Cryocooler and Front-End Integration

Peer Review

Michael Britcliffe
Jet Propulsion Laboratory, California Institute of Technology
Antenna Microwave Engineering Group
Section 333
Dec 18, 2003
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- Status
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- Cryocooler selection
- Description of Breadboard System
- Test Results
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Task Overview

- Select cryocooler for large array application
  - Long (>85000 hour) MTBF goal
  - Optimize 30 year life-cycle cost
- Design and test Unit#0 LNA package
  - Minimize fabrication cost
  - Simplified system design
  - Provide for Cryocooler options
- Design and test integrated front-end system
  - Cryocooler and vacuum system
  - Feed
  - Electronics
  - Monitor and control interfaces
- Provide 3 complete systems for Breadboard system
Cryocooler and Front-End Integration

**Status**

- Developed initial large array LNA cooler requirements
- Identified potential cryocoolers
- Designed and tested breadboard unit
- Designed and tested Feed Window
- Designed Cryogenic Controller
  - Designed and tested thermometer current source
  - Developed Thermometer software
  - Developed vacuum sensor software
  - Demonstrated operation with low-cost vacuum system
- Tested Integrated system
  - Cryogenic Performance
  -- Preliminary Noise Testing
- Adapted design for 6m antenna
Breadboard Requirements

- Cool Feed components to a maximum temperature of 60K
- Cool LNA modules to maximum of 20K
- Compact/ Lightweight-2 person handling
- Maximum heat loading
  - <5 watt first stage @ 60K
  - <1 watt second stage @20K
- “Generic” cryostat design for use with different coolers
- Emphasize simple design to minimize manufacturing cost
- Minimize power consumption
- Design passive components with >10 year life goal
## Noise Temperature Requirements

<table>
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<tr>
<th>X-Band 8.45 GHz</th>
<th>GOAL</th>
<th>MAX</th>
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<tr>
<td>LNA</td>
<td>6.14</td>
<td>12.4</td>
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<td>Antenna*</td>
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<td>5</td>
</tr>
<tr>
<td>SKY</td>
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<td>5</td>
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<tr>
<td>Total System Temperature</td>
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<table>
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<tr>
<th>Ka-Band 32 GHz</th>
<th>MAX</th>
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<td>LNA</td>
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<td>Antenna*</td>
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<td>SKY</td>
<td>15</td>
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<tr>
<td>Total System Temperature</td>
<td>39.6</td>
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</table>

*Antenna Contribution is from 34m measurements*
Cryocooler and Front-End Integration

Cryocooler Selection

- Initiated competitive procurement for suitable coolers
- Procured 3 potential coolers
  - CTI 350
  - CryoMech GB-15
  - Sunpower Cryotel
- No optimum currently available cooler
- CTI-350 is best choice
  - 1.8kw input power
  - 17000 hr MTBF in DSN operation
- CTI unit selected for Breadboard
- Sunpower Cryotel meets all requirements except for cold stage temperature (not trivial)
- An effort is underway to optimize the Sunpower for lower temperature operation
- An option using two Sunpower coolers is being designed
- Industry may be able to produce a cooler that meets all requirement with a $1-2M engineering effort
Signal Block Diagram

Ka LCP out

X LCP out

X-injection

X RCP out

KA RCP out

Ka-injection

LNA bias

Cryo Monitor

(.141 Coax)

30-dB

30-dB

30-dB

30-dB

(multi-conductor)
Cryocooler and Front-End Integration

Unit 0 LNA

LNA/Feed Internal View
Vacuum housing removed
Vacuum Housing Installed
Noise Temperature Measurements

- Preliminary noise temperature measurements were performed using existing DSN LNA modules
  - Special thanks to Jose Fernandez and Manuel Franco for developing wide-band noise temperature measurement
- DSN LNA modules are not normally used in wide band mode
  - No pre-filters
  - No Isolators
- Ka-band noise performance at 32 GHz as estimated but higher at band edges
- X-band noise performance meets specification but is higher than predicted
- Testing will resume using MMIC amplifiers more suitable to wide-band operation
Measured X-band Noise Temperature

