DSS-28 Implementation Preliminary Definition & Cost Review

Lewis Center for Educational Research

Jet Propulsion Laboratory
California Institute of Technology

Radiometer System

Sander Weinreb
February 15, 2006

GAVRT

Radiometer System PDCR Outline

- Introduction – principle objectives
- Available existing design resources – Spin On’s
- Design plan
- Block diagram and Interfaces
- Expected antenna efficiency and radiometer sensitivity
- Operation, maintenance, and safety.
- Interferometer operation
- Cost Estimate

Design Objectives and Principles

- Meet the GAVRT educational program requirements
- Make use of JPL and Caltech developments to give the system unique capabilities
  - Commercial wideband feeds for 2:1 or 3:1 bands
  - Caltech-developed wideband cryogenic InP MMIC LNA's – 5K noise from 1 to 14 GHz for $5K!
  - Downconverter and IF processor being developed by Caltech under contract to U. of Arizona for 64 element sub-mm radiometer array
  - Utilize monitor and control hardware and packaging concepts developed by JPL for DSN array
- Build to cost – allow variables for number of 1 GHz bandwidth spectrometers and gaps in 1.2 to 14 GHz frequency coverage
- Flexible optics to allow quick change or upgrade of receivers
- Involve Caltech graduate students and research technician

Octave+ Bandwidth Commercial Feeds

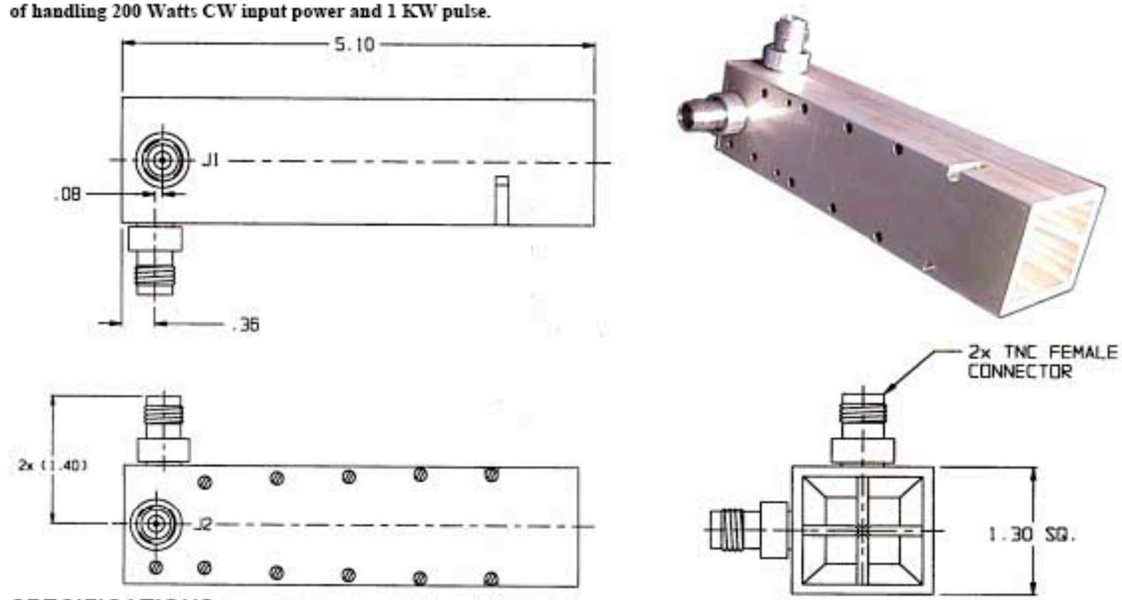
Commercial 6 to 18 GHz Feed

- Could be scaled to 4.5 to 13.5 GHz
- C, X , and Ku Bands
- Small size accommodates cryogenic cooling

m·e·c	DUAL-POLARIZED HORN ANTENNAS C390-205	DATA SHEET No: T161

DESCRIPTION

MEC's model C390-205 is a 3:1 bandwidth broadband quad-ridge horn antenna operating from 6 to 18 GHz. The antenna which has dual-orthogonal input ports provides polarization diversity. The inputs are TNC female connectors. The antenna is capable of handling 200 Watts CW input power and 1 KW pulse.



SPECIFICATIONS:

Frequency	6 – 18 GHz
Gain	6 – 14 dBil
3-dB Beamwidth	80° - 30° E-plane
	74° - 38° H-plane
Polarization	Dual linear vertical / horizontal, or both
	Circular polarizable available with additional hybrid
VSWR	2.0:1 max.

