Cryocooler and Front-End Integration Peer Review

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Section 333

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Cryocooler and Front-End Integration

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

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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

Cryocooler and Front-End Integration

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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

X-Band 8.45 GHz		
	GOAL	MAX
LNA	6.14	12.4
Antenna*	5	5
SKY	5	5
Total System Temperature	16.14	22.4

Ka-Band 32 GHz		
		MAX
LNA	18.6	30.2
Antenna*	6	6
SKY	15	15
Total System Temperature	39.6	51.2

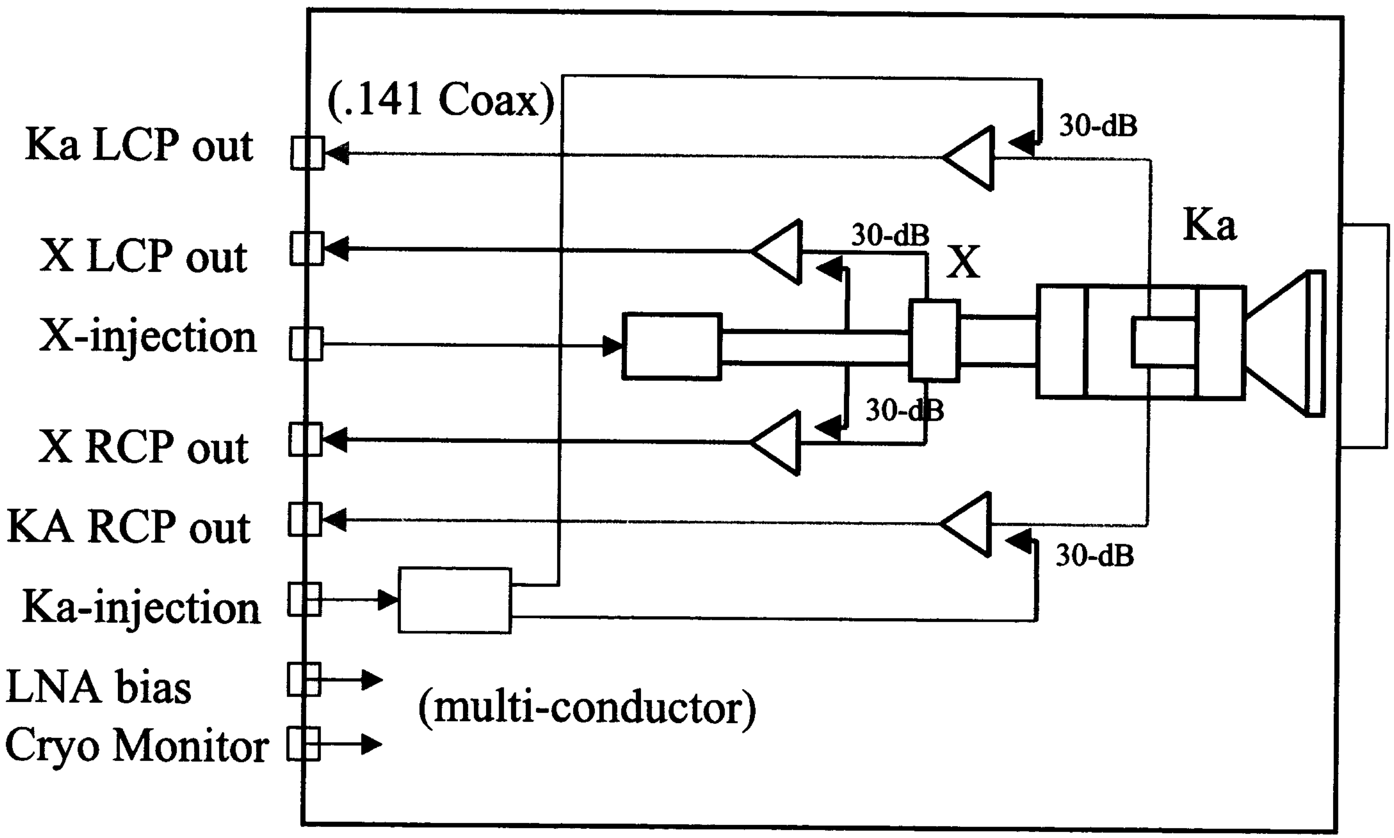
*Antenna Contribution is from 34m measurements

Cryocooler Selection

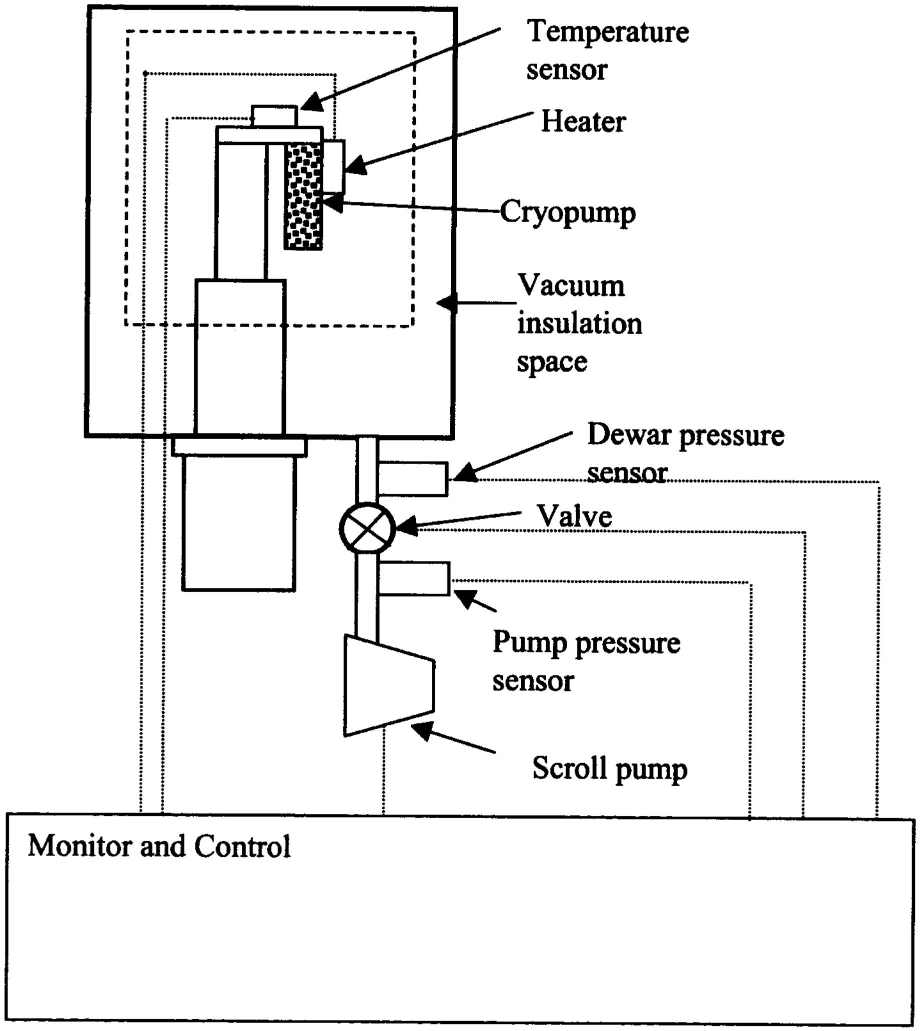
- Initiated competitive procurement for suitable coolers
- Procured 3 potential coolers
  - CTI 350
  - CryoMech GB-15
  - Sunpower Cryotel
- No optimum currently available cooler
- CTI-350 is best choice
  - 1.8kw input power
  - 17000 hr MTBF in DSN operation
- CTI unit selected for Breadboard
- Sunpower 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

