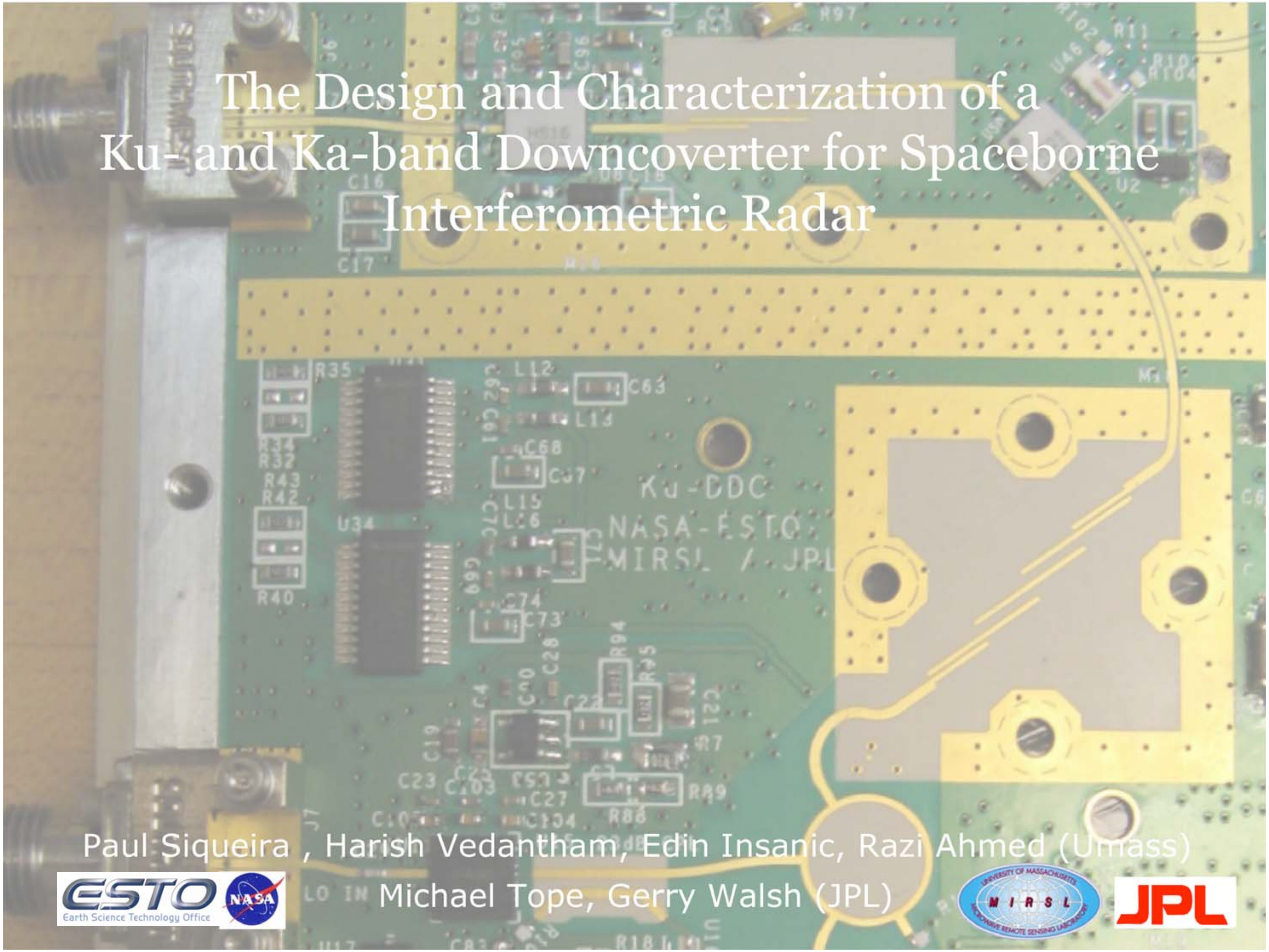
The Design and Characterization of a Ku- and Ka-band Downcoverter for Spaceborne Interferometric Radar

Paul Siqueira , Harish Vedantham, Edin Insanic, Razi Ahmed (Umass)
Michael Tope, Gerry Walsh (JPL)



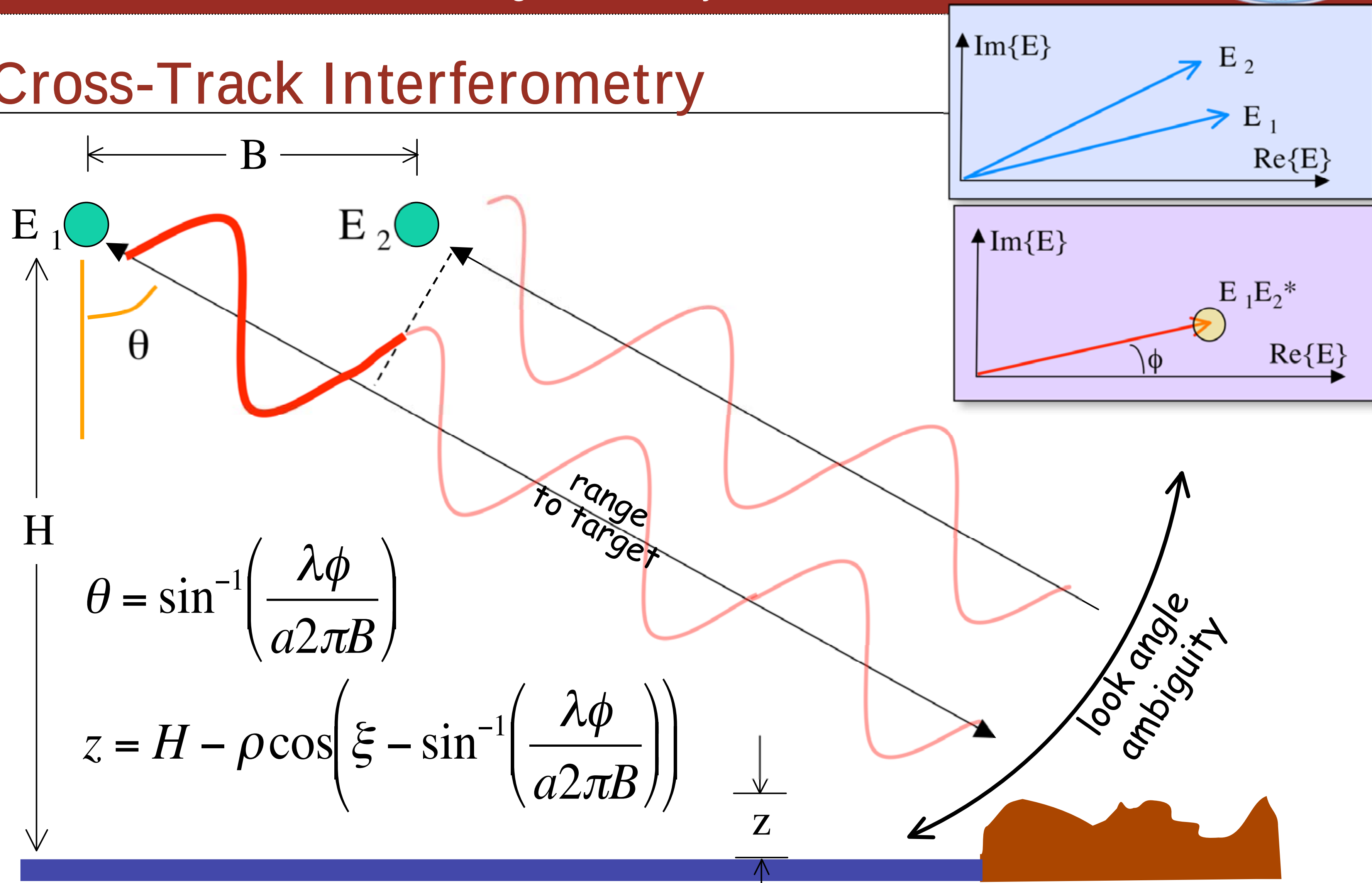
Approach

- Ku-band system
  - Construct breadboard model to understand basic characteristics
  - Build on breadboard experience to create flight prototype model
  - Perform functional tests (noise figure, gain, etc.) on prototype model
  - Performance tests on prototype model (phase and amplitude stability over temperature)
  - Use prototype model in a working interferometric system
- Repeat above for Ka-band system

Design Specifications

Design Constraint	Ku-band DDC	Ka-band DDC
Signal Bandwidth	20 MHz	20 MHz
Effective Noise Bandwidth	< 30 Mhz	< 30 MHz
Input Frequency Range	13275 – 13295 MHz	34975 – 34995 MHz
Operating Temperature	-10 to 50 degrees C	-10 to 50 degrees
Noise Figure	< 4.5 dB	< 4.5 dB
Output Frequency Range	5-25 MHz	5-25 MHz
Channel to Channel Isolation	> 80 dB	> 80 dB
Input/Output VSWR	< 1.5:1	< 1.5:1
Relative Channel to Channel Phase Stability	0.050 degrees RMS over BW	0.050 degrees RMS over BW
Receiver Phase Variation over Best Quadratic Fit	3 deg RMS over BW	3 deg RMS over BW
Receiver Amplitude Variation	2 dB over BW	2 dB over BW
Receiver Amplitude Variation over Best Linear Fit	0.3 dB RMS over BW	0.3 dB RMS over BW
Input Signal Range	-100 to –65 dBm	-100 to –65 dBm
DDC End to End Gain	65 to 70 dB	65 to 70 dB
Image Rejection	> 30 dB	> 30 dB

Cross-Track Interferometry

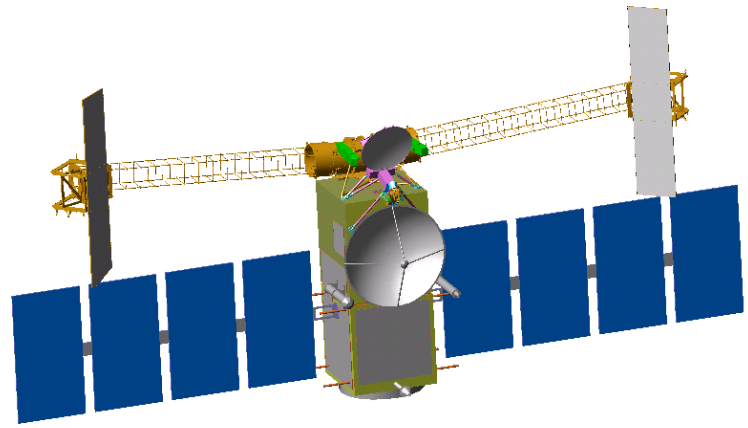


$$\theta = \sin^{-1}\left(\frac{\lambda\phi}{a2\pi B}\right)$$

$$z = H - \rho\cos\left(\xi - \sin^{-1}\left(\frac{\lambda\phi}{a2\pi B}\right)\right)$$

Phase Measurement Accuracy

WSOA, Ku-band 6.4m



$$\sigma_z^2 = \left(\frac{dz}{d\phi}\right)^2 \sigma_\phi^2 + \left(\frac{dz}{dB}\right)^2 \sigma_B^2 + \left(\frac{dz}{d\xi}\right)^2 \sigma_\xi^2 + \left(\frac{dz}{dH}\right)^2 \sigma_H^2 + \left(\frac{dz}{d\lambda}\right)^2 \sigma_\lambda^2 + \left(\frac{dz}{d\rho}\right)^2 \sigma_\rho^2$$