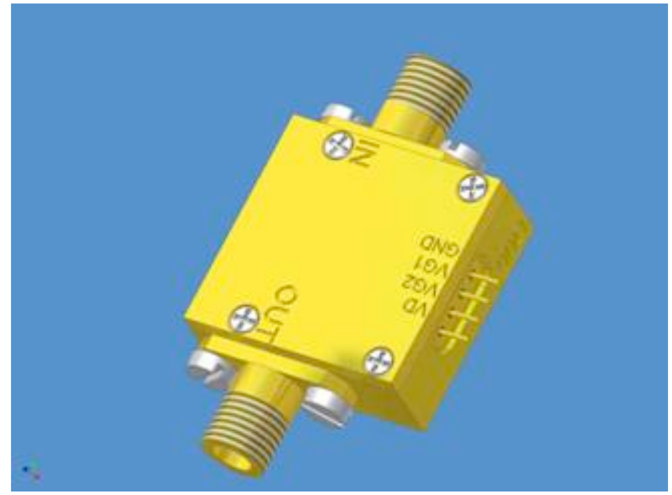
Caltech-Developed Cryogenic LNA's

3 Models, @ 12K

0.5 to 11 GHz, Tn < 5K

4 to 14 GHz, Tn < 8K

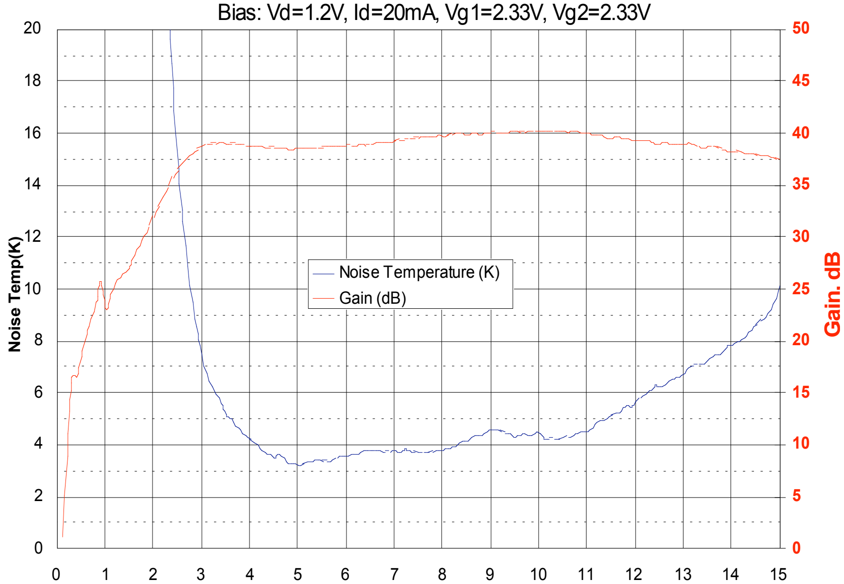
6 to 20 GHz, Tn < 12K



4-12GHz LNA #82D at 12K

MMIC: WBA13, CIT1 4254-065 , R8C2

Bias: Vd=1.2V, Id=20mA, Vg1=2.33V, Vg2=2.33V

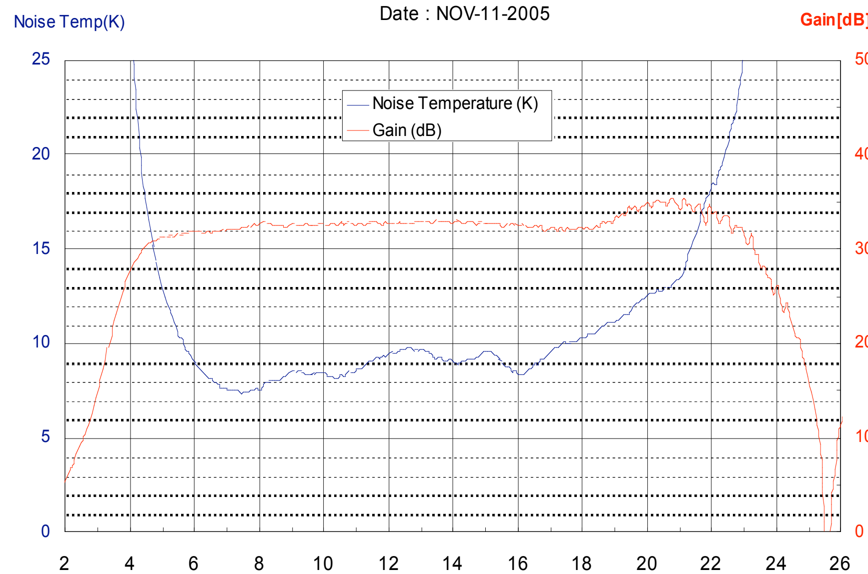


6-18GHz LNA #40A03 at 12K

MMIC WBA618 R7C1M0 CRYO10-4292-014, Bias: Vd=0.65V, Id=16mA

, Vg1=1.9V , Vg2=1.9V

Date : NOV-11-2005

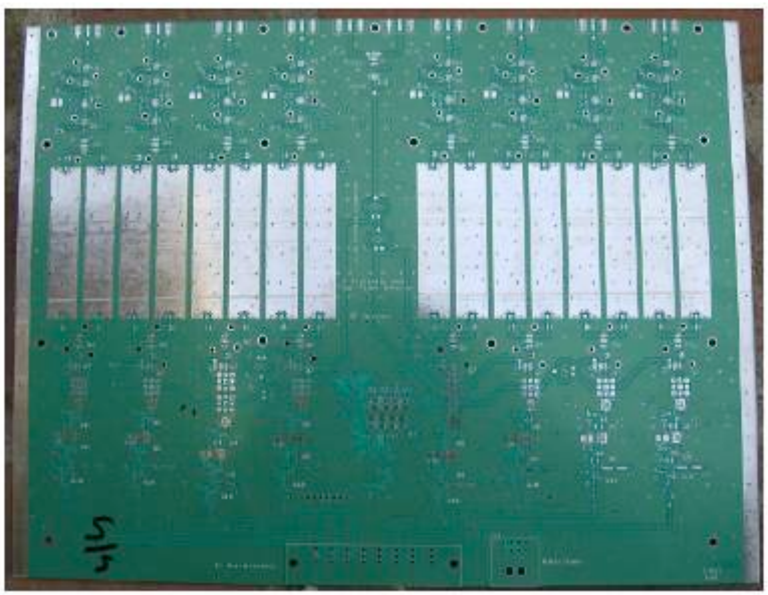