Cryocooler and Front-End Integration

Signal Block Diagram



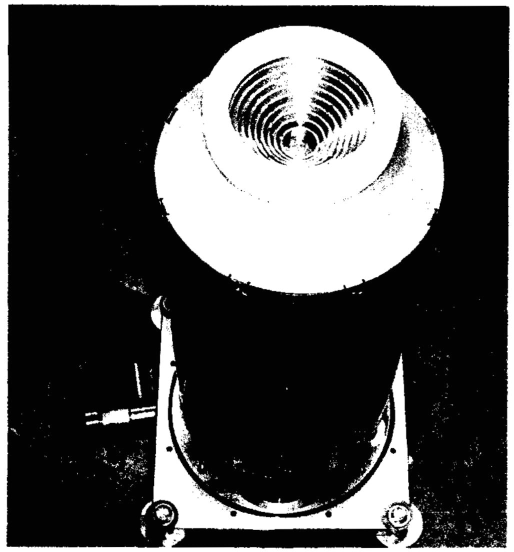
Cryogenic Monitor and Control Interface



Cryocooler and Front-End Integration

Unit 0 LNA

LNA/Feed Internal View



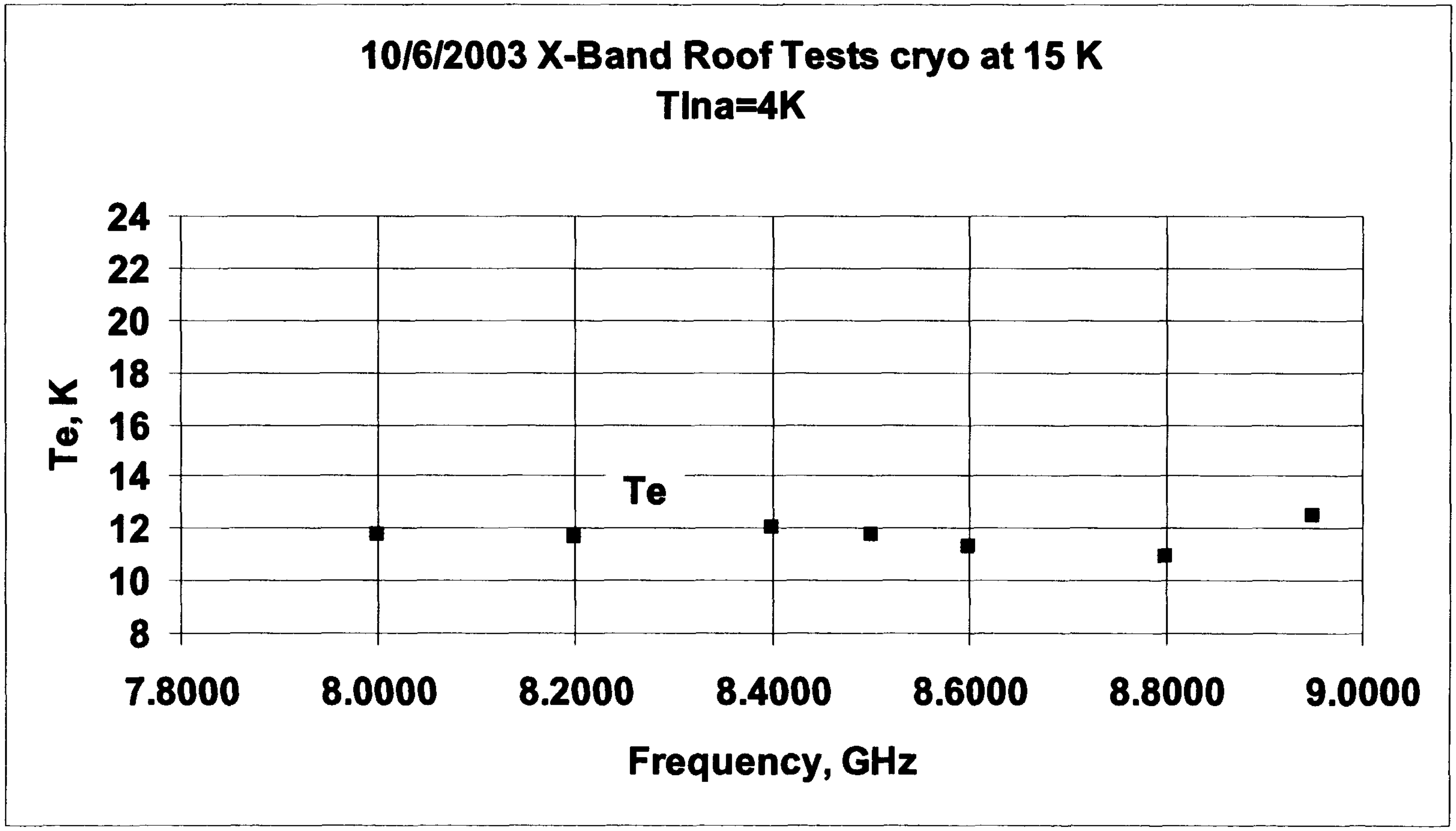