A_ϕ, phase noise

A_B, baseline length

A_ξ, baseline tilt

A_H, altitude

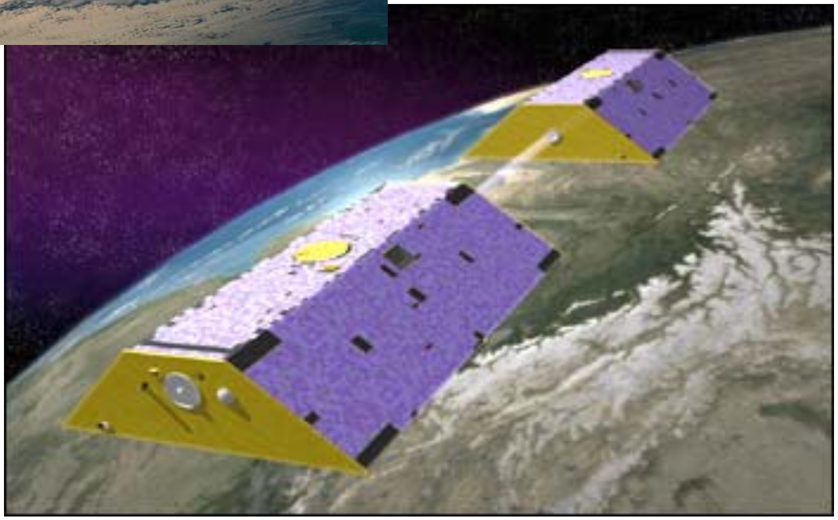
A_λ, wavelength stability

A_ρ, target range

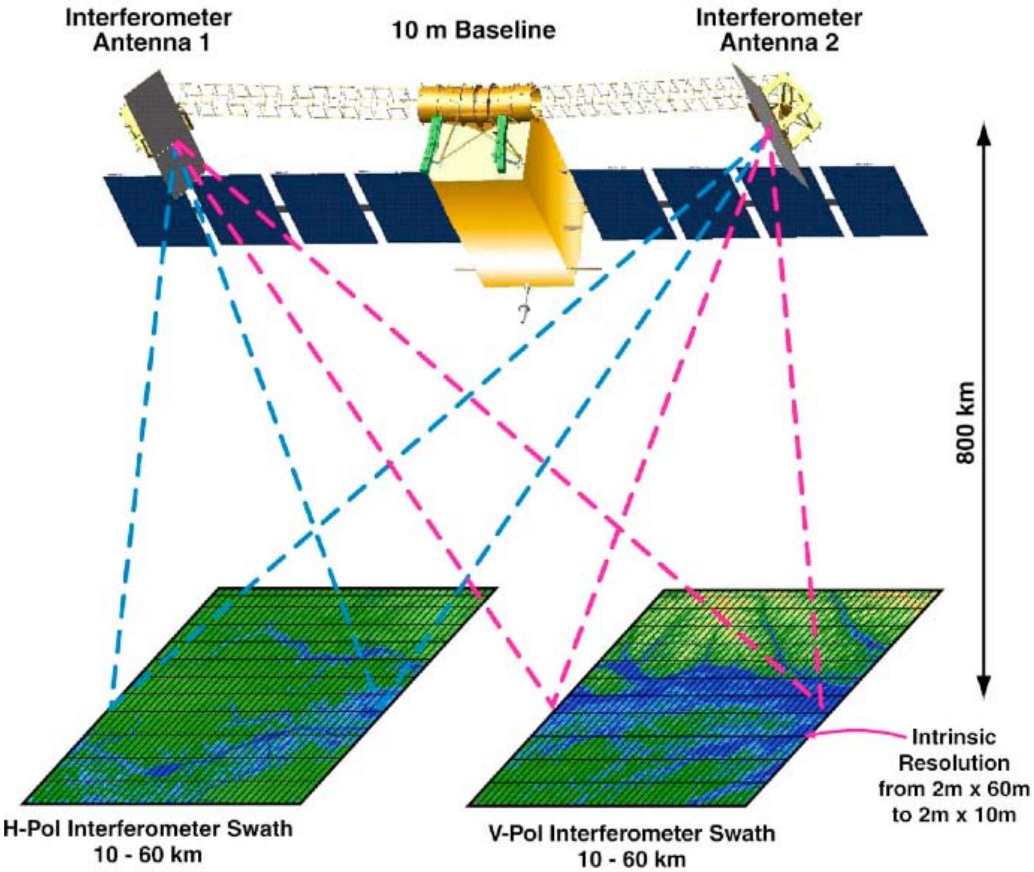
Introduction

- OSTM: WSOA (ocean surface topography mission: wide swath ocean altimeter)

- GRACE (gravity recovery and climate experiment)



SWOT/KaRIN



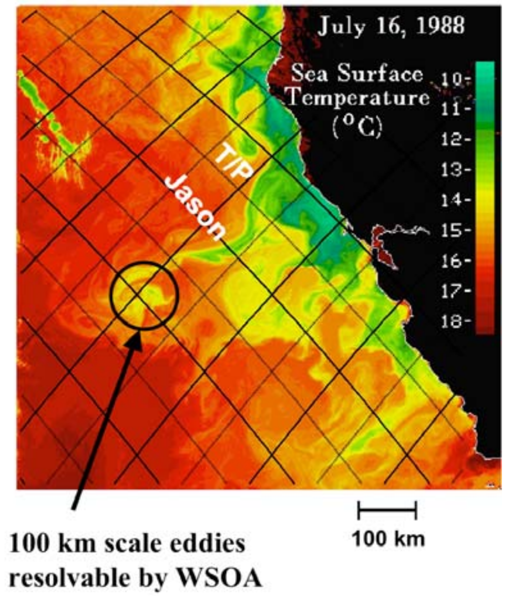
<u>Surface Water and Ocean Topography Mission</u>

Decadal Survey, 2013-2016

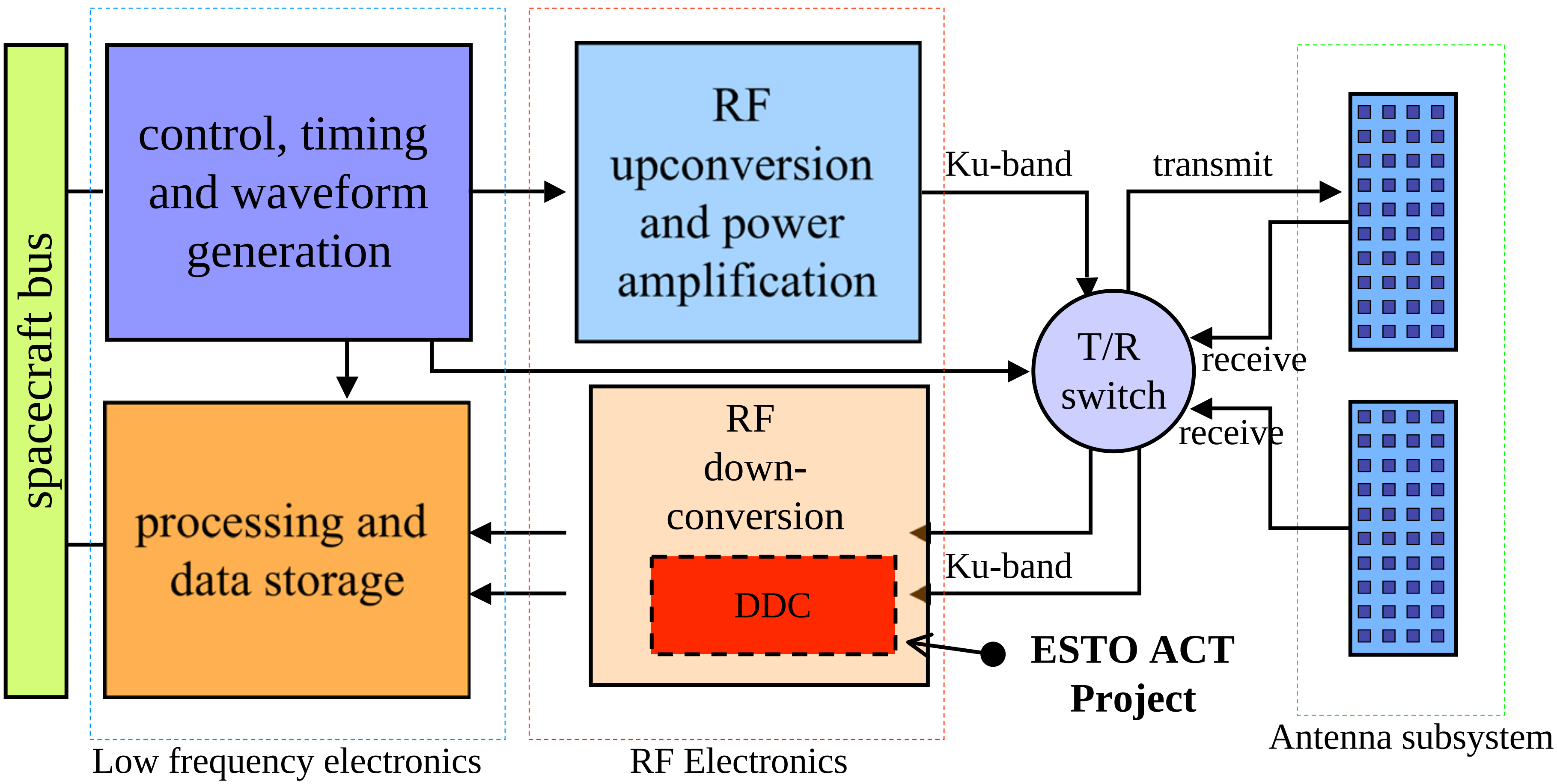
200 MHz Bandwidth

Technology Follow-on to WSOA

River discharge estimates; Lake, wetland and reservoir storage; ocean eddies and currents

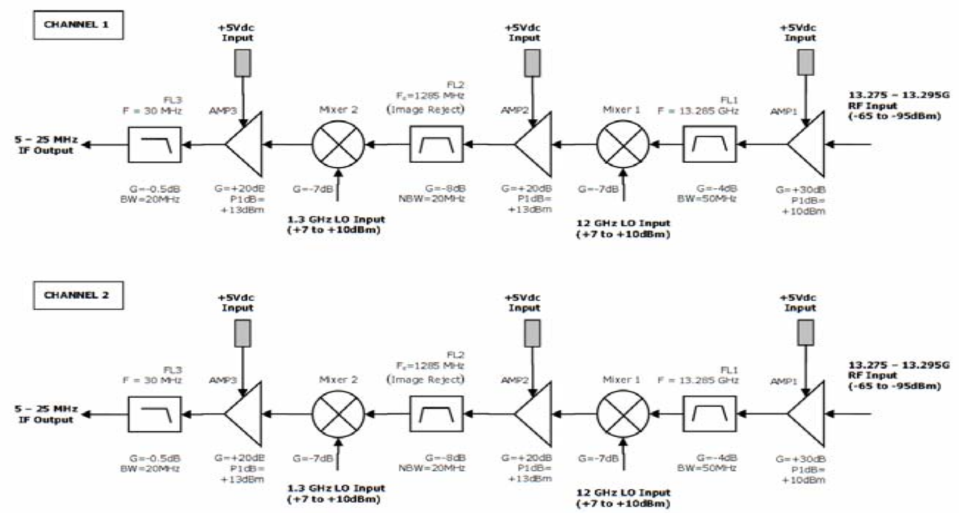


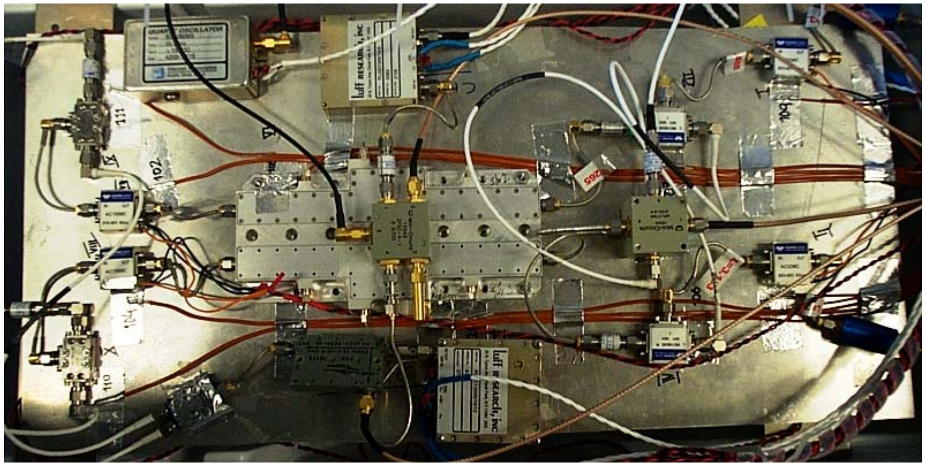
Block Diagram of an Interferometric System