Caltech Downconverter Development

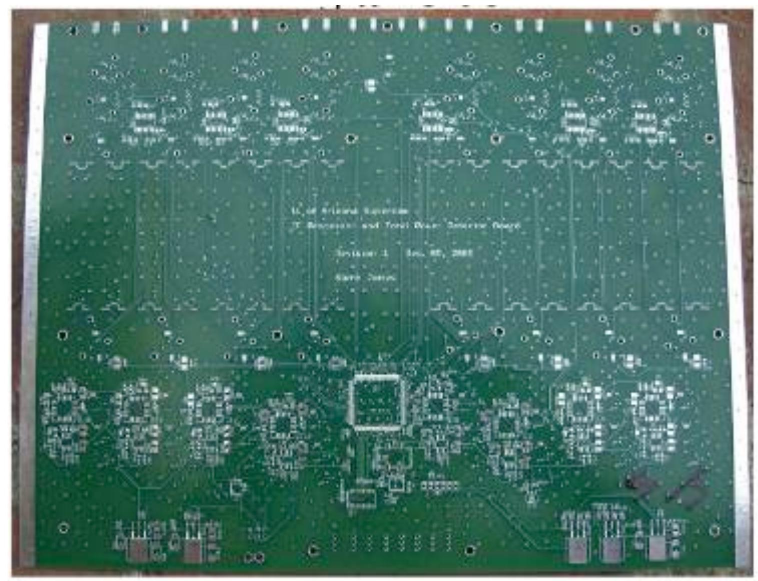
- Caltech is designing a low-cost downconverter for the 64-element millimeter wave camera (Supercam) at U. of Arizona

- Eight channels of conversion, amplification, gain control, switched filtering, detection, integration, and serial interface are on one 9” x 11” printed circuit board.

RF Side of Board

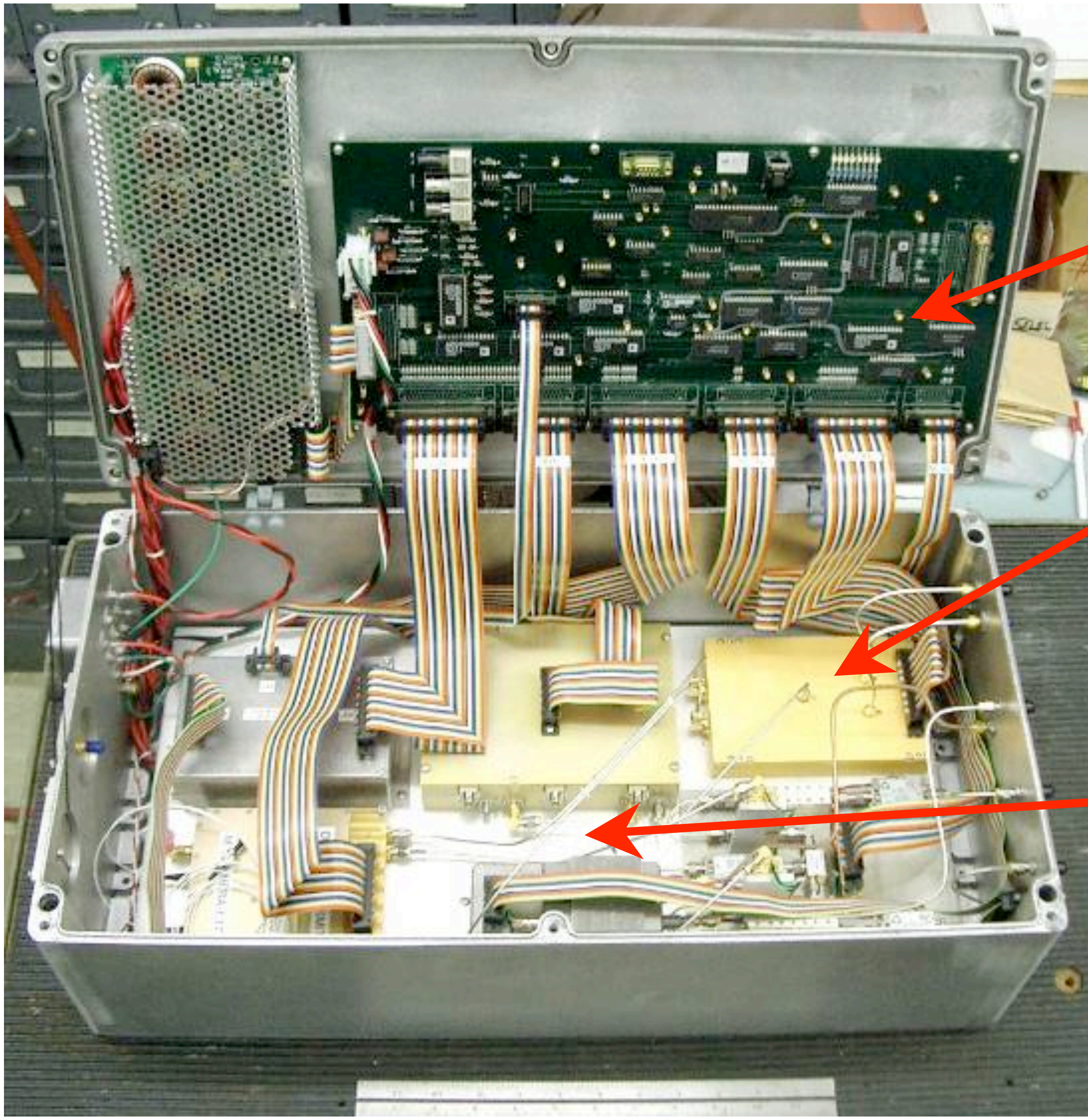


Power and M/C Side



Spin-Off from DSN Array

Compact, low-cost, stable, maintainable, RF packaging.