Vacuum housing removed

Vacuum Housing Installed

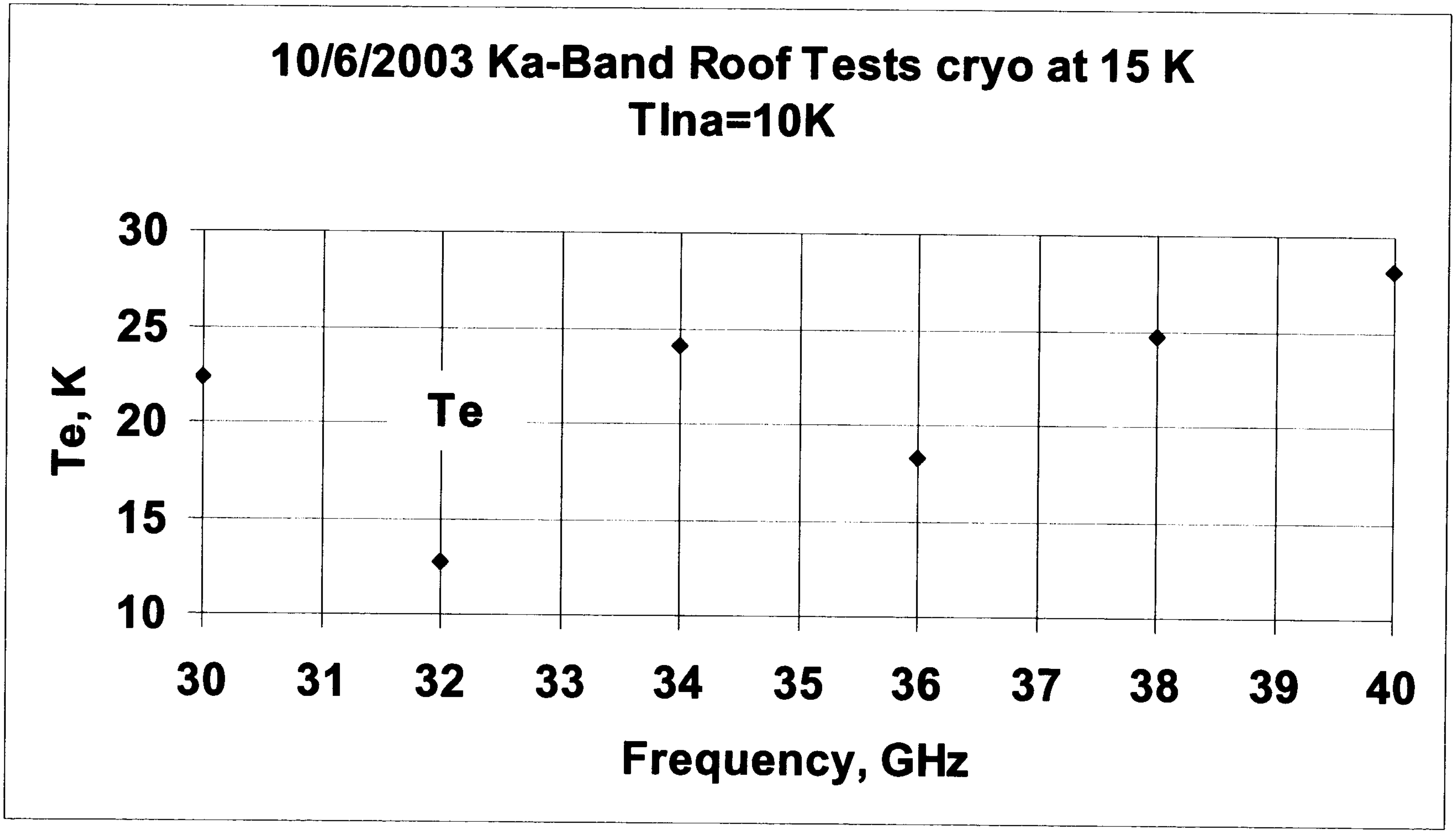
Noise Temperature Measurements

- 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

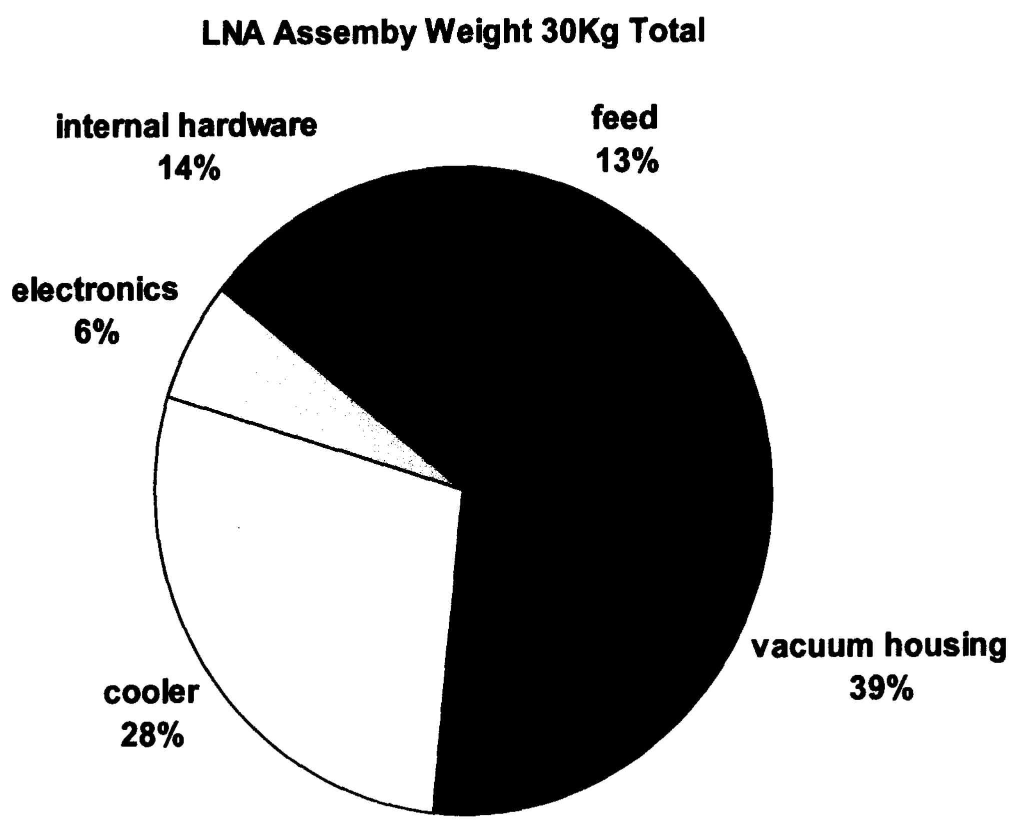
Measured X-band Noise Temperature