Ku-band Downconverter Development

DDC Version 1

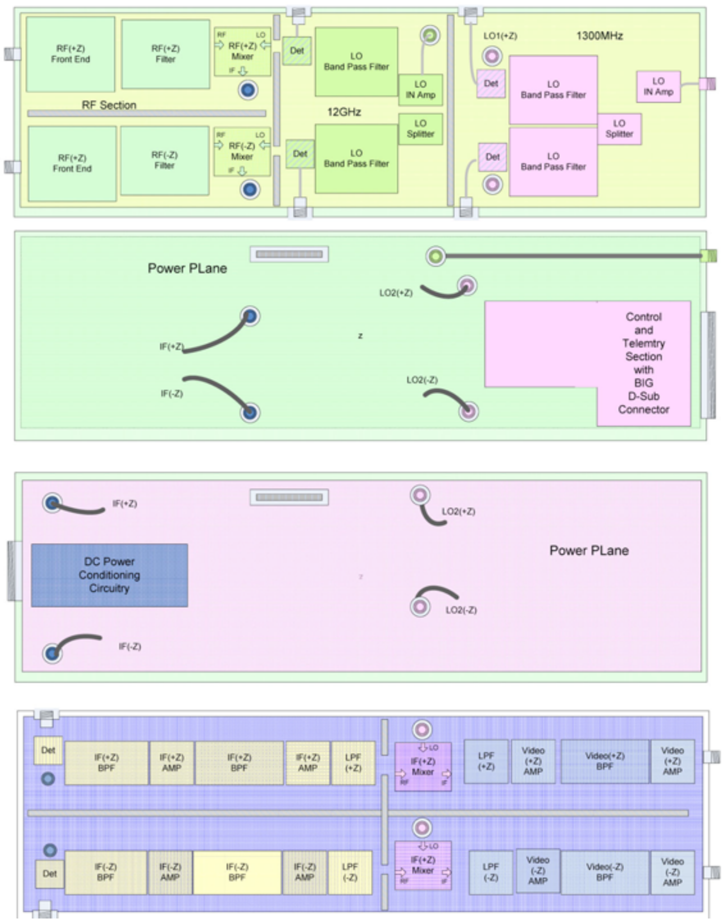




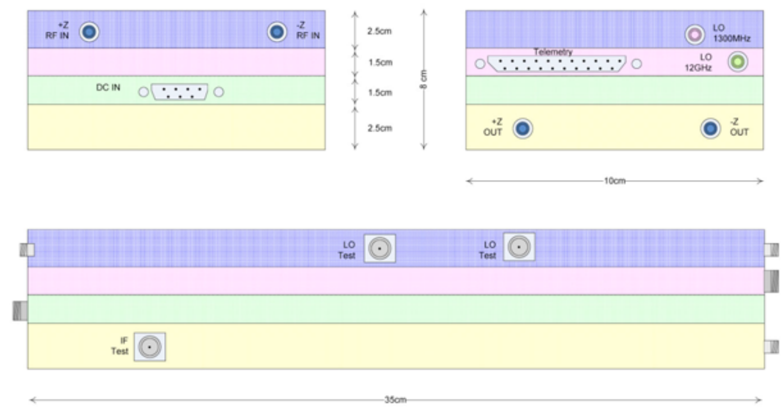
Alternate Clamshell Layout

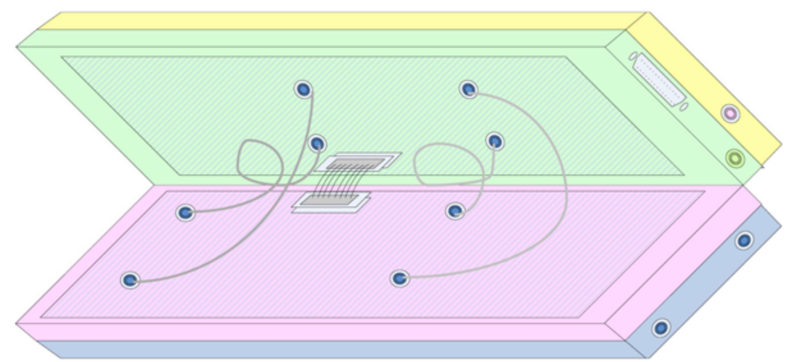
TOP VIEW

layers are presented from top to bottom



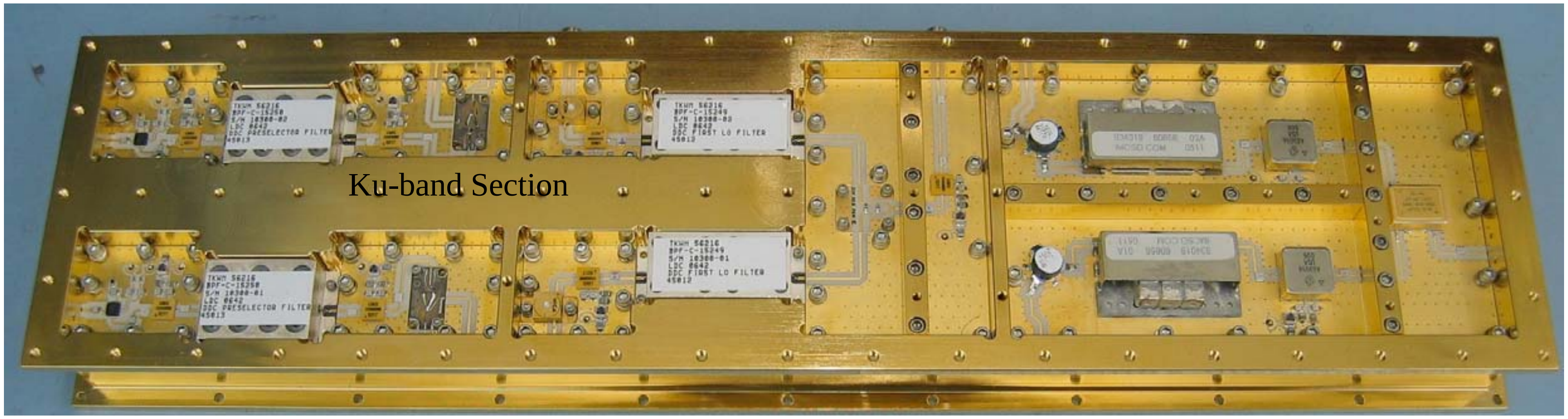
SIDE VIEW

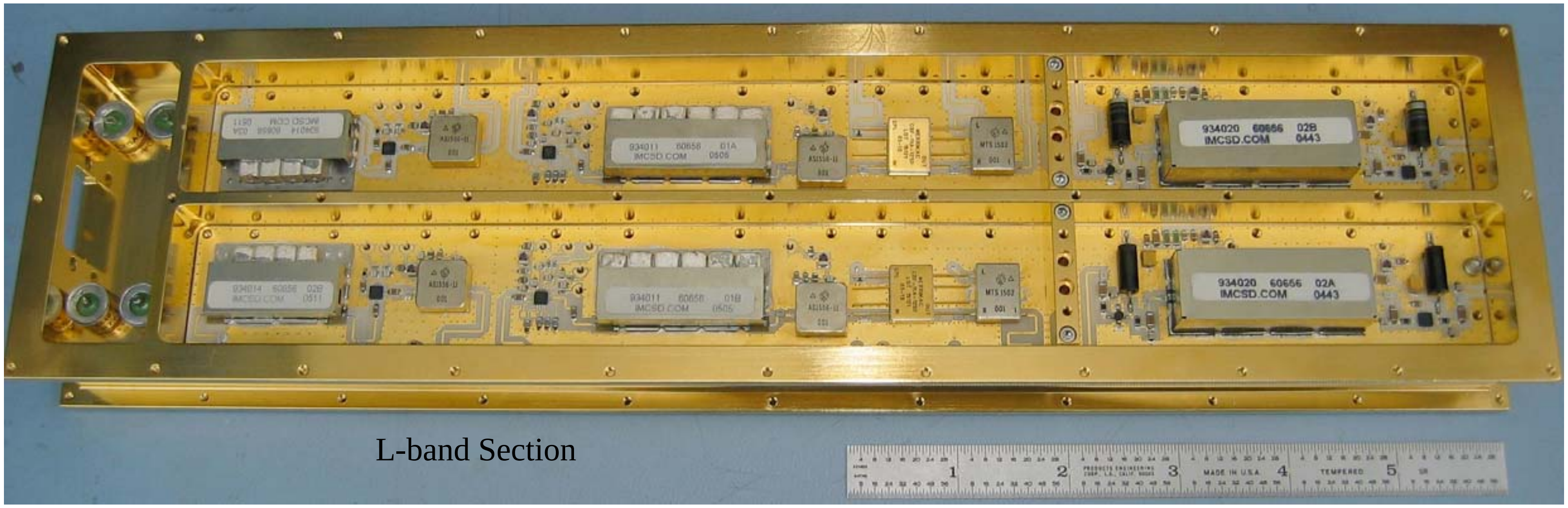




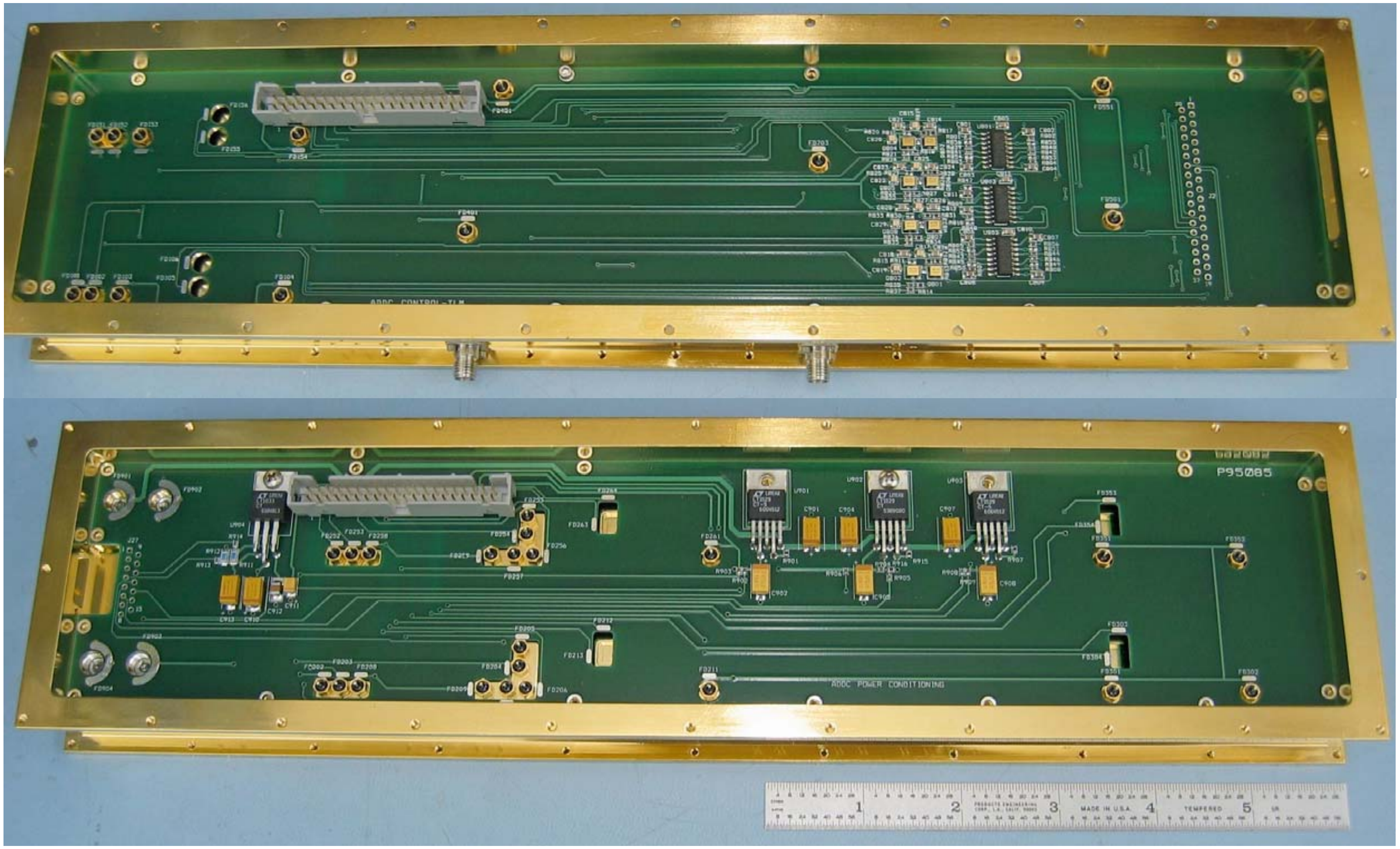
3D view

Critical Signal Path



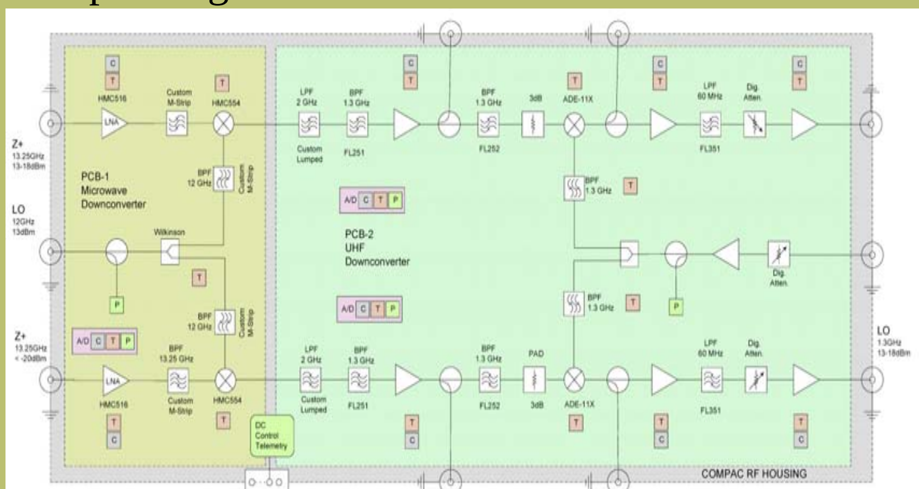


DC power and low frequency electronics



Ku-Band Downconverter

A careful system design approach was used to meet strict performance requirements and to monitor the downconverter under various operating environments



design layout

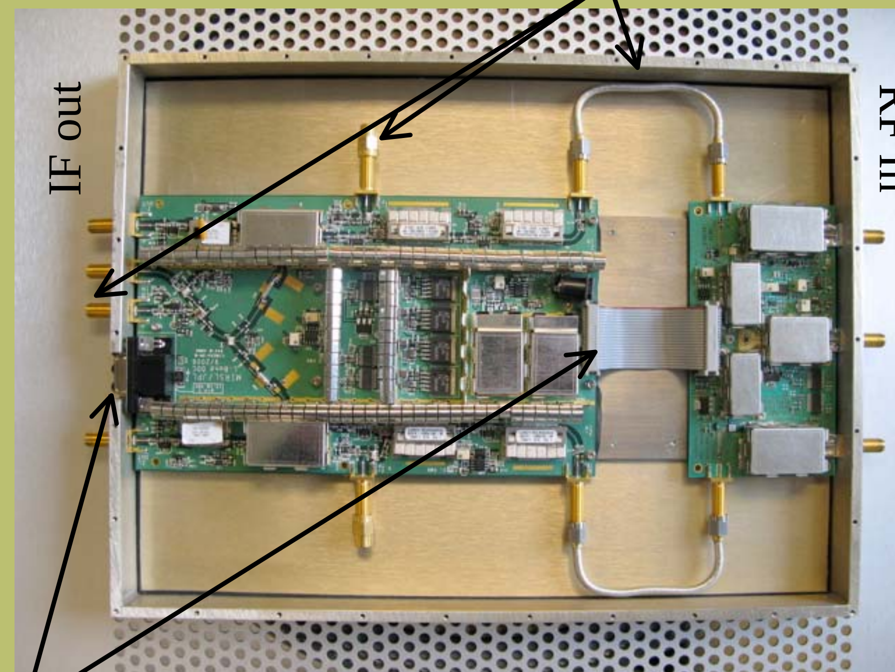
Space qualifiable design principles and practices used throughout the development process