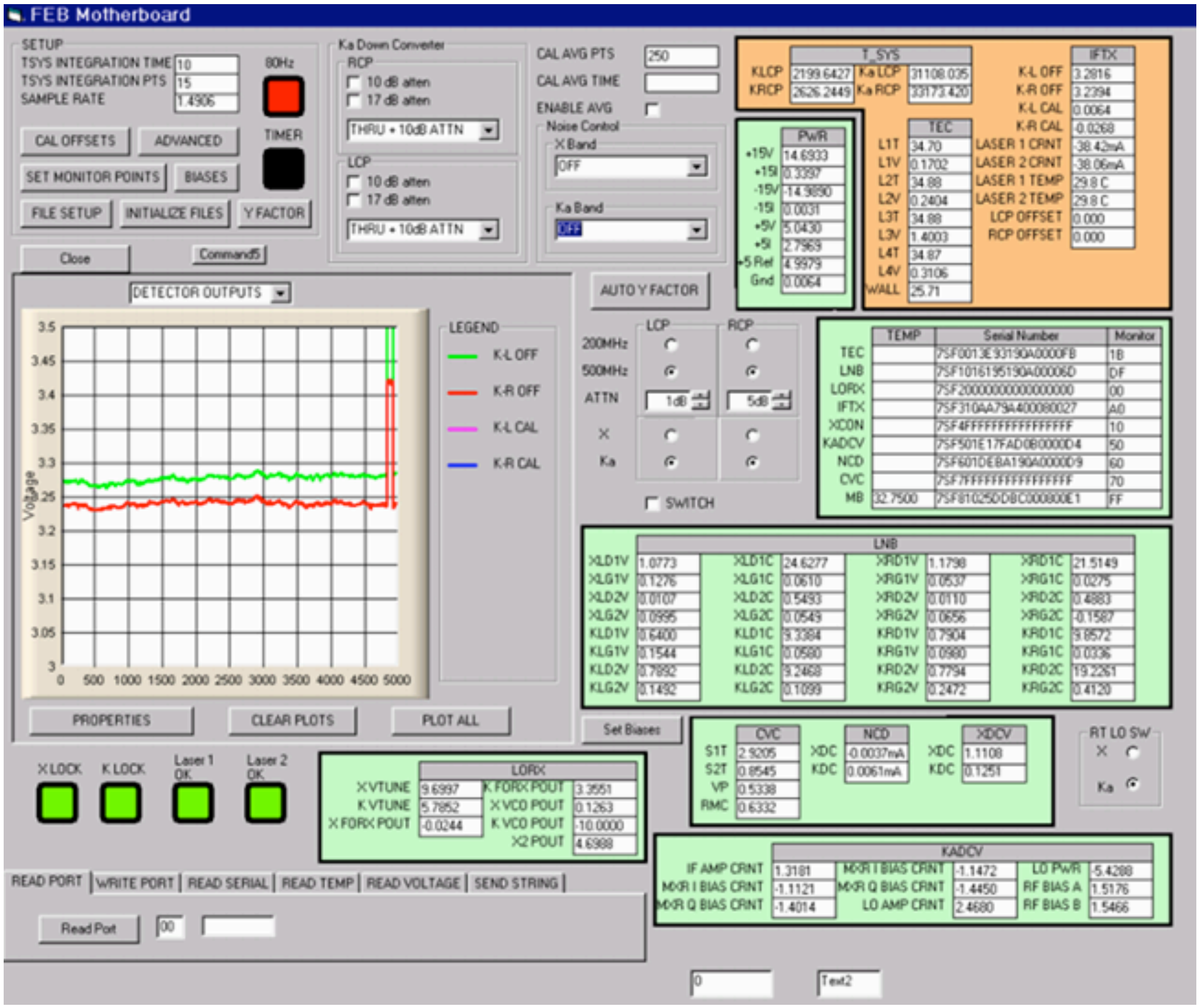


Motherboard provides monitor, control, and power distribution

Dual Ka band downconverter

Temperature controlled plate for receiver stability

System Maintenance Software – DSN Array Spinoff

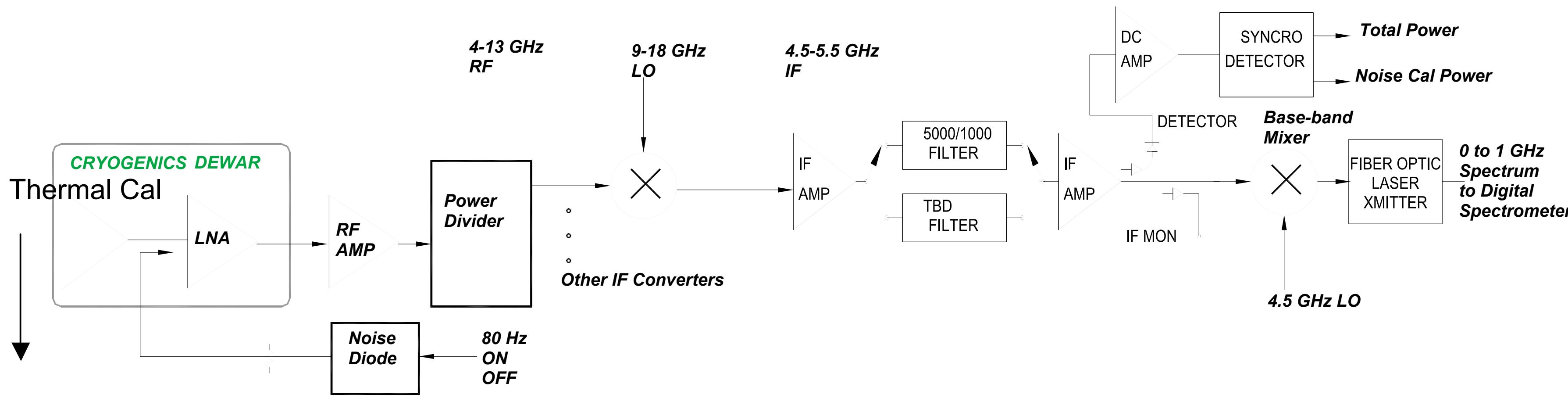


FY06 Design Study

- RFI Study at Goldstone
  - Process started to measure statistics of RFI in the 0.7 to 18 GHz range at Goldstone. RFI > - 55dBm received by an isotropic antenna at any frequency within the feed and LNA bandwidth will cause LNA gain compression. Measurements so far have not found such high level signals.
  - The RFI must be much lower in the band being the observed by DSS28 - in the -120 dBm to -160dBm range but this is beyond the sensitivity of the current survey.
- Octave+ Bandwidth Feeds
  - There are commercially-available feeds with 2.25:1 and 3:1 bandwidth. We are assessing the efficiency of these feeds by using the vendor-supplied patterns in the optics study of efficiency. One 5.7 – 13.0 GHz feed has been purchased and will be tested at 15K with an LNA in the next few months. Purchase and tests of a 3:1 prototype feed, 4.6 – 13.8 GHz is planned as part to the study to evaluate patterns, cooling effects, and impedance match.
- System Design
  - Develop complete block diagram, cost estimate, and implementation plan by the end of 2006 – a JPL/Caltech collaboration with Caltech funded directly by LCER and prototype components purchased by LCER.