Measured Ka-Band Noise Temperature



LNA Assembly Weight



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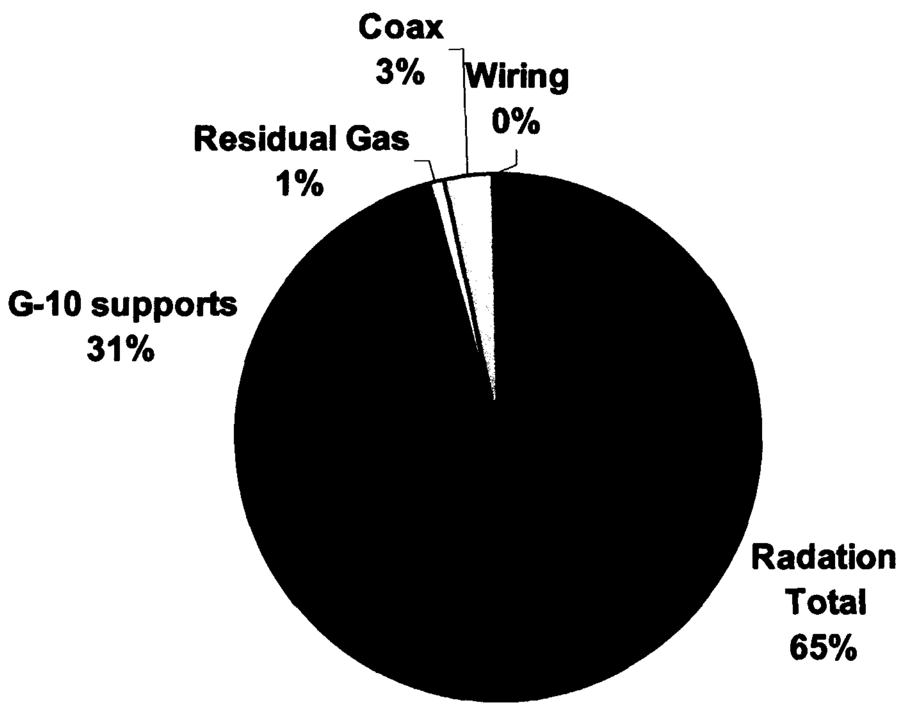
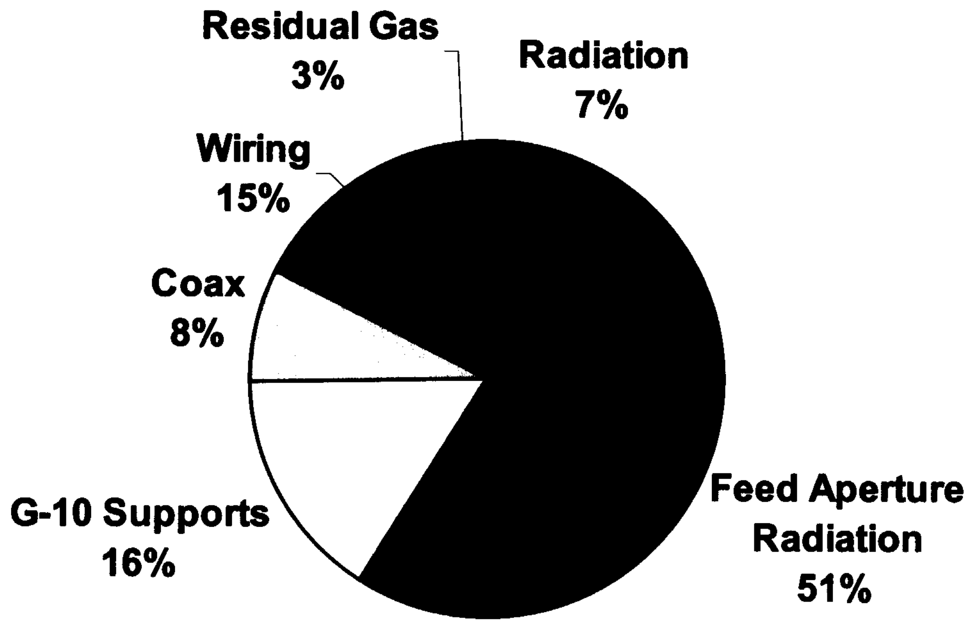
First Stage Heat Load
5 Watts Total