A new, final enclosure, is currently being designed to improve isolation

test ports

IF out

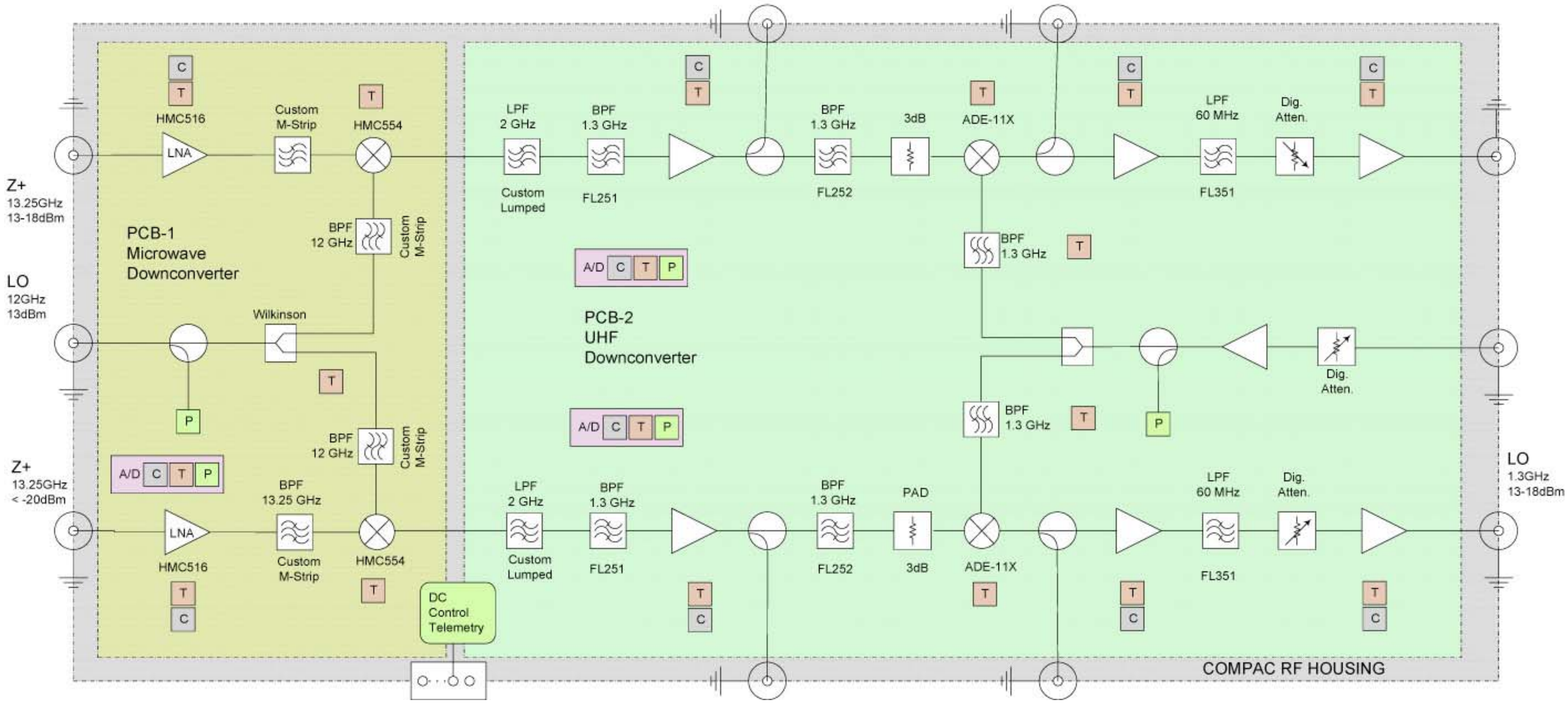
RF In



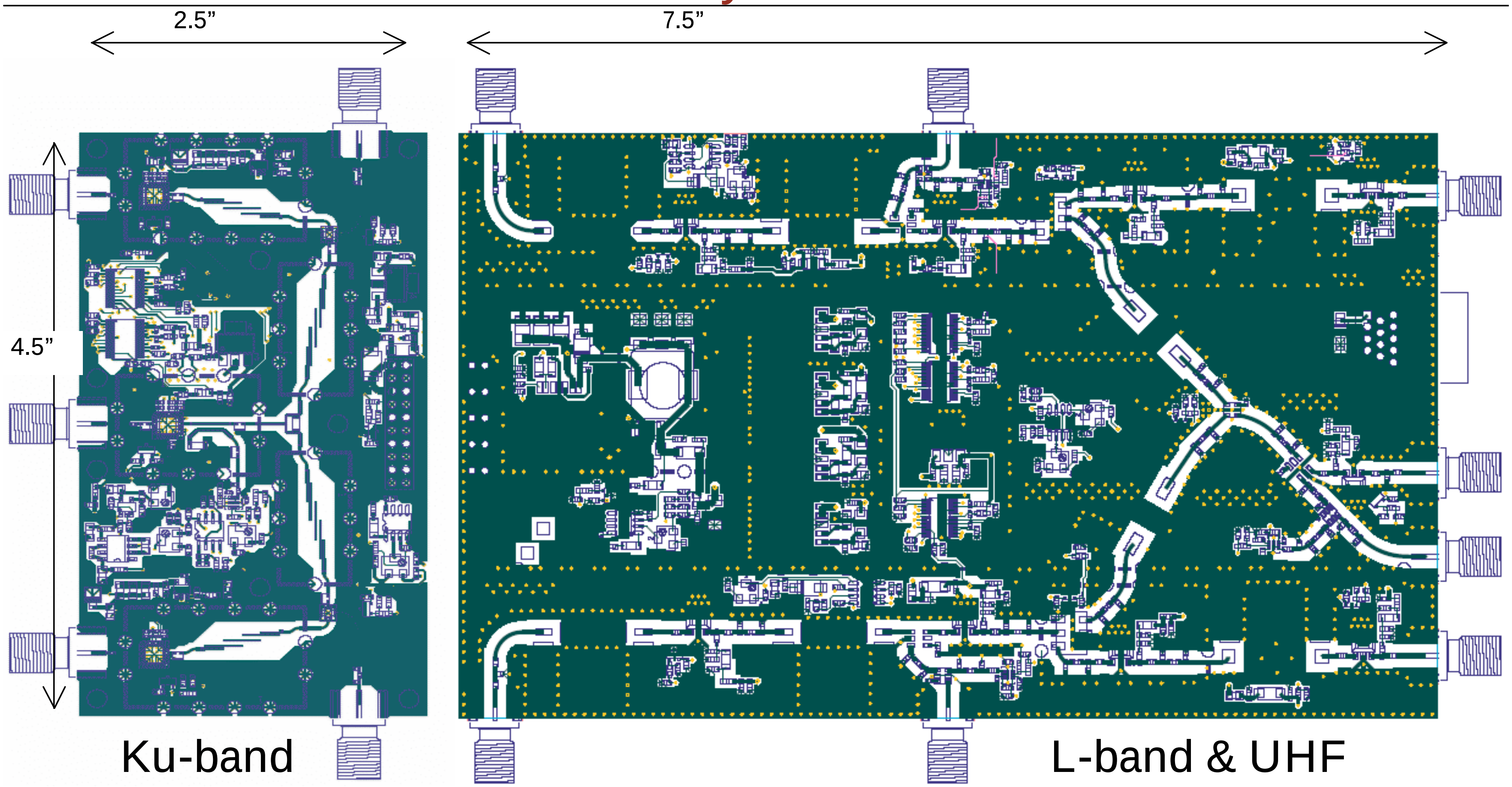
temperature, power and current telemetry

