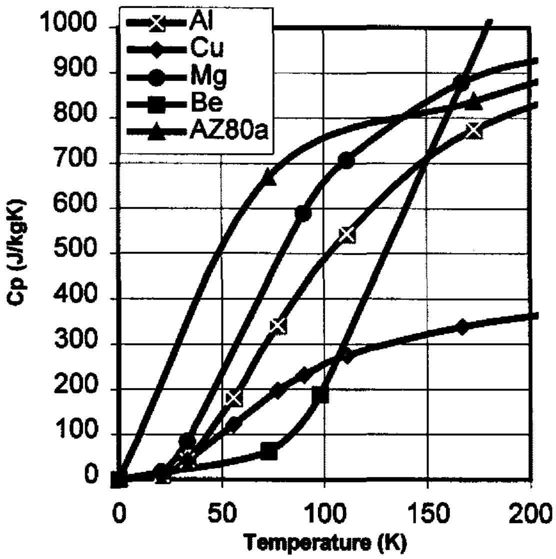

Figure 8. Specific heat of various materials at low temperatures[10].

Table 8. Estimated material properties of Magnesium AZ80a

Property		AZ80a
Specific Heat @ 55 K	J/kgK	560
Thermal Conductivity @ 55 K	W/m K	10.0
Density	kg/m^3	1800
Thermal Diffusivity @ 55 K	m^2/s	9.92 (10)$^{-6}$

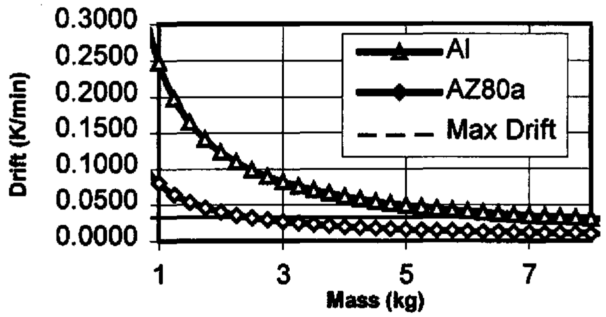

Figure 9. Estimated mass necessary to maintain the RAMOS sensor within 0.5 K over 15 minutes. (C_p @ 55K): general aluminum (0.182 J/kg K), AZ80a magnesium alloy (0.56 J/kgK). The data assume a FPA heat load of 0.75 W.

(Sounding of the Atmosphere using Broadband Emission Radiometry) cooling system by the Space Dynamics Laboratory, can greatly reduce the conductive component of the sensor parasitic heat loads. The RAMOS thermal design team is optimistic that fiber support technology (FiST) will be sufficiently advanced in the future to incorporate its benefits into the RAMOS sensor design.

Operation Scenario

The cooling system operation scenario is based on the combination of the TSU and cryocoolers in synch with the sensor operation. The primary MMS cryocoolers will provide cooling for the system while the backup TI cooler remains dormant. During target acquisition, sensor calibration, and operation, both the MMS and TI coolers will be dormant with the TSU maintaining the FPA temperature, roughly constant. Once the sensor operation data has been acquired, the primary coolers will resume operation and relieve the TSU. In the case of primary cooler failure, the TI cryocooler will be employed.

System Summary

The RAMOS cooling system may be characterized as an advanced IR cooling system. The design incorporates leading-edge technology to obtain an optimal sensing environment for an extended space-based mission. These advanced concepts are backed by traditional spacecraft tactics, which include designing a redundant system with components that have proven reliable.

The conceptual RAMOS cooling system consists of multiple cryocoolers. The baseline design includes two space-proven Matra-Marconi cryocoolers operating head-to-head at approximately 55 K. This configuration easily provides adequate cooling to the sensor. In addition, the MMS coolers have a predicted reliability of greater than 98 percent over the RAMOS mission lifetime. As a complement to this reliability, a space-modified Texas Instruments tactical cryocooler will be coupled to the sensor to provide cooling in the case of a primary cooler failure. The TI cooler is compact, inexpensive, and proven to operate effectively in space. The combination of these three cryocoolers provides a unique cooling solution.

To combine dormant cryocoolers to a FPA without suffering from large parasitic heat loads through the non-operating cooler requires a thermal switch. For RAMOS, two solutions have been proposed. The first is a passive thermostat metal device utilizing the thermal expansion of the bimetal to create or break a thermal path. This system is compact and does not require any external power or control. The temperatures imposed on each end of the switch determine whether the switch is on or off. A secondary solution is an actively controlled stepper motor. This concept consists of joining and disjoining the cooling path by means of a thumb-size linear stepper motor. This idea has excellent off-state resistances yet causes an additional on-state parasitic imposed on the cryocooler. This parasitic, however, is minimal in relation to the primary cooling capacity. In addition, the stepper motor can be connected and disconnected in seconds, requiring only a burst of power. Because the switch operation is needed only once, the power requirements are negligible compared with the cryocoolers.

The main disadvantage of a cryocooler for use with an IR sensor is induced vibration. Precise sensor operation can be greatly disturbed by the presence of a mechanical refrigerator. This severe disadvantage, however, is eliminated by the use of a high specific-heat magnesium alloy. The SHD is placed near the focal plane and essentially absorbs the FPA heat load for a period of 15 minutes while maintaining the temperature deviation within 0.5 K. Thus, the sensor can take data without the effects of vibration and the cooling system can benefit from the cryocooler advantages.

The cooling configuration also contains two radiators to reject the cryocooler compressor and displacer input power as well as the telescope housing parasitic loads. The type of radiators to be used, as well as surface coatings, has not yet been determined. As the design progresses, these items will resolved based on spacecraft surface area, orbital heat loads, and current technology.

Future Considerations

The main focus of the RAMOS thermal design in the near future will be the prototype testing of thermostat metals and magnesium alloys at cryogenic temperatures. This testing will verify the bimetal thermal switch concept and promote improvements in the overall design. The TSU Mg AZ80a alloys will also be tested to verify their thermal storage capacity at low temperatures. This testing, although relatively simple, will ultimately determine the future of multiple cryocoolers on RAMOS.

The RAMOS preliminary design review (PDR) is set for the first quarter of 1999. The time leading up to this review will be spent verifying the concepts outlined in this paper. In addition, more detailed thermal models will begin to take shape. These models will range from advances in the current cooling link model to an entire spacecraft thermal depiction. These models will serve as excellent guides as the design proceeds past PDR.

Conclusion

Overall, the RAMOS cooling system incorporates various new facets of thermal technology to meet the rising standards of the IR sensing community. The concepts outlined in this paper are key elements in the effective use of current cryogenic technology. Cryocoolers have become the rage of the thermal community while cryostats are beginning to fade. These coolers offer benefits that far exceed the capacity of cryogenic dewars. Their main drawbacks, however, must be addressed in order to fully realize their potential in space systems design. Thermal storage units and thermal disconnects are two important components in this realization. The concept design for the thermal management of RAMOS illustrates various notions that can improve the performance, lifetime, and cost of a cooling system. The ballooning IR standards can be met by high-capacity cryocoolers with heat load leveling devices and passively controlled thermal switches. It is the hope of the author that the discussion contained in this paper may provide enough insight to entice others to investigate these essential cooling solutions. The direction of spacecraft cooling systems depends simply on the intriguing problems of design and the enthusiasm to realize their solutions.

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