Cryocooler and Front-End Integration

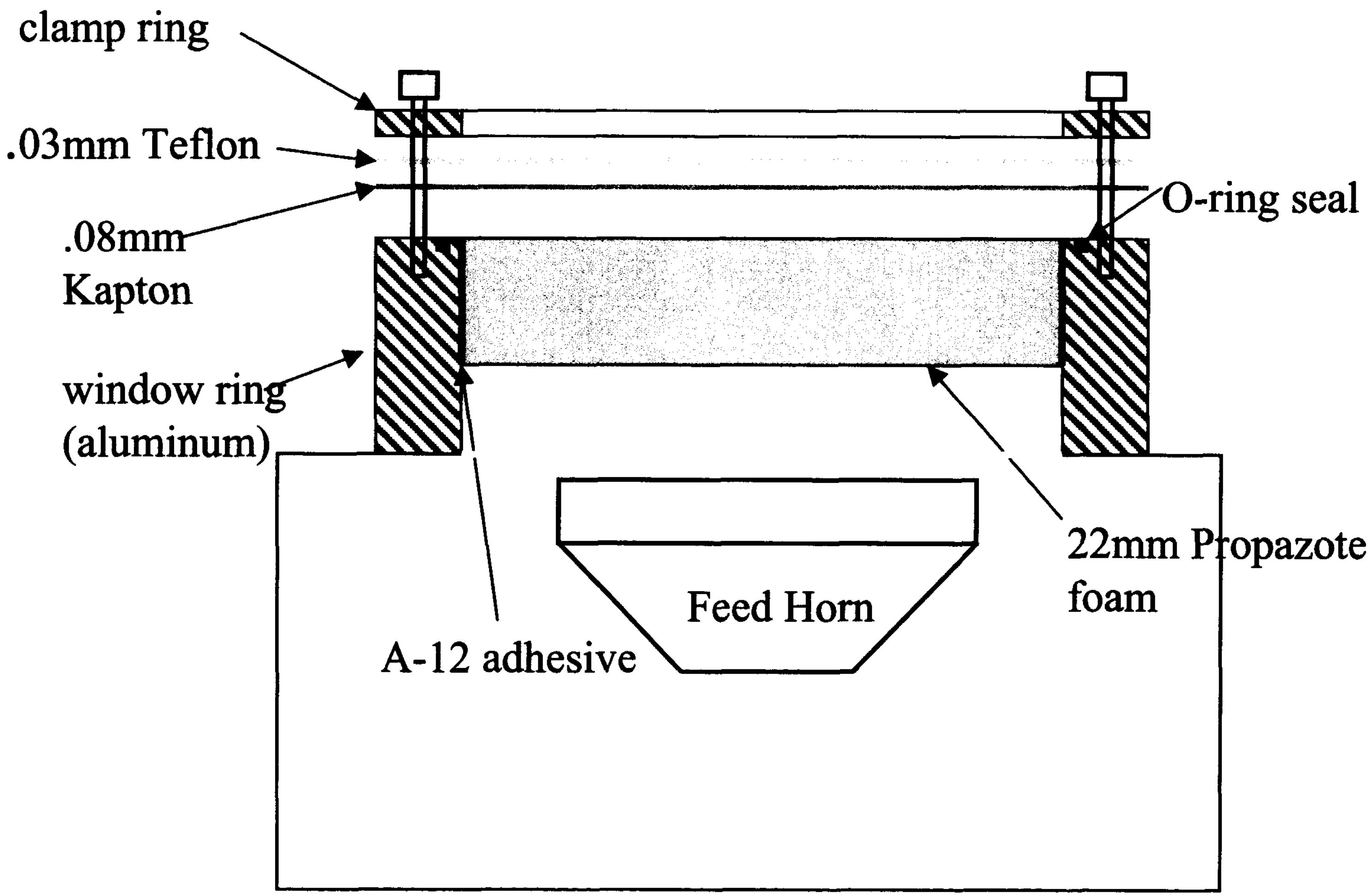
Second Stage Heat Load
1-Watt Total Load