System Design Study and Current Point Design

Simplified System Block Diagram



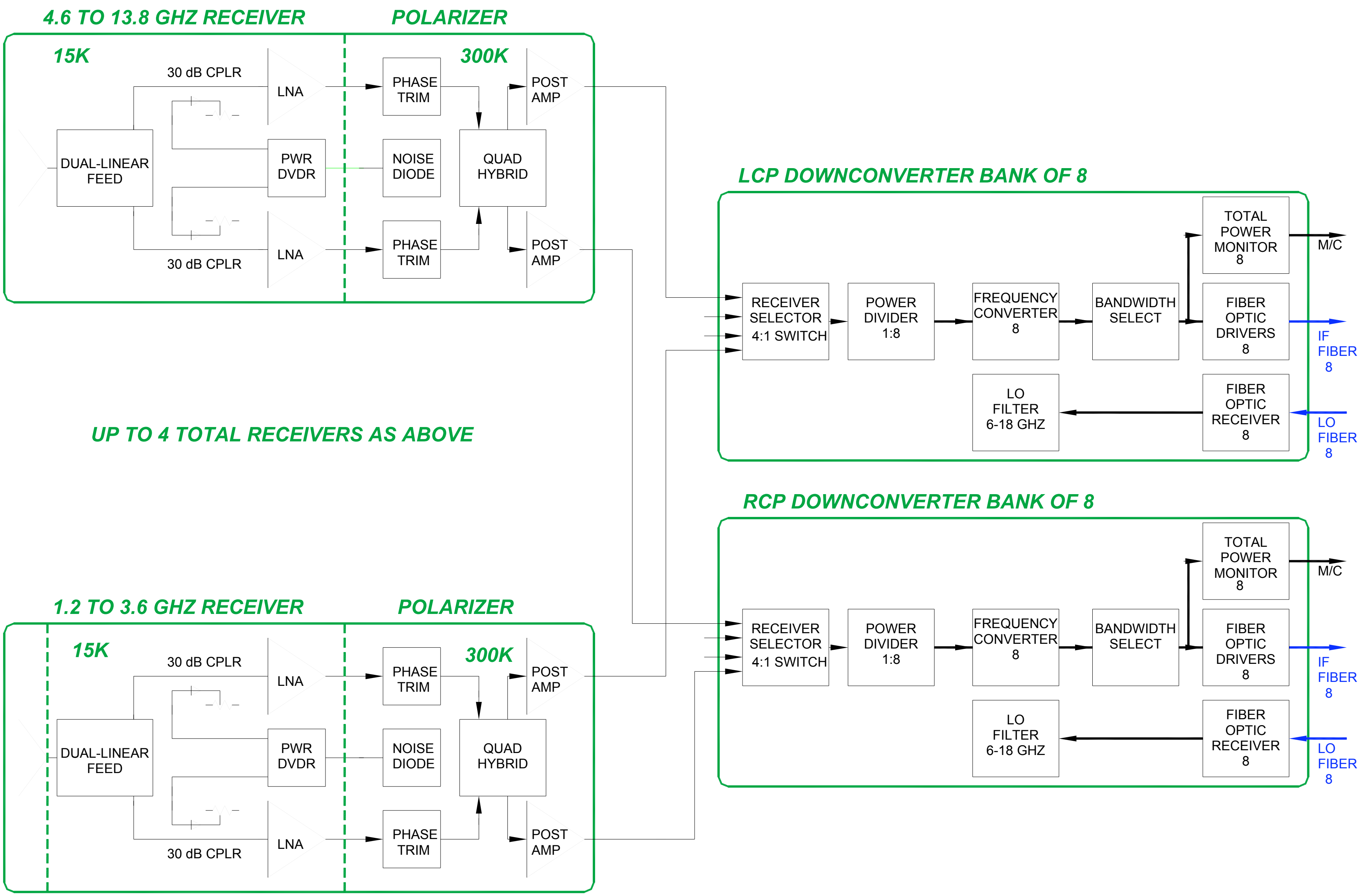
1) Where is fiber optic link – RF, IF, or baseband? – **Baseband, because of lower cost and lower dynamic range requirement. For stability reasons, the continuum total power detector signal does not go through the fiber**

2) Small or large noise cal? – **Both, 2% and 20% of Tsys**.