10/6/2003 X-Band Roof Tests cryo at 15 K
Tlna=4K

Frequency, GHz

Te, K
Measured Ka-Band Noise Temperature

10/6/2003 Ka-Band Roof Tests cryo at 15 K
Tlna=10K

Te, K

Frequency, GHz
Cryocooler and Front-End Integration

LNA Assembly Weight

LNA Assembly Weight 30Kg Total

- Cooler: 28%
- Vacuum Housing: 39%
- Electronics: 6%
- Internal Hardware: 14%
- Feed: 13%
First Stage Heat Load
5 Watts Total

- G-10 supports 31%
- Residual Gas 1%
- Coax 3%
- Wiring 0%
- Radiation Total 65%
Second Stage Heat Load
1-Watt Total Load

- Feed Aperture Radiation: 51%
- Coax: 8%
- Wiring: 15%
- Residual Gas: 3%
- Radiation: 7%
- G-10 Supports: 16%
Feed Window

- Vacuum window considered a critical component
- Dewar pressure must remain below 1E 10^-5 Torr
- A membrane of .08mm Kapton is the vacuum seal
  - High strength
  - Low-loss
  - Low Resistance to UV (bad)
  - High permeability for H2O (maybe bad)
- Modeled after existing DSN R&D windows
  - 90 GHz Radiometer
  - Ultra-Low-Noise Maser
  - X/Ka
Cryocooler and Front-End Integration

Kapton/Foam Feed Window

- clamp ring
- .03mm Teflon
- .08mm Kapton
- window ring (aluminum)
- A-12 adhesive
- Feed Horn
- 22mm Propazote foam
- O-ring seal
Feed Window (cont)

- Kapton is backed up with high-strength Propazote foam
  - Reduces stress on Kapton
  - Low-loss
  - Propazote Foam may not be available (bad)
- Teflon sheet covers to block UV and water
  - 20 year life in radome service
  - low-loss
  - Blocks water vapor
- Kapton sized to have a factor-of-3 safety factor
  - Determined imperially from burst tests
- Measured noise contribution:
  - 1K @ 32 GHz
  - .2K @ 8.4 GHz
Cryocooler and Front-End Integration

Feed Window (cont)

- Original window has been cycled >150 cycles
- No evidence of degradation
- A solid Rexolite (cross-linked polystyrene) window is being developed
  - Low-loss solid with excellent mechanical performance
  - May be adversely effected by UV (bad)
  - Challenging microwave design
- Conclusion
  - More experience is needed to assess the long-term performance of the Kapton window
  - Alternatives exist
  - Easy to retrofit
  - Not a show-stopper
Sunpower Cooler

- The Sunpower Cryotel is a commercially available single stage cooler
  - 1 watt of cooling at 40K.
  - 19 watts at 70K
  - 160-250 watts input power compared to 1800 watts for CTI-350
  - 3kg mass
  - 80000 hour MTBF
  - Zero maintenance for life (sealed system)
- Does not meet 20K maximum temperature but meets all other requirements for performance
- A system with two coolers may still be a viable alternative
  - One cooler intercepts radiation and conduction loads at 70K
  - A separate cooler is used for LNA modules at 40K
A Ka-Band LNA was designed and constructed using a Sunpower cooler.

- **Performance**
  - 1 watt at 40K
  - 10-watts at 77K
  - 160-250 watt input power
  - Total weight 8kg
  - 1 hr cool down

- Results in the smallest lightest cryogenically cooled LNA ever constructed
Figure 1 - Location of electronics on 6m array antenna. The cryogenics compressor and servo box attach to the yoke above the azimuth bearing and rotate in azimuth. Cables from the servo box to motors and encoders do not need to go through wraps.
Cryocooler and Front-End Integration