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

Kapton/Foam Feed Window



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

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

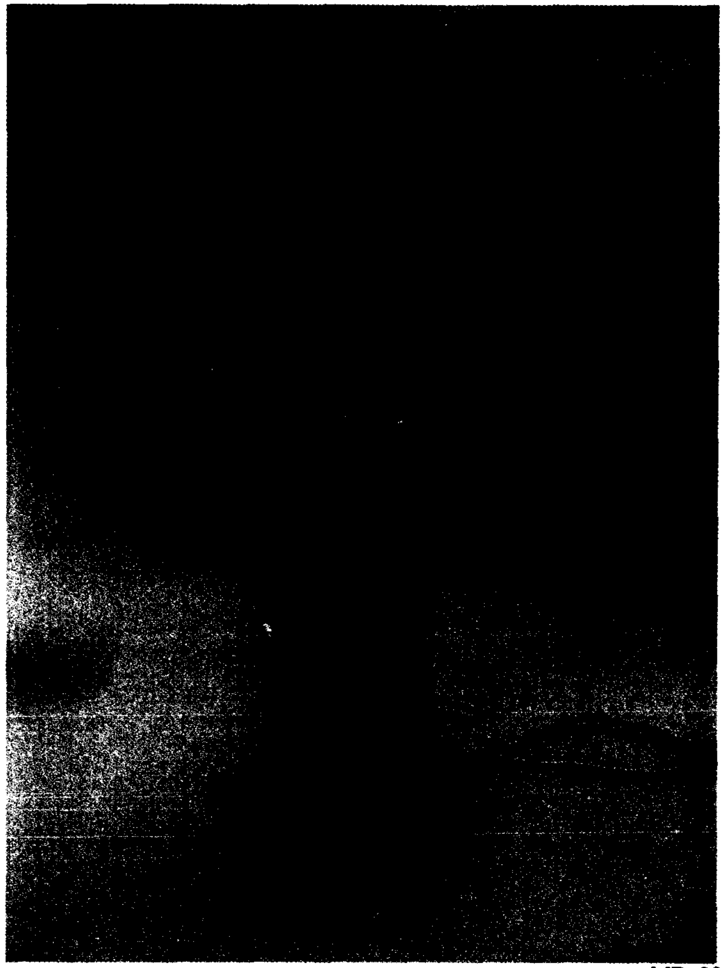
Sunpower Cooler

- 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