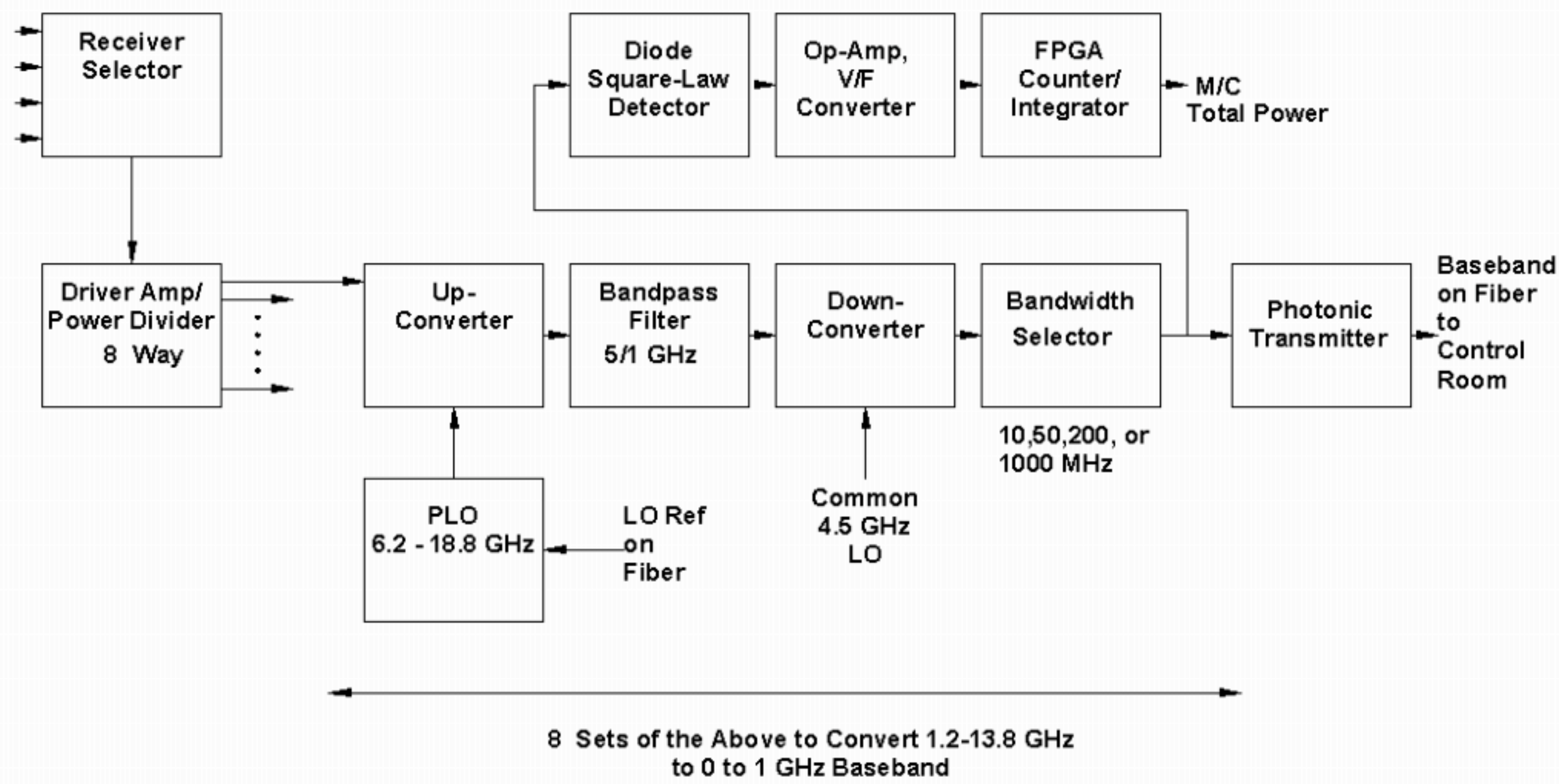
3) Alternative I/Q converters with low pass filters? – **No, too difficult to get image rejection desired for RFI**

4) How to insert RFI filters? – **Switched filters at baseband with bandwidths of 1000, 200, 50, and 10 MHz.**

DSS-28 Receiver System Block Diagram



Downconverter Block of Eight



Radiometric System Continuum Sensitivity

	Receiver <	1.2 to 3.6			4.6 to 13.8		
A	Test Frequency, GHz	1.4	2.3	3.6	5	8.4	13.8
B	Trcvr K	20	15	20	20	15	20
C	Tsys, K	35	25	35	35	25	35
D	Antenna efficiency	0.45	0.65	0.5	0.5	0.65	0.45
E	Jansky/K	6.8	4.7	6.1	6.1	4.7	6.8
F	Bandwidth, MHz	50	50	200	200	1000	1000
G	DT, mK, Inherent, Tsys/ √BT	4.9	3.5	2.5	2.5	0.8	1.1
H	DT, mK, Gain Stability, 1 sec	3.5	2.5	**3.5**	**3.5**	**2.5**	**3.5**
J	DT, mK, Gain Stability, 100 sec	35	25	35	35	25	35
K	DT, mK, Confusion	**28.2**	**7.4**	2.2	0.9	0.2	0.1
L	Beamwidth, Degrees	0.63	0.38	0.24	0.18	0.10	0.06

Conclusions

Sensitivity for continuum sources is limited by confusion (too many astronomical sources per beam) at S band and lower frequencies and by gain instability at C band and above. The gain instability of .01% rms at 1 sec gap is due to inherent transconductance fluctuations in microwave FET transistors

Operation, Maintenance, and Safety

- The radiometric system will be designed for remote control of operation and fault diagnosis. Switching of frequency bands, bandwidth, attenuation, and continuum or spectral line modes will be computer controlled.
- The expected level of maintenance is on-site 8 person hours per week, and off-site maintenance at JPL at a level of 1 person-month per year. Typical on-site maintenance will be weekly review of monitor data and replacement of defective modules.
- Spares will be limited to a few known failure-rate components such as cryocoolers and power supplies. It is estimated that there will be two failures a year requiring off-site maintenance with four day down-times. Off site maintenance will include component-level repair of modules.
- During the first year of operation the above figures may triple due to infant mortalities and correctable design faults.
- The radiometric system does not require high voltage or high power components. Equipment on the antenna will be in protected locations where a fall is not possible while maintaining the equipment. Access to the equipment by walkways and hatches will conform to OSHA standards. A hoist with 500 lb capacity is needed for installation and removal of equipment in the vertex area.