actual device

Single Surface, multilayer (4) layout

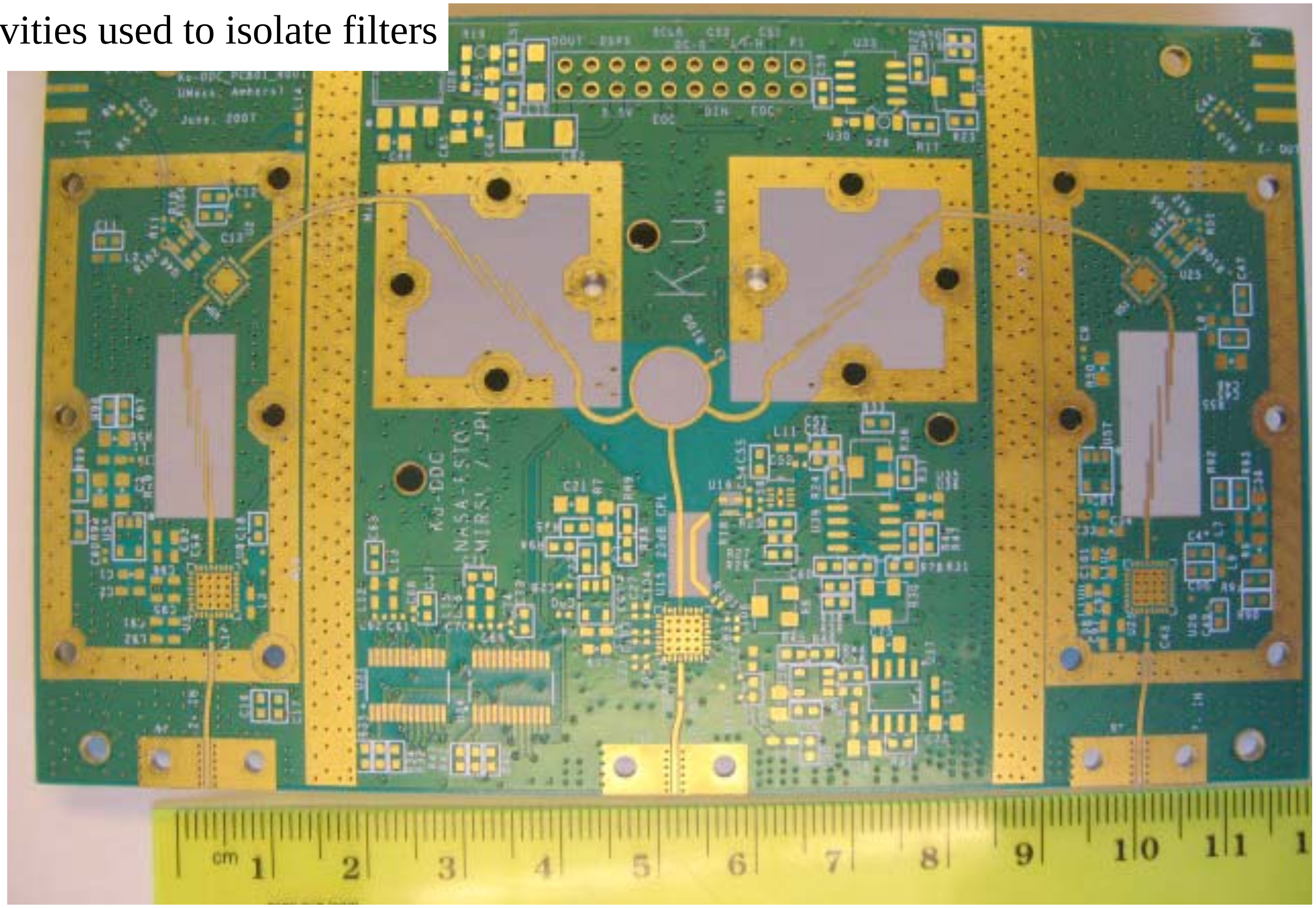


Ku-band DDC Silkscreen Layout



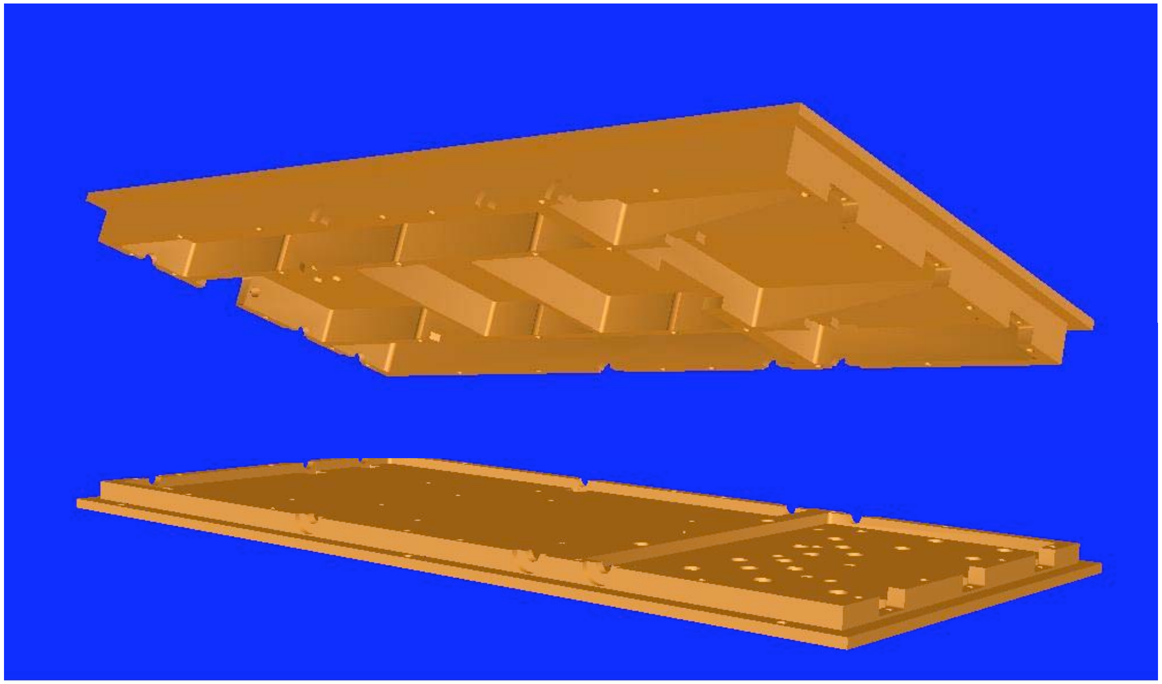
Ku-band Respin to improve isolation

On-board cavities used to isolate filters

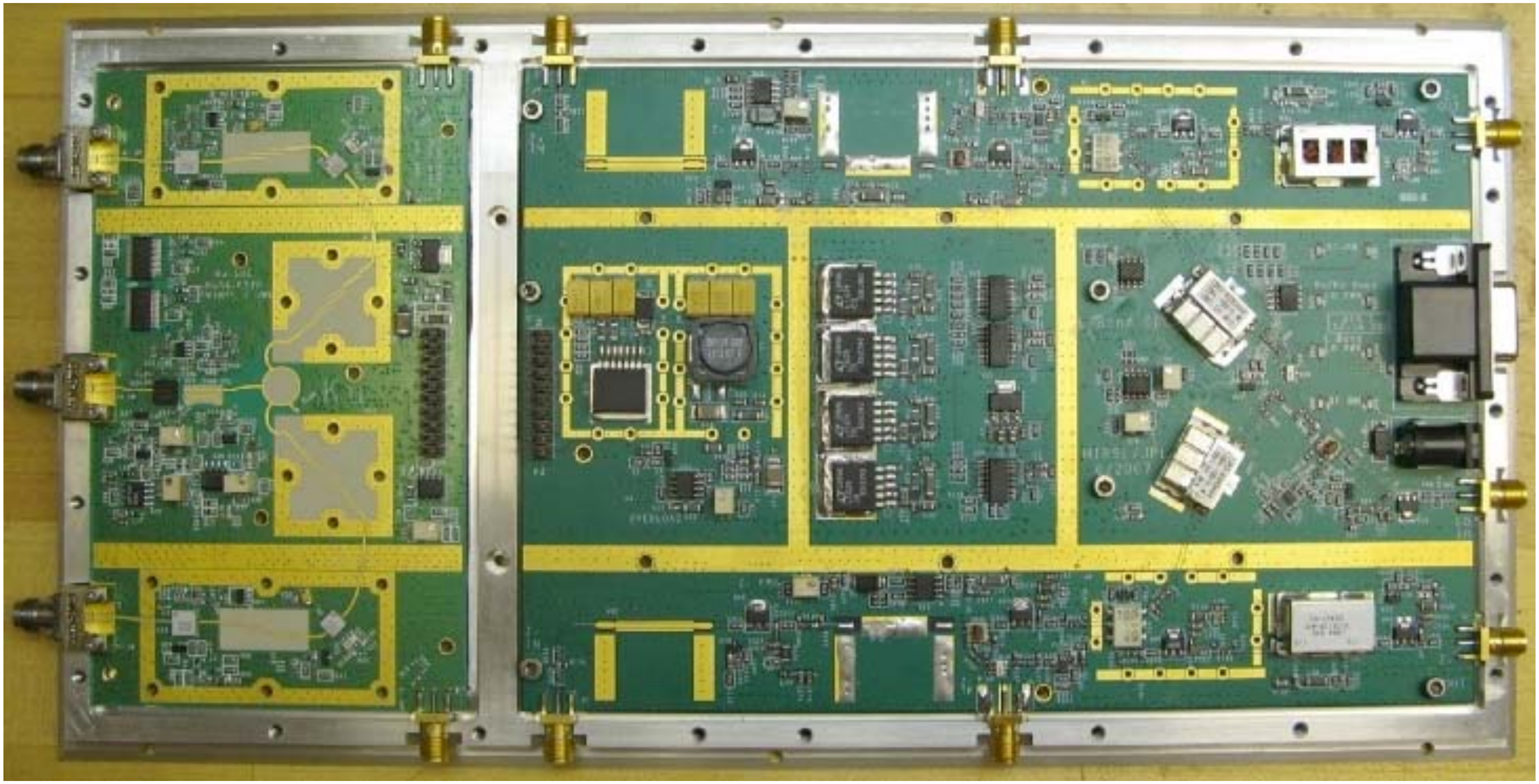


New Ku-band DDC Housing

Additional cavity walls carved into housing to improve isolation



Final Ku-band board

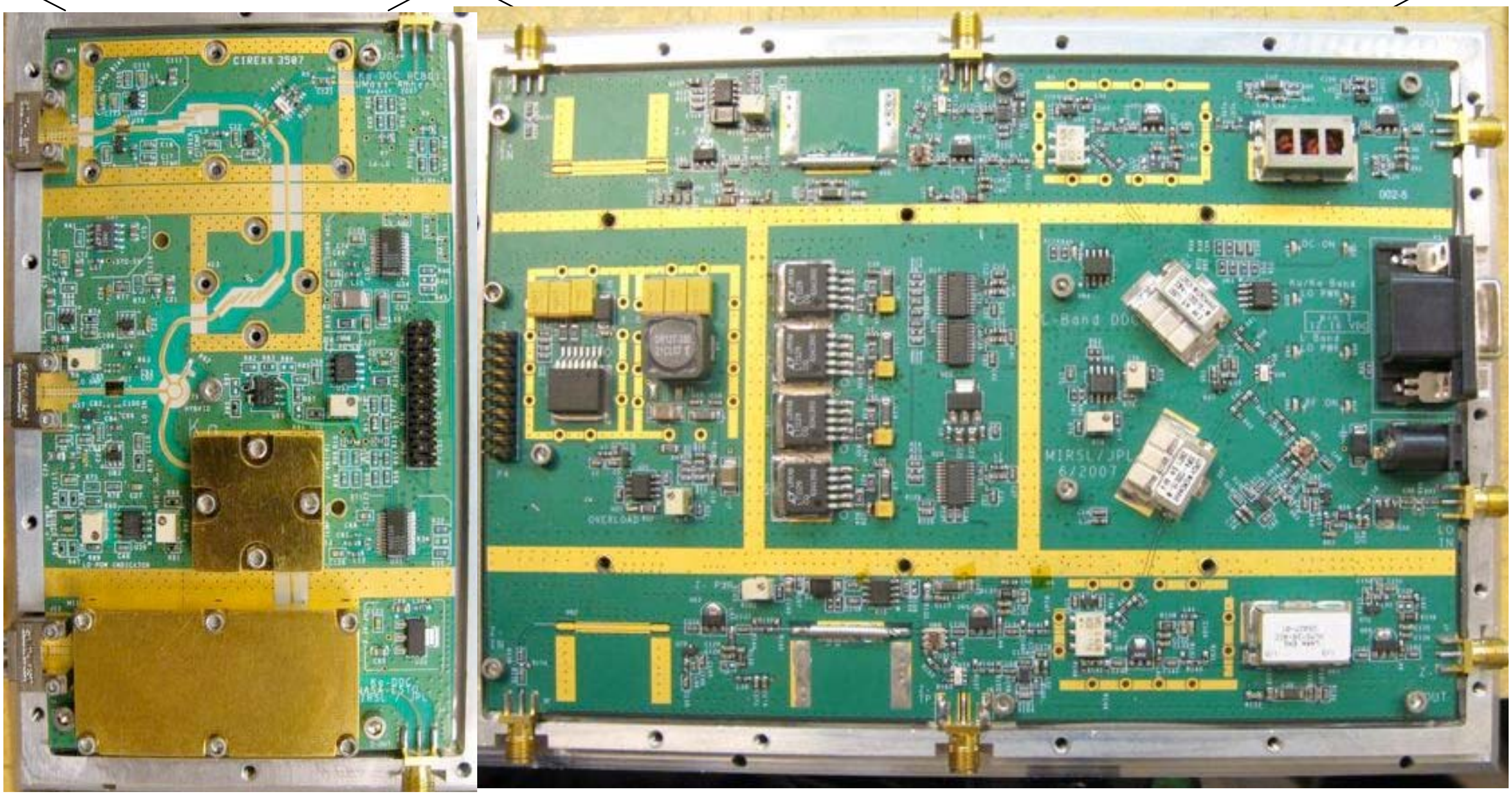


Ka-Band Downconverter Development

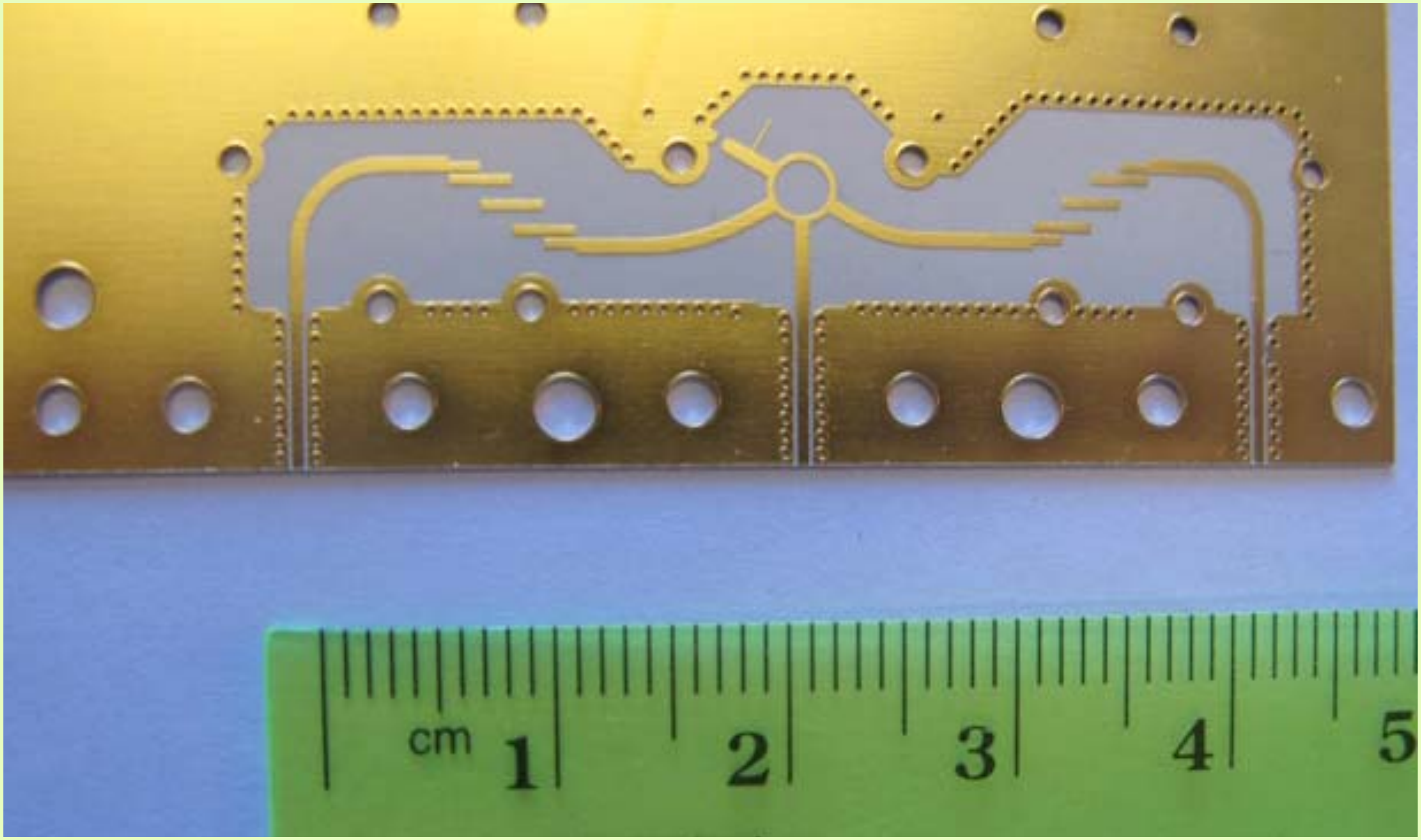
Silkscreen for Ka-band to UHF DDC

3” 7”