Cryocooler and Front-End Integration

Sunpower Ka-Band Test Bed

- 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



LNA Equipment Layout on Antenna

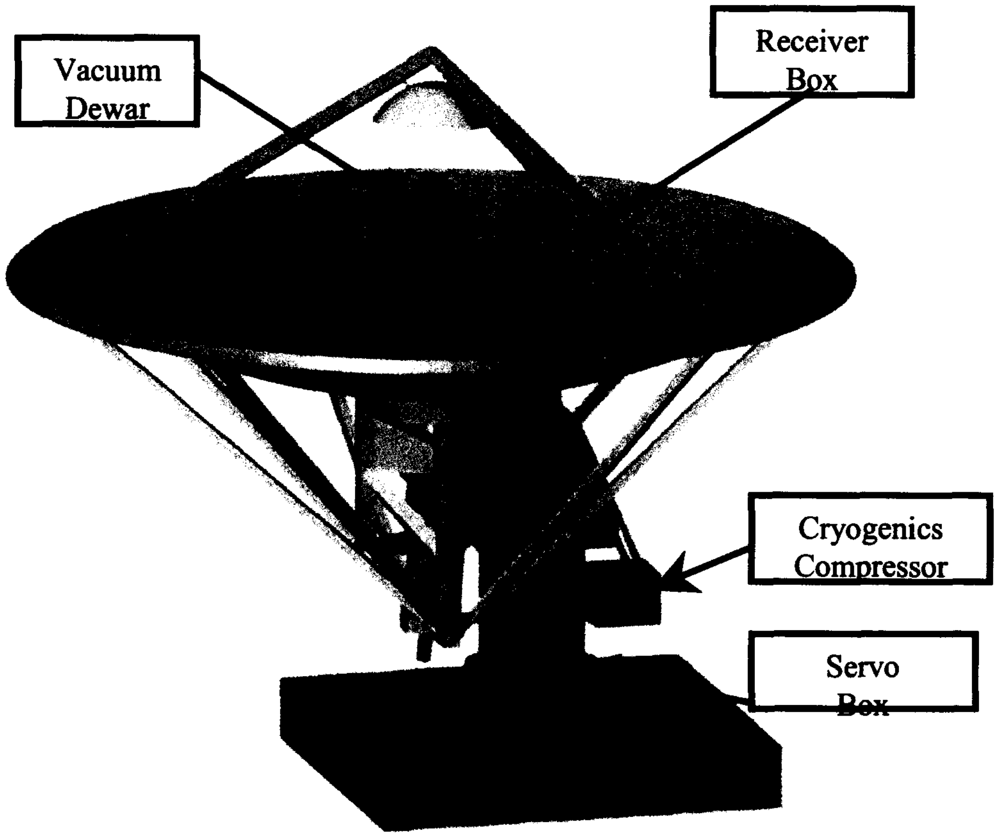
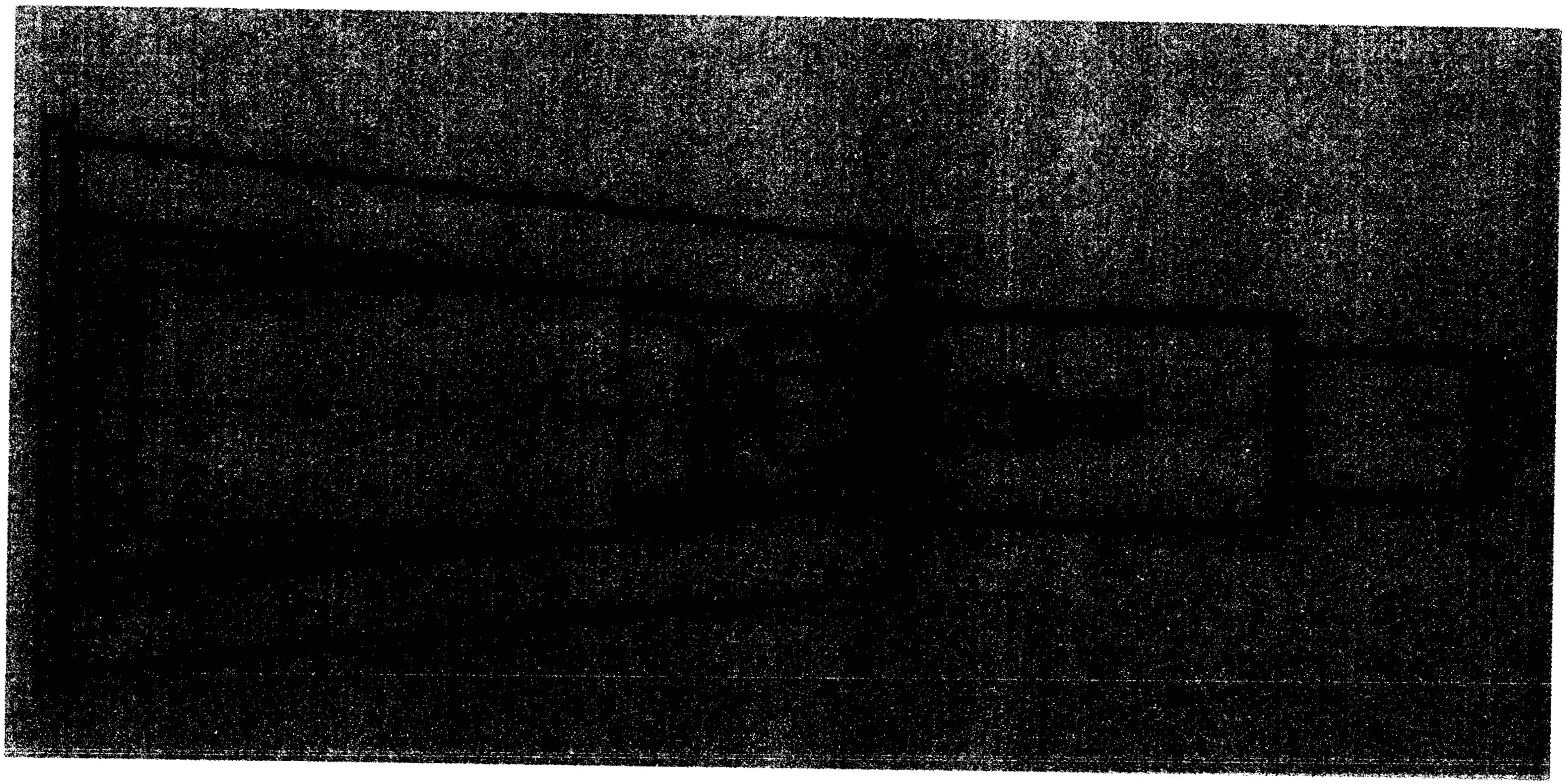
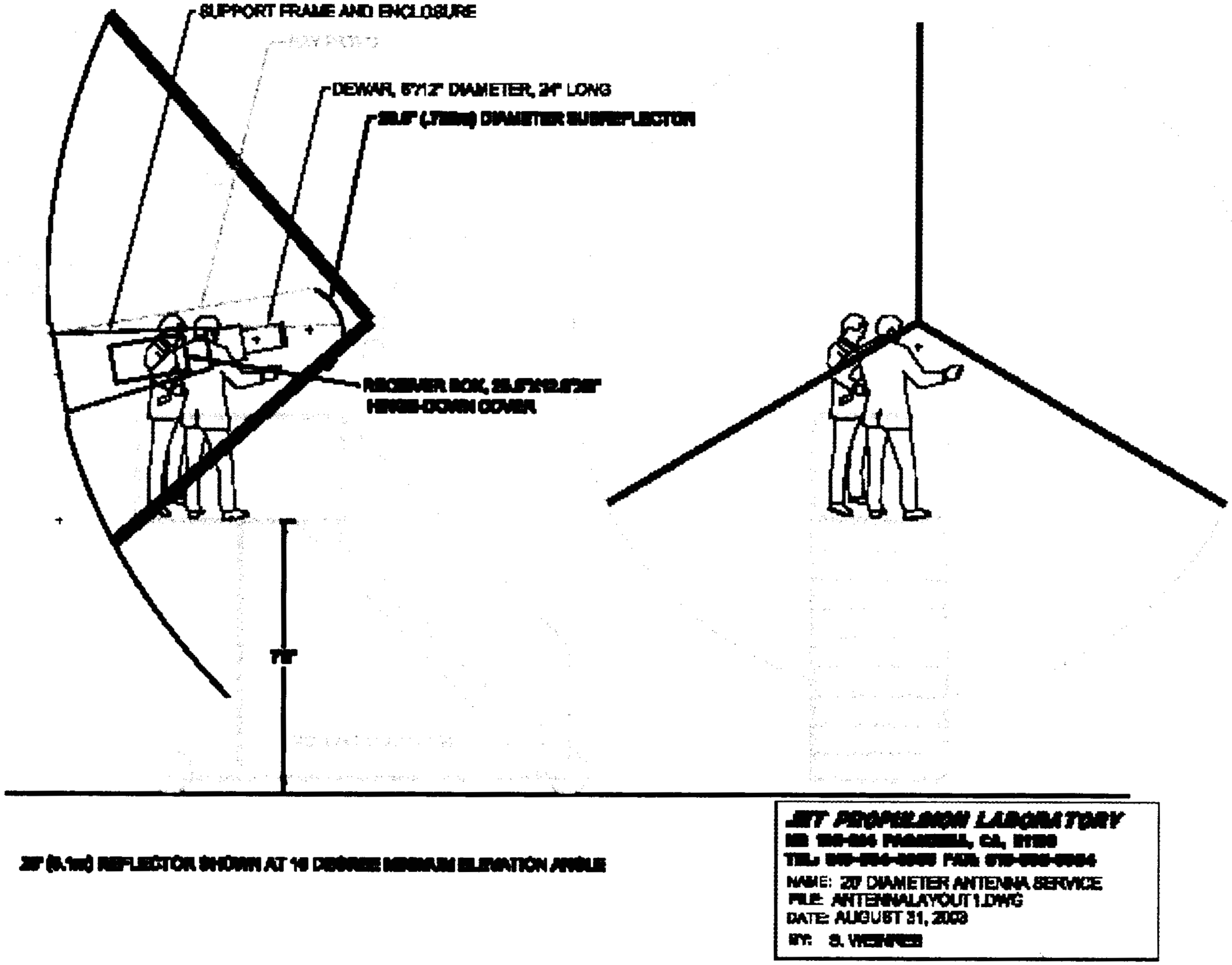