Interferometry (1 of 2)

- A distinction needs to be made between VLBI in which the antenna elements have independent local oscillators derived from frequency standards and connected-element, phase-stable, interferometry where a common local-oscillator is delivered to each antenna element.
- VLBI mode requires that all local oscillators in the system be derived from one high-quality frequency standard (typically a hydrogen maser) and that baseband data be recorded and time tagged. DSS28 will comply with this; the local oscillators will be determined by frequency synthesizers with external 10 or 100 MHz reference signals connected to the Goldstone FTS standard which should provide an Allan Variance stability of 5 x 10^-15 at 1000 seconds
- <u>Connected-element interferometry requires common LO synthesizers for the connected elements – presumably DSS28, DSS12 and DSS13</u>. (The outputs of separate synthesizers usually do not sufficient phase stability). Multiple wideband synthesizers are required for the DSS28 wideband system and these will be located at a common point, probably the DSS13 control building with buried fiber and a round-trip phase correction system to the receiver

Interferometry - Conclusions

- The DSS28 system will be designed for connected-element interferometry but the same LO system will be required at the other elements for phase stable interferometry. Revisions of DSS12 and DSS13 LO systems are not included in the DSS28 implementation task.
- An LO return fiber from the receiver vertex to synthesizer location will be incorporated in the DSS28 fiber cable but the round-trip phase measurement system to measure the phase changes in the fiber is not included.

Bottom Line

- The DSS28 system will be designed for future interferometer connection to other Goldstone antennas but the complete system changes for this mode of operation are not included in this PDCR plan.

Cost Estimate

	Cost Item	Org	FY06	FY07	FY08	Total
A	System Design & Test	CIT	115	100	50	265
B	4.6 to 13.8 GHz Cryo Receiver	LCER	30	60	20	110
C	1.2 to 3.6 GHz Receiver	LCER	20	70	20	110
D	IF Processors (16)	LCER	10	150	160	320
E	LO Synthesizers (8)	LCER		50	50	100
F	JPL Engineering	JPL	90	100	80	270
G	Rotating Tertiary	LCER		75		75
						0
						0
		Total ($K)	265	605	380	1250

Backup Slides

Statement of Work

Jan 2, 2006 - December 31, 2006

- Design a radiometric system to meet the above requirements and also encompass as many of the desirable features, also stated above, as feasible within a cost cap. The design will be in the form of a report with a detailed block diagram and packaging plan with a source and cost estimates for each block.
- Fabricate and test one low noise amplifier (LNA) of each type required in the above system.
- Design, fabricate, and laboratory test one or more prototype receiver front ends (feed and LNA) to demonstrate noise temperature and feed efficiency
- Design, fabricate, and test prototype downconversion system compatible with front end and spectrometers. The system includes power detection and noise-adding synchronous detection for continuum observations. See Figure 2.

Deliverables

- Radiometric system design, preliminary presentation by Sep 30, 2006
- Radiometric system design, final report by Dec 31, 2006
- One LNA of each type required by the system by Sep 30, 2006
- Prototype receiver front-end with test data by December 31, 2006
- Prototype downconverter by December 31, 2006