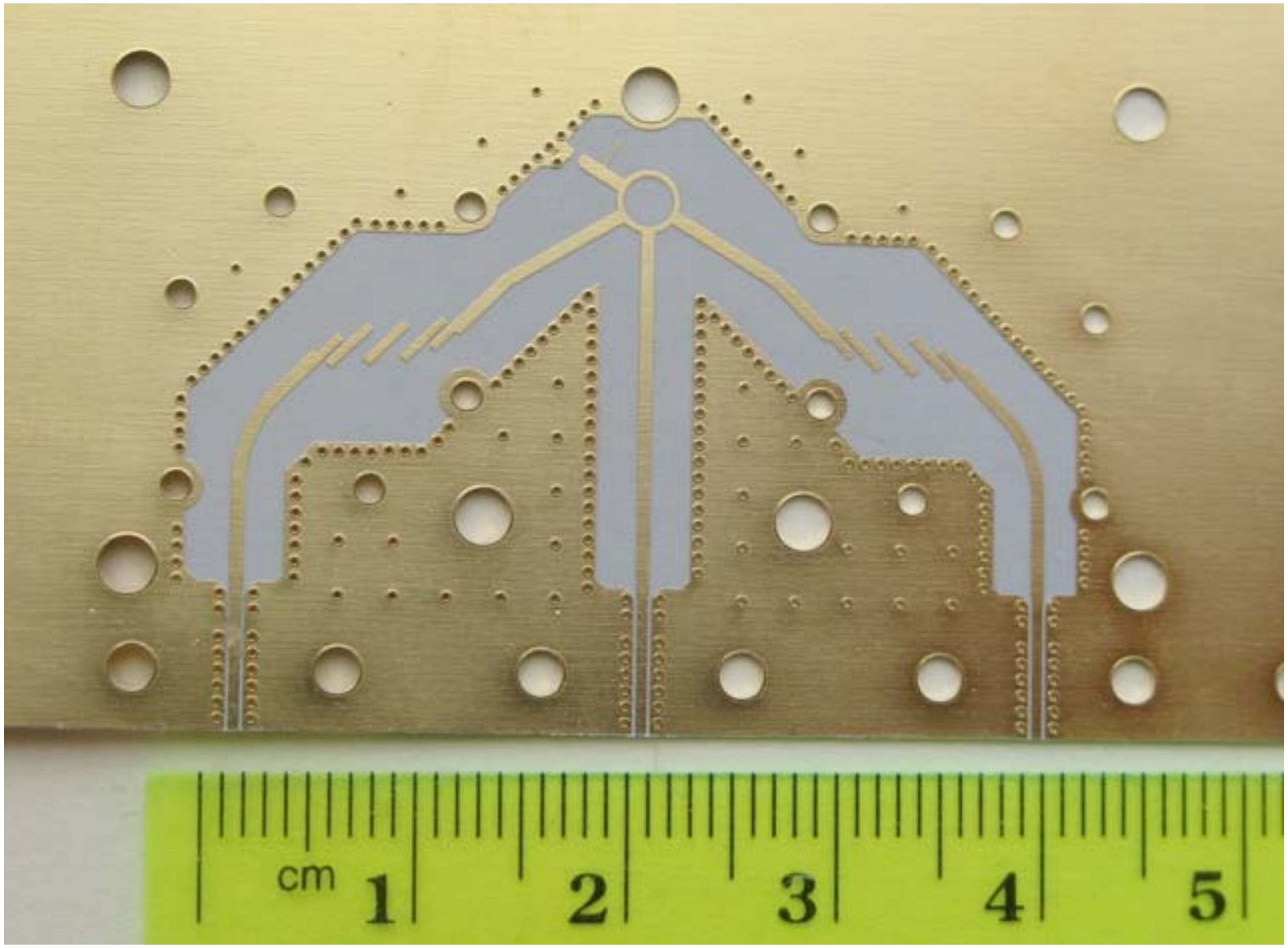
5”



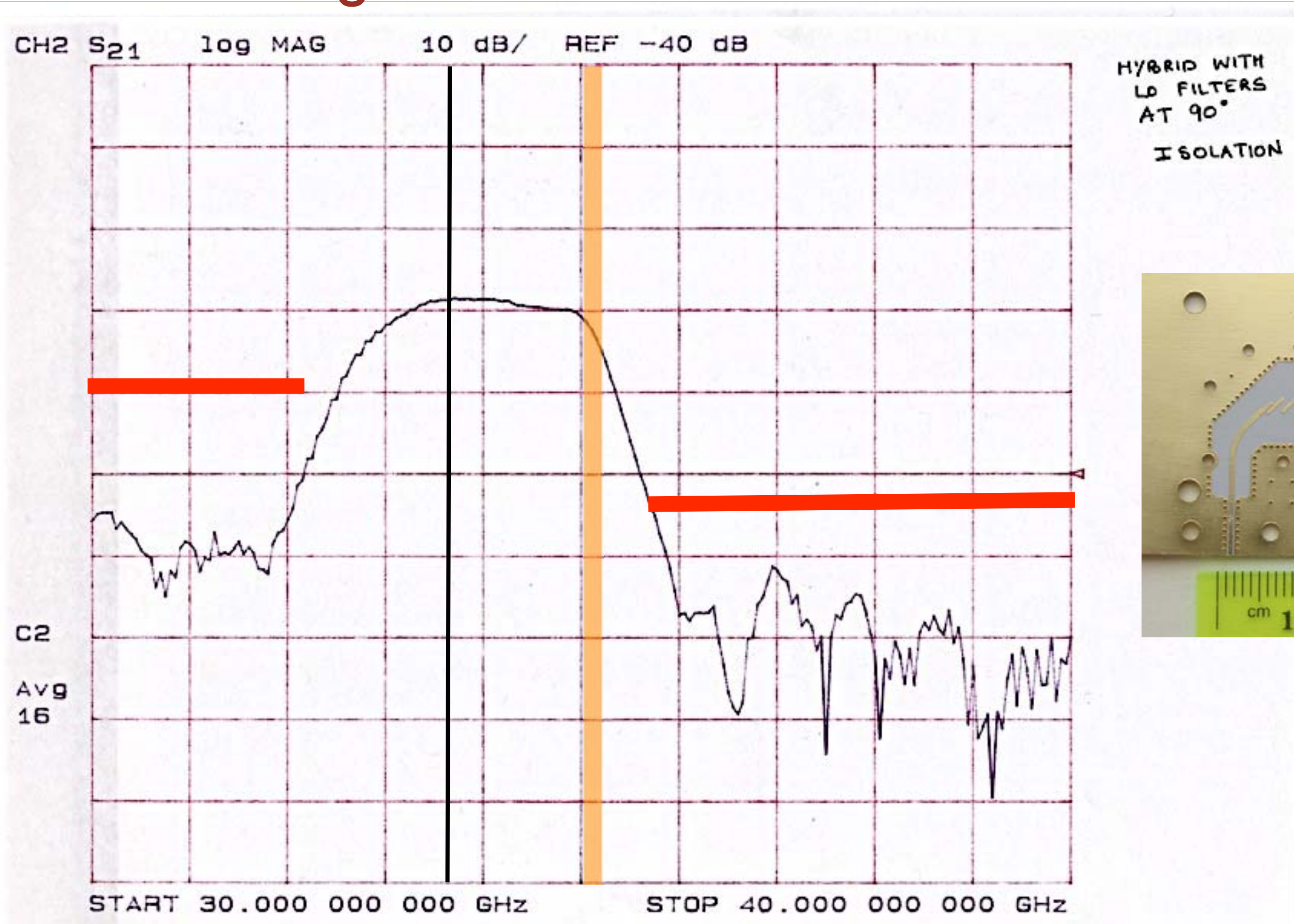
In-line LO filter (small footprint)

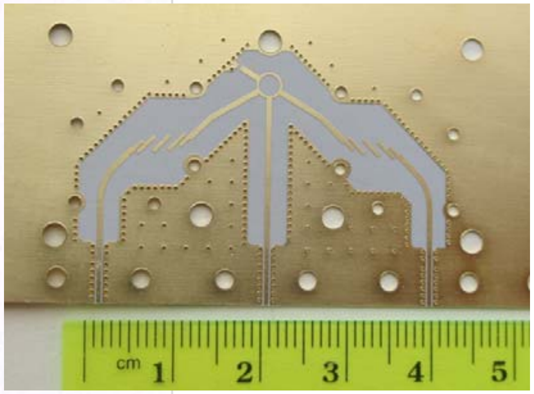


Orthogonal LO filter (large footprint, better isolation?)