Figure 1 - Location of electronics on 6m array antenna. The cryogenics compressor and servo box attach to the yoke above the azimuth bearing and rotate in azimuth. Cables from the servo box to motors and encoders do not need to go through wraps.

Front-End Module

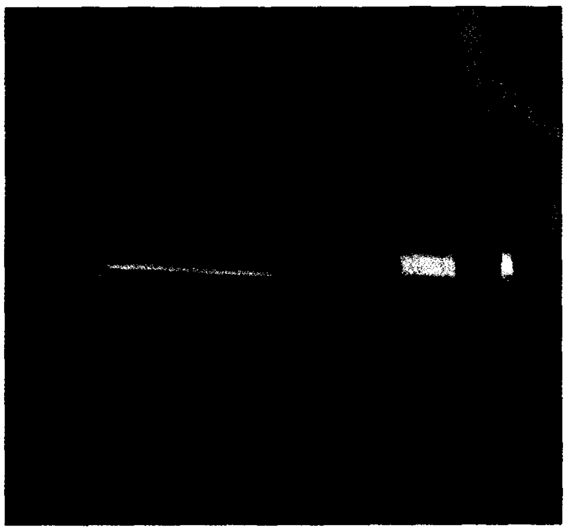


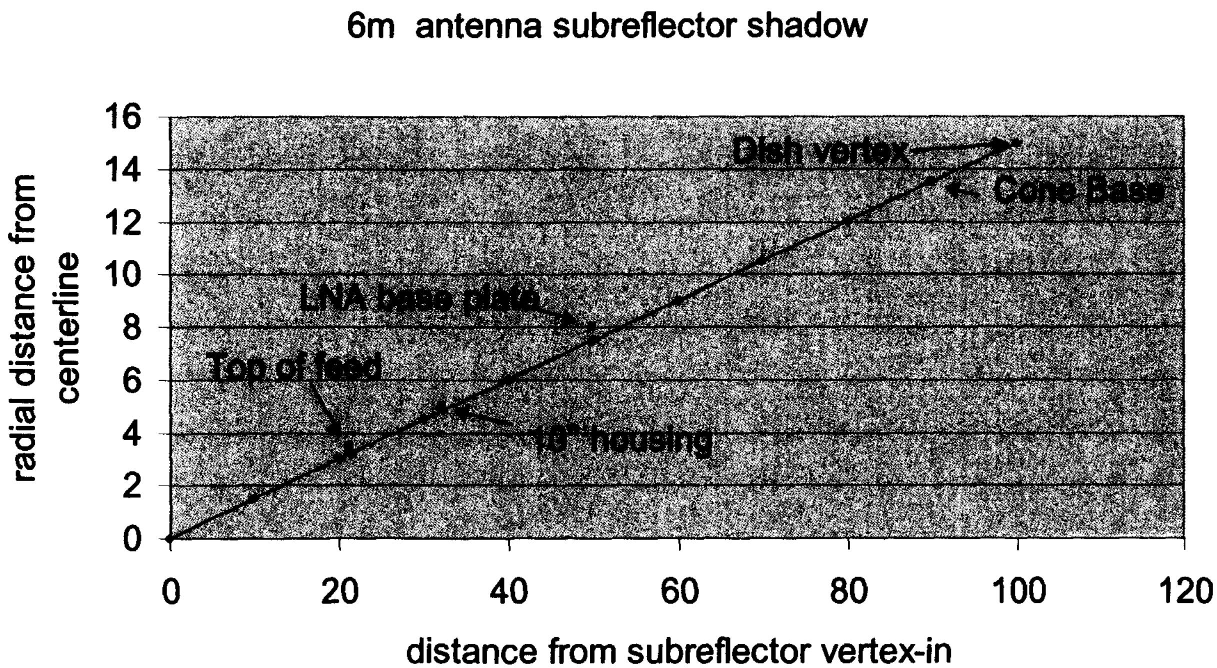
Cryocooler and Front-End Integration



Cryocooler and Front-End Integration

Breadboard Subreflector Shadow Mitigation





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

Cryocooler and Front-End Integration

X-Band Noise Budget (S.Petty/M.Britcliffe)

ITEM	LOSS L (dB) Goal	LOSS L (dB) Max	PHY TEMP T(K) Goal	PHY TEMP T(K) Max	GAIN G (dB) Goal	GAIN G (dB) Max	Tin (K) Goal	Tin (K) Max	NOISE (K) Goal	NOISE (K) Max
MISMATCH LOSS, VACUUM WINDOW (INCLUDED IN VAC WINDOW RESISTIVE LOSS TERM BELOW)									0.00	0.00
X-BAND COMBINERS ISOLATION NOISE TERM. ISOLATION = 26 dB GOAL, 23 dB MAX									0.03	0.06
X-BAND POLARIZER ISOLATION NOISE TERM. ISOLATION = 23 dB GOAL, 20 dB MAX									0.06	0.12
VACUUM WINDOW	0.004	0.015	293	293					0.29	1.00
GOAL: 11mil Teflon, 3mil Kapton, 1" Propozote										
MAX: 11 mil Teflon, 0.25" Rexolite, 1" Propozote										
FEEDHORN	0.008	0.014	50	60					0.10	0.19
TEFLON TORPEDO/FOAM SUPPORT	0.015	0.020	20	30					0.07	0.14
Waveguide Cu 1.5 INCHES	0.002	0.003	15.0	18.0					0.01	0.01
SLOT COMBINER	0.025	0.050	14.0	16.0					0.08	0.19
WR112 7.5 INCHES STRAIGHT, 2 MITER BENDS	0.027	0.050	13.0	15.0					0.08	0.18
SLOT COMBINER	0.025	0.050	13.0	15.0					0.08	0.18
HYBRID POLARIZER	0.030	0.050	13.0	15.0					0.09	0.18
WR BEND	0.006	0.008	13.0	14.0					0.02	0.03
WR CAL COUPLER (LOSS)	0.025	0.035	13.0	14.0					0.08	0.12
WR CAL CPLR (INJ NOISE)	30.0	29.0	293	293					0.30	0.39
GOAL: COUPLER INTEGRATED IN MMIC MODULE										
MAX: COUPLER SEPARATE (Same performance)										
WR/SMA MALE ADAPTER	0.090	0.120	13.0	6.9					0.28	0.21
MMIC HEMT MODULE					35.0	31.0	4.00	7.00	4.24	7.70
0.141 OUTPUT COAX, 12K-70K	0.56	0.67	50	50					0.00	0.01
0.141 OUTPUT COAX. 70K-293K	0.56	0.67	210	210					0.01	0.04
LOSS BETW VAC FEEDTHRU, RCVR ASSY	0.40	0.50	293	293					0.01	0.04
RECEIVER ASSY							150	250	0.15	0.90
INPUT NOISE TEMP Te(K):									6.14	12.35

Cryocooler and Front-End Integration

Ka-Band Noise Budget (S.Petty/M.Britcliffe)

ITEM	LOSS L (dB)		PHY TEMP T(K		GAIN G (dB		Tin (K)		NOISE (K)	
	Goal	Max	Goal	Max	Goal	Max	Goal	Max	Goal	Max
MISMATCH LOSS, VACUUM WINDOW (INCLUDED IN VAC WINDOW RESISTIVE LOSS TERM BELOW)									0.00	0.00
Ka-BAND POLARIZER ISOLATION NOISE TERM. ISOLATION = 20 dB GOAL, 17 dB MAX									0.25	0.35
VACUUM WINDOW	0.015	0.038	293	293					1.01	2.57
GOAL: 11mil Teflon, 3mil Kapton, 1" Propozote										
MAX: 11mil Teflon, 0.25" Rexolite, 1" polystyrene										
FEEDHORN	0.020	0.032	50	60					0.23	0.45
TEFLON TORPEDO/FOAM SUPPORT	0.045	0.060	20	30					0.21	0.42
Round WG Cu 4.0 INCHES	0.004	0.006	15.0	18.0					0.01	0.03
HYBRID POLARIZER	0.050	0.075	13.0	15.0					0.15	0.27
WR28 WAVEGUIDE BEND	0.005	0.005	13.0	15.0					0.02	0.02
WR28 30dB CAL COUPLER (LOSS)	0.060	0.060	13.0	15.0					0.19	0.22
WR28 30dB CAL CPLR (INJ NOISE)	30.0	29.0	293	293					0.31	0.39
GOAL: COUPLER INTEGRATED IN MMIC MODULE										
MAX: COUPLER SEPARATE										
MMIC HEMT MODULE					40.0	38.0	15	22	15.70	23.44
OUTPUT COAX, 12K-70K, 8 IN. LONG	2.00	2.50	50	50					0.00	0.01
OUTPUT COAX. 70K-293K, 8 IN. LONG	2.00	2.50	210	210					0.02	0.05
LOSS BETW VAC FEEDTHRU, RCVR ASSY	1.00	1.40	293	293					0.02	0.06
RECEIVER ASSY							600	800	0.42	1.59
INPUT NOISE TEMP Te(K):									18.6	30.2