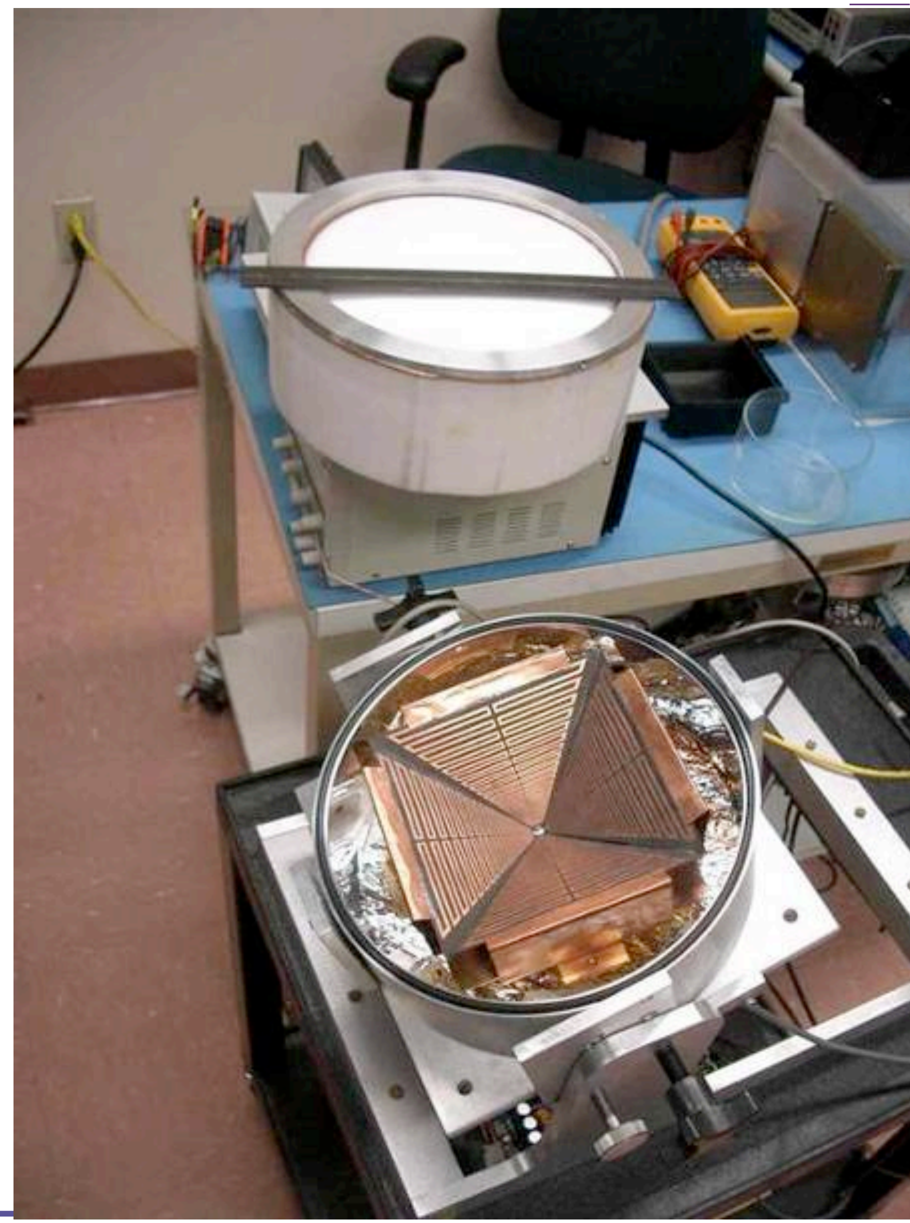
Cost Breakdowns

Cost of a Cryogenic Receiver	**91**
Dewar Machining	15
Cryocooler	13
Helium lines	4
Vacuum Parts, Monitoring	5
LNA's	10
Calibration Couplers	2
Coax Fittings	2
Feed	15
Polarizer	5
Assembly and Test	20

Cost of Downconverter	**20**
(In quantity of 16)	
UpConverter Mixer	0.8
Bandpass Filter	0.7
PLO, 6.2 to 18 GHz	3
Downconverter, 5 to 1 GHz	0.5
Bandwidth selection switches	0.5
Filters, 1000, 200, 50, and 10 MHz	2
Photonic transmitter	1.5
MMIC amplifiers	0.5
Detector parts	0.5
Enclosure, brackets, connectors	1
PC boards, cables	1
Assembly and Test	8

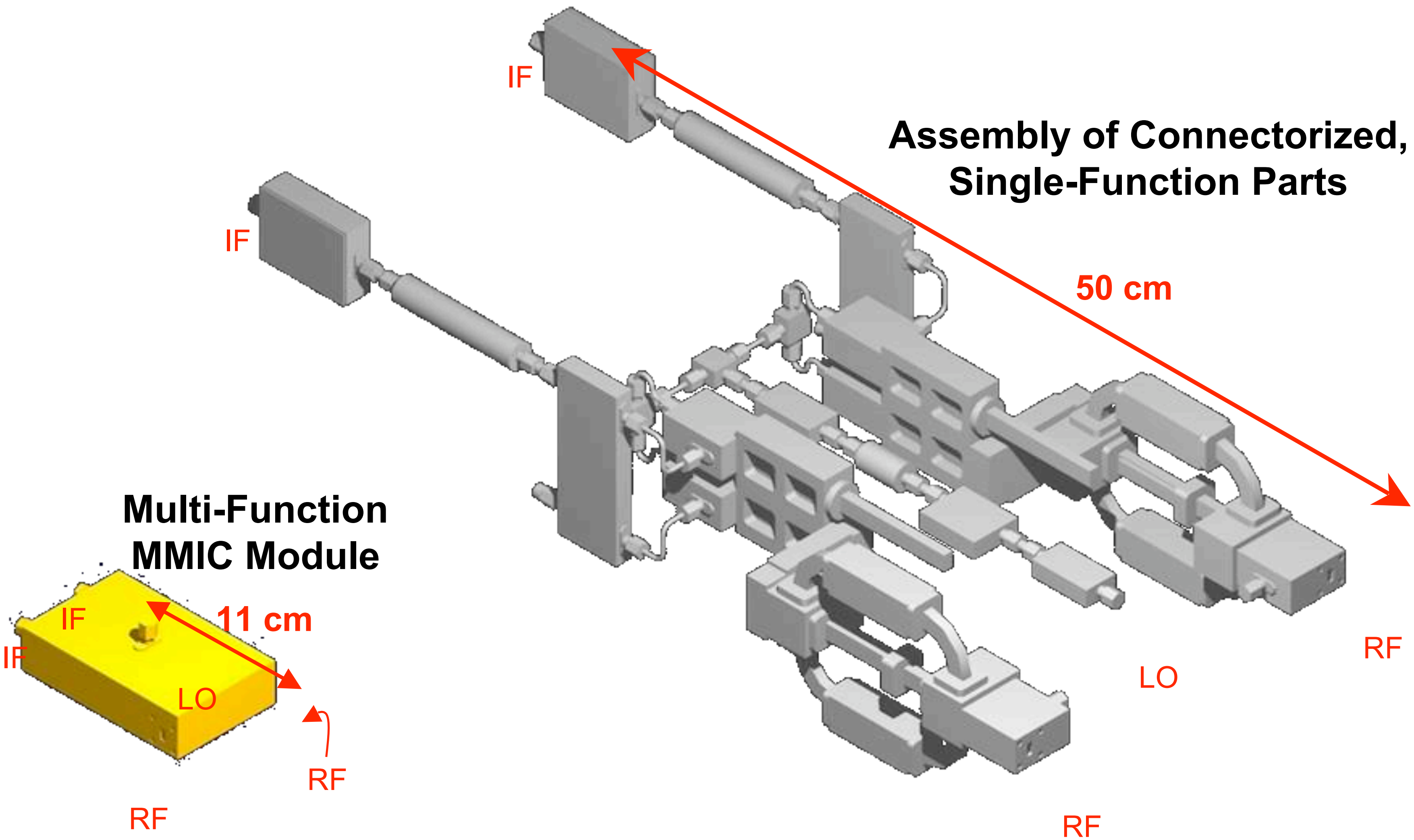
Chalmers Decade Bandwidth Feed

Chalmers 1.2 to 11 GHz feed integrated into cryogenics dewar with active balun LNA and Zotefoam window for tests at Caltech.



RF Design with Muliti-Function MMIC Modules

MMIC technology enables an order of magnitude cost reduction in the DSN array Ka band downconverter designed at Caltech.



Caltech Low-Cost Downconverter