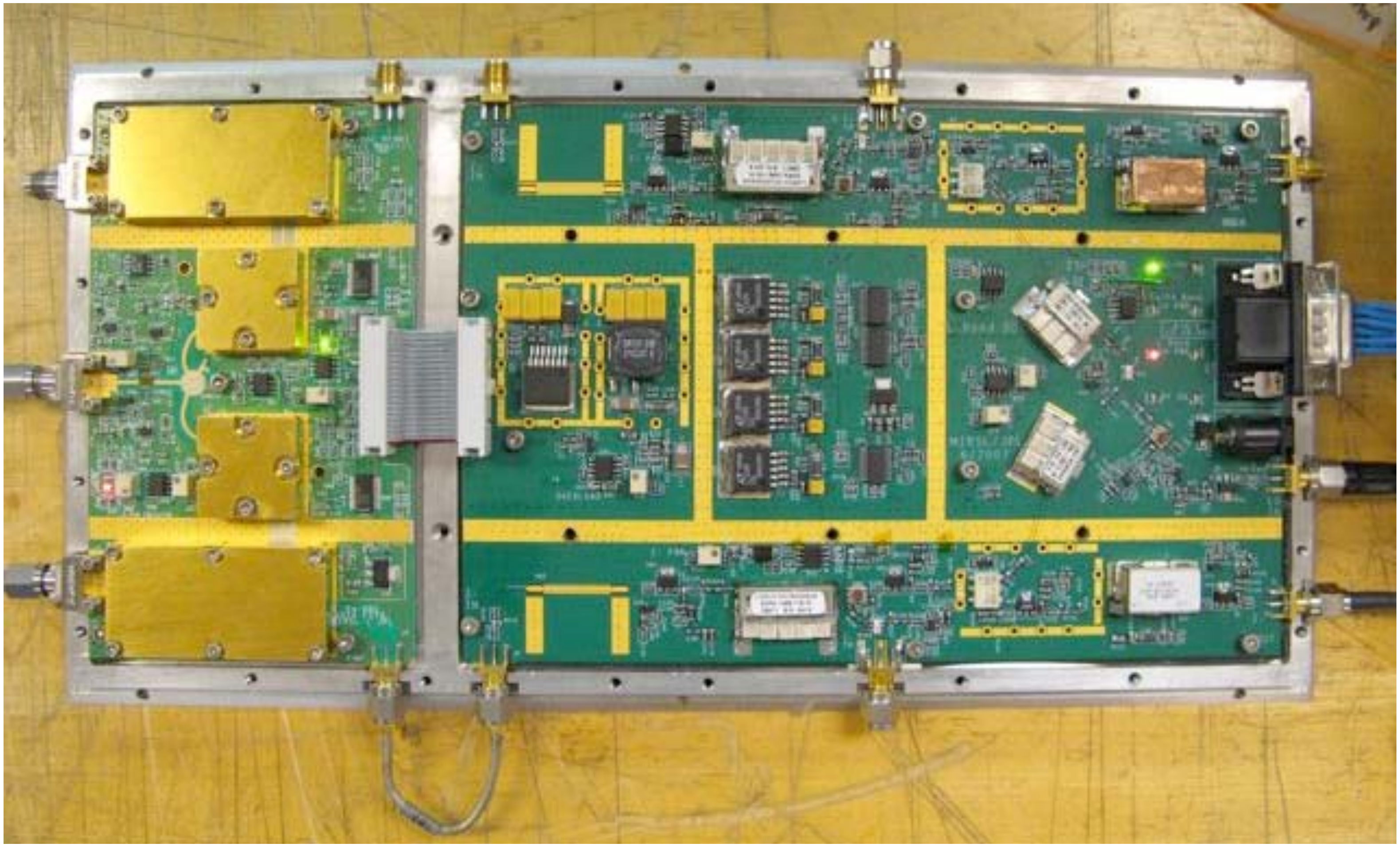


Addressing Isolation

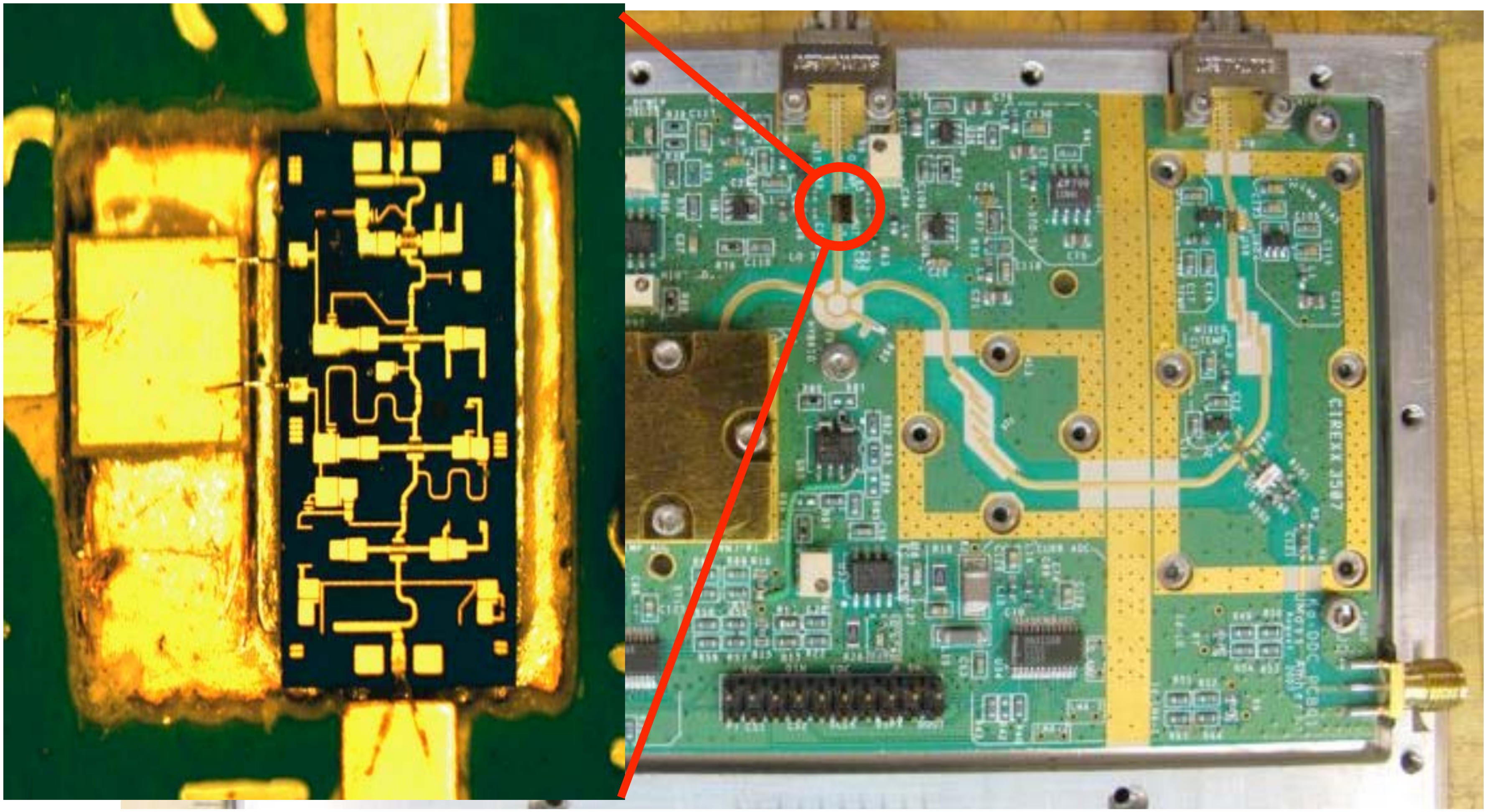




The final product



Top Layer of Ka- to L-band downconverter

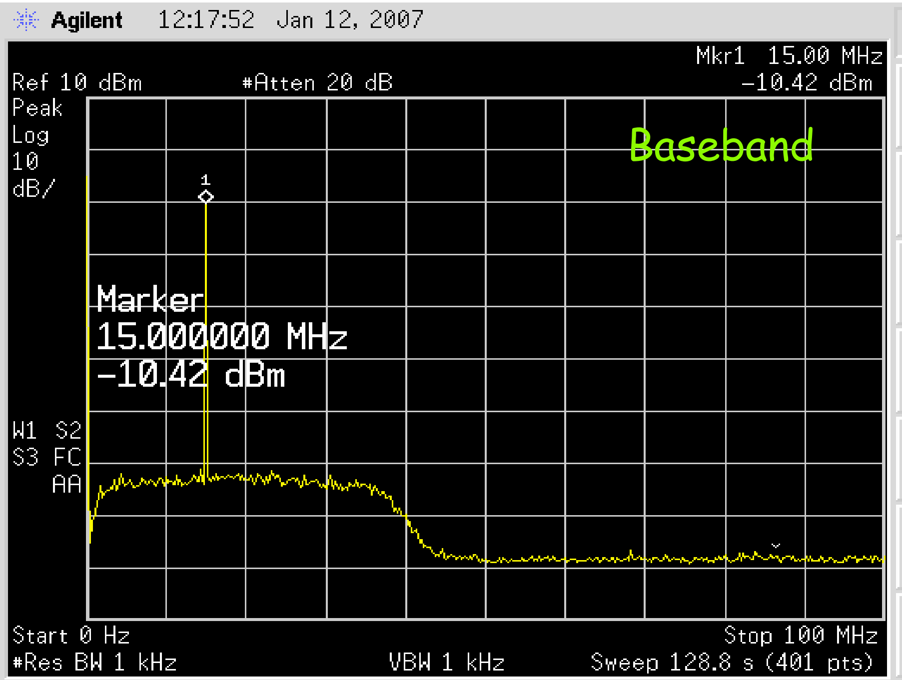


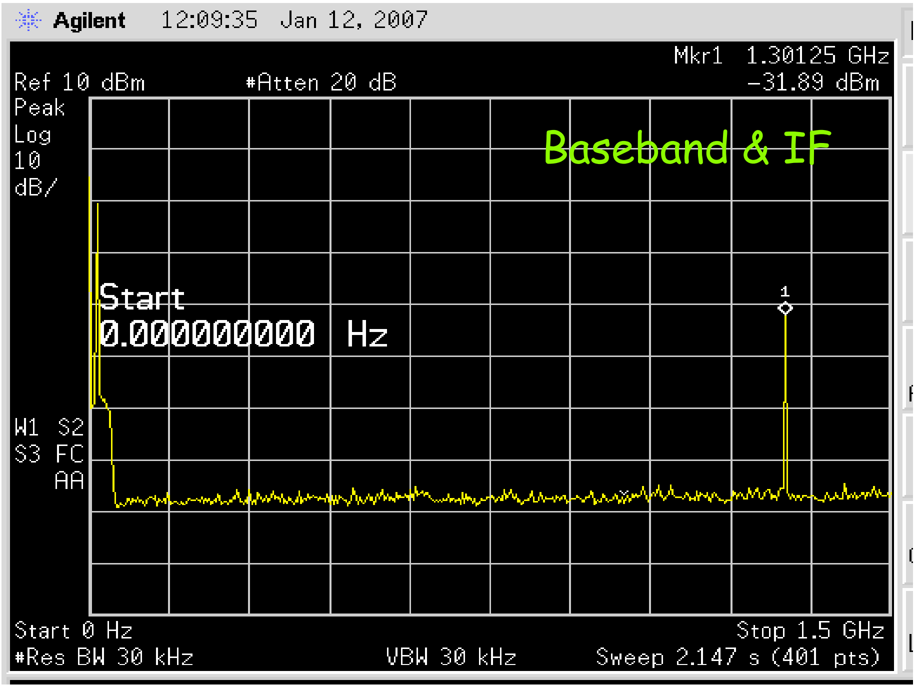
Testing

Basic Performance: Downconversion of 14 GHz tone

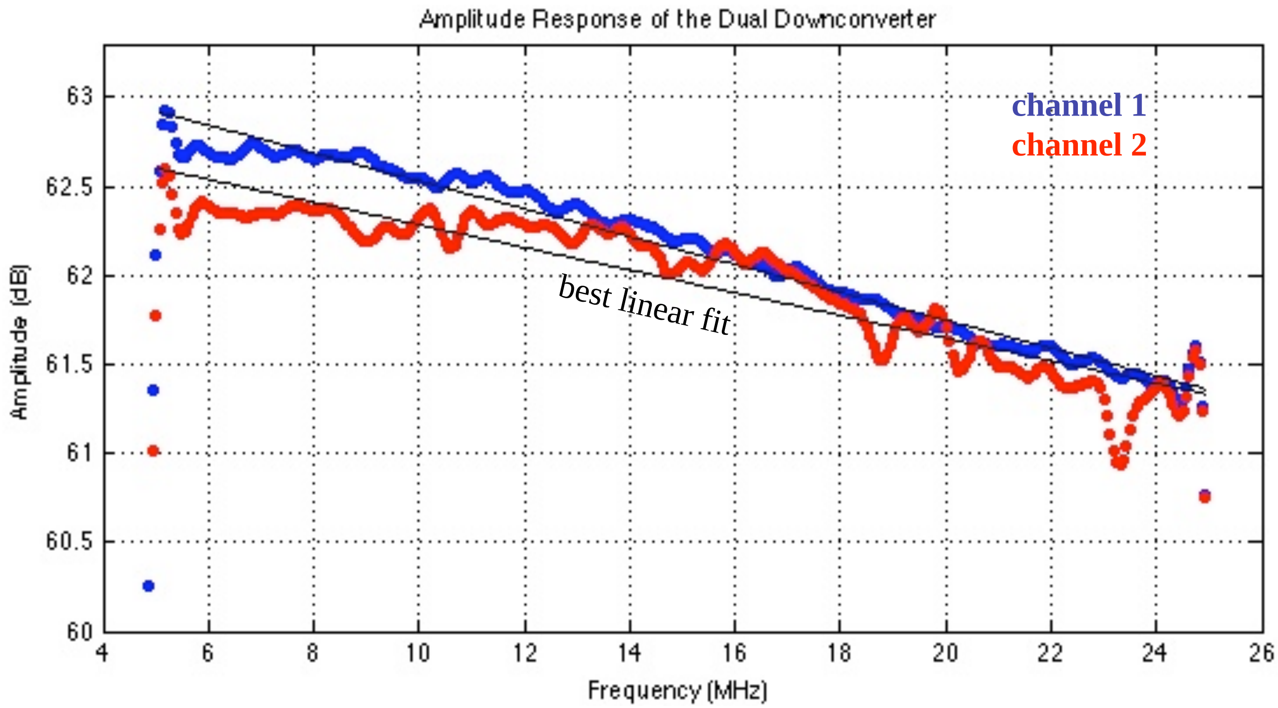
DC Power			
Voltage	10V	to	16V
Current	1.3A		0.8A
Power Consumption	13W		

RF Performance			
	Z(-) Channel	Z(+) Channel	
Gain	62dB	61.2dB	
P1dB	-44dBm	-44dBm	
Input R.L.	17dB	12dB	
Isolation	61dB	70dB	(injected on opposite)
Noise Floor	-115dBm	-115dBm	
Rough NF	3dB	3dB	