Front-End Module
Breadboard Subreflector Shadow Mitigation

6m antenna subreflector shadow
12 M Plans

- The system designed for the 6m is fully adaptable to the 12m antenna
- The vacuum housing may be simplified for the 12m
  - Less difficult subreflector shadow constraint
- The outstanding issue is input power requirements
Cryocooler and Front-End Integration

Plans

- Continue system tests with Test Feed/LNA’s in unit#0
- Fabricate 3 Systems in FY04
- First Breadboard System due January 25
- One system cooled with two Sunpower coolers
- Complete Cryogenic Control System
- Complete design of Front-End-Enclosure
- Integrate front-end assembly and support installation on antenna
- Continue development of feed window
Milestone Dates

- Unit-0 Complete 9-2003
- Unit-0 Noise Temperature Testing Complete- 10-2003
- Breadboard Design Complete 12-2003
- Breadboard 1 ready for noise testing 2-2004
- Breadboard 2 ready 4-2004
- Breadboard 3 Ready (Sunpower Cooled ) 6-2004
- 12m PDCR 7-2004
Conclusion

- A LNA system that meets most requirements of the large array task has been designed and tested.
- The Requirements not met are:
  - 80000 hr MTBF (expected is 17000)
  - Input Power Requirement remains 1.8KW
- The long term life of the feed window is a concern
  - An alternate window is under development
- Work should continue on developing a source for an ideal cryocooler
Backup Charts
### X-Band Noise Budget (S. Petty/M. Britcliffe)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LOSS L (dB)</th>
<th>PHY TEMP T(K)</th>
<th>GAIN G (dB)</th>
<th>Tin (K)</th>
<th>NOISE (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Goal</td>
<td>Max</td>
<td>Goal</td>
<td>Max</td>
<td>Goal</td>
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<tr>
<td>MISMATCH LOSS, VACUUM WINDOW (INCLUDED IN VAC WINDOW RESISTIVE LOSS TERM BELOW)</td>
<td>0.00</td>
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<tr>
<td>X-BAND COMBINERS ISOLATION NOISE TERM. ISOLATION = 26 dB GOAL, 23 dB MAX</td>
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<td>X-BAND POLARIZER ISOLATION NOISE TERM. ISOLATION = 23 dB GOAL, 20 dB MAX</td>
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<td>VACUUM WINDOW</td>
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<tr>
<td>GOAL: 11mil Teflon, 3mil Kapton, 1&quot; Propozote</td>
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<tr>
<td>FEEDHORN</td>
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<td>TEFLON TORPEDO/FOAM SUPPORT</td>
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<td>Waveguide Cu 1.5 INCHES</td>
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<td>SLOT COMBINER</td>
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<td>SLOT COMBINER</td>
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<td>MAX: COUPLER SEPARATE (Same performance)</td>
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<td>0.141 OUTPUT COAX, 12K-70K</td>
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<td>0.141 OUTPUT COAX, 70K-293K</td>
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<td>RECEIVER ASSY</td>
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**INPUT NOISE TEMP Te(K):** 6.14 | 12.35
### Ka-Band Noise Budget (S.Petty/M.Britcliffe)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LOSS L (dB)</th>
<th>PHY TEMP T(K)</th>
<th>GAIN G (db)</th>
<th>T_{in} (K)</th>
<th>NOISE (K)</th>
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<tbody>
<tr>
<td></td>
<td>Goal</td>
<td>Max</td>
<td>Goal</td>
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<tr>
<td>MISMATCH LOSS, VACUUM WINDOW (INCLUDED IN VAC WINDOW RESISTIVE LOSS TERM BELOW)</td>
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<td>Ka-BAND POLARIZER ISOLATION NOISE TERM. ISOLATION = 20 dB GOAL, 17 dB MAX</td>
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<td>GOAL: 11mil Teflon, 3mil Kapton, 1&quot; Propozote</td>
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<td>GOAL: COUPLER INTEGRATED IN MMIC MODULE</td>
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<td>MAX: COUPLER SEPARATE</td>
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<td>MMC HEMT MODULE</td>
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INPUT NOISE TEMP T_e(K): 18.6 30.2