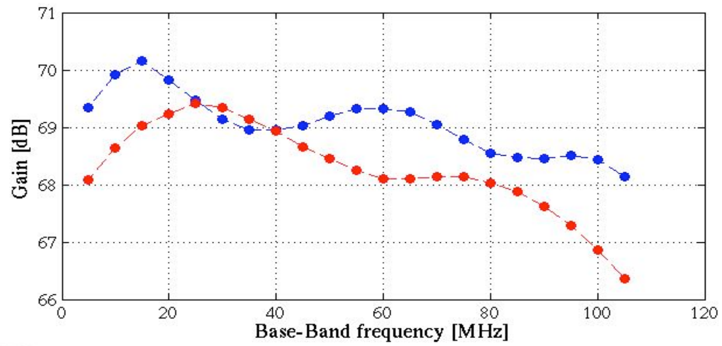


Two Channel Amplitude Performance



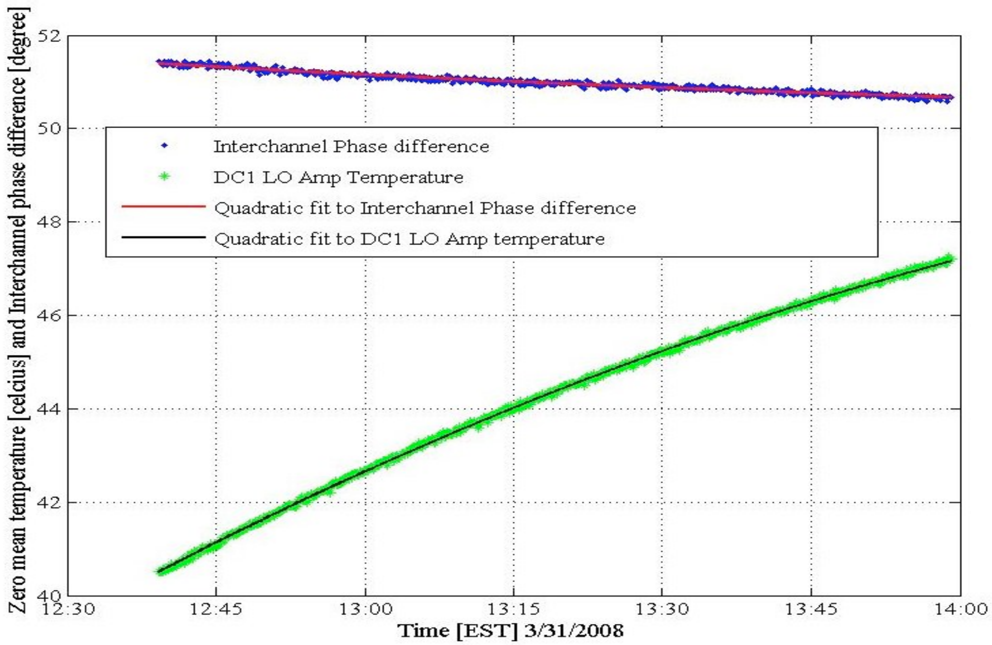
- < 1 dB between the two channels over frequency.
- < 1.5 dB variation over BW (2 dB reqm't)
- Better than 0.15 dB from linear fit over the passband (0.3 dB reqm't)

First Evaluation Results



Supply = 14.5 V,
830 mA
Power = 12W

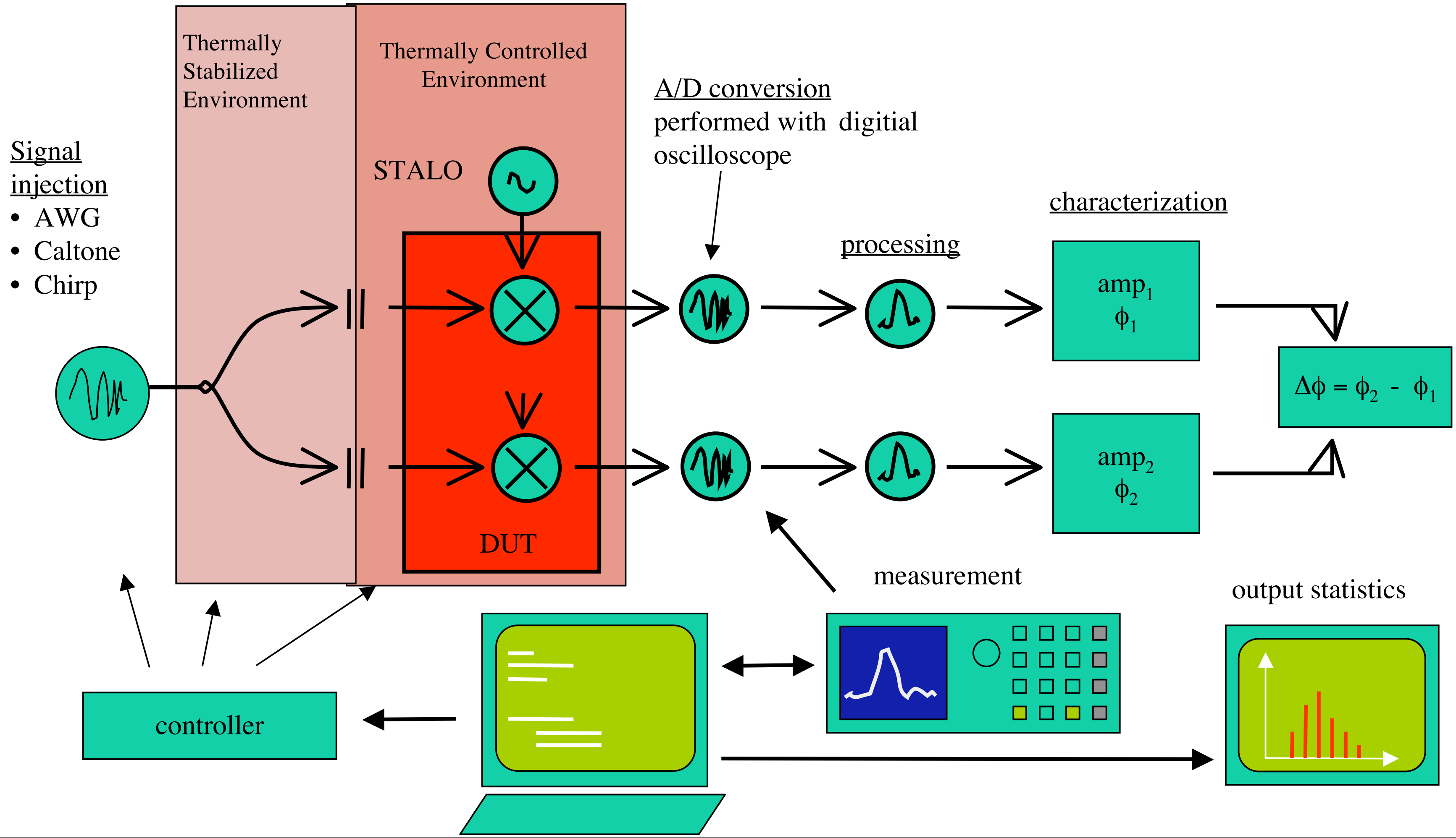
Two-Channel Gain Balance=1.5dB
Nominal Gain = 70 dB
P1dB=19dBm
Noise figure=3.5dB
Input Return Loss ~ 11 dB
Two-channel isoloation = 66 dB



Inter-channel phase difference stability (Standard Deviation) = 0.213°

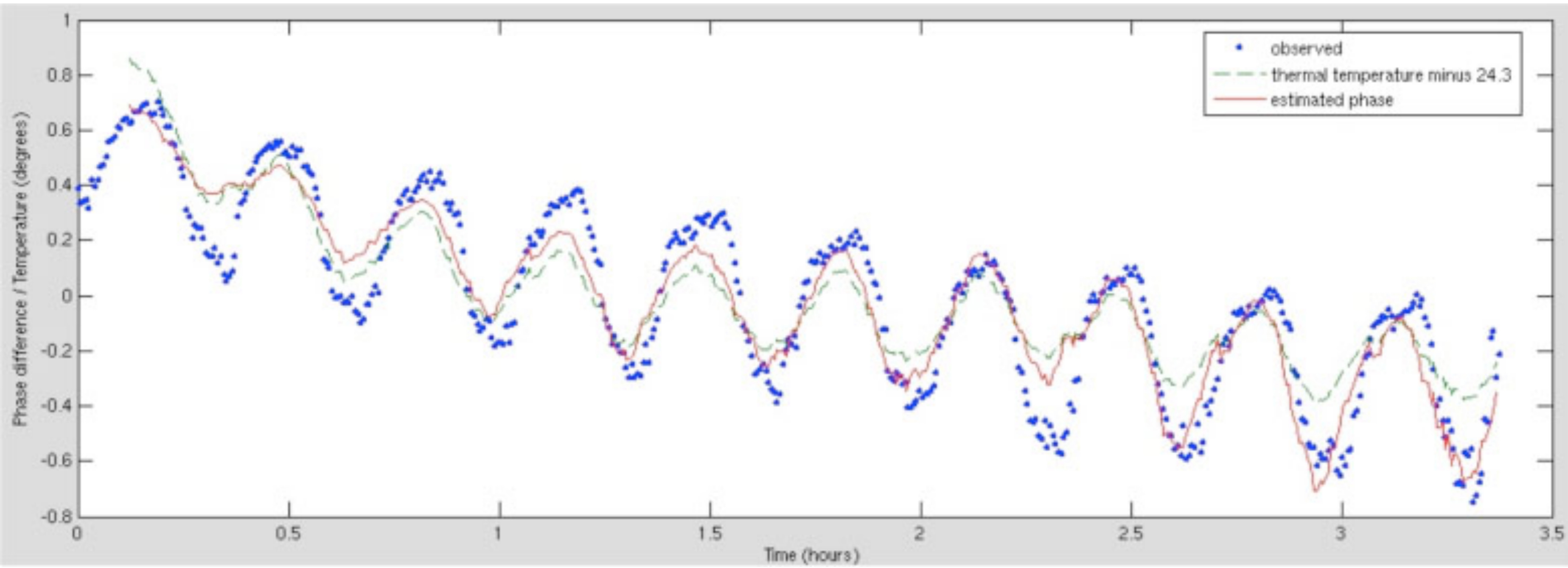
Phase standard deviation from best quadratic fit = 0.04° (0.05 ° rqmt.)

Test Setup Schematic



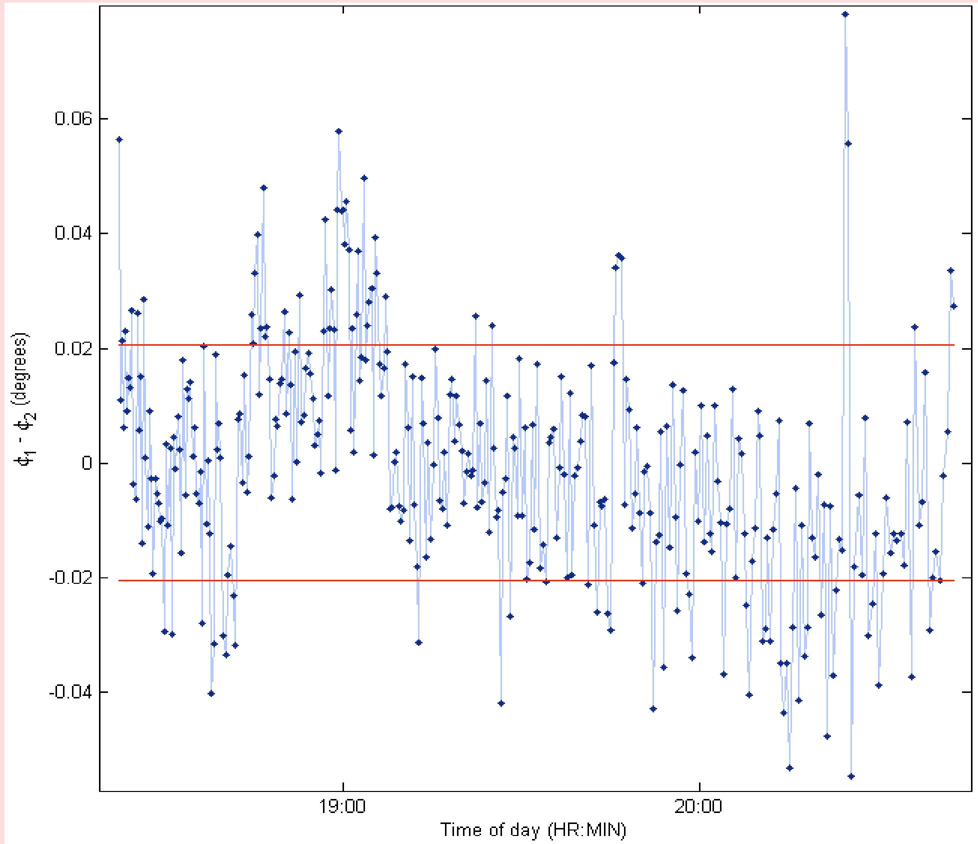

TIMMi
ARE DELICATE WIRE-BONDS
A PUFF OF AIR CAN BREAK
PLEASE REFRAIN FROM TOUCHING
THE PCBs.
TIMMi

Phase Difference, Temperature, and Best Fit Model



Thermal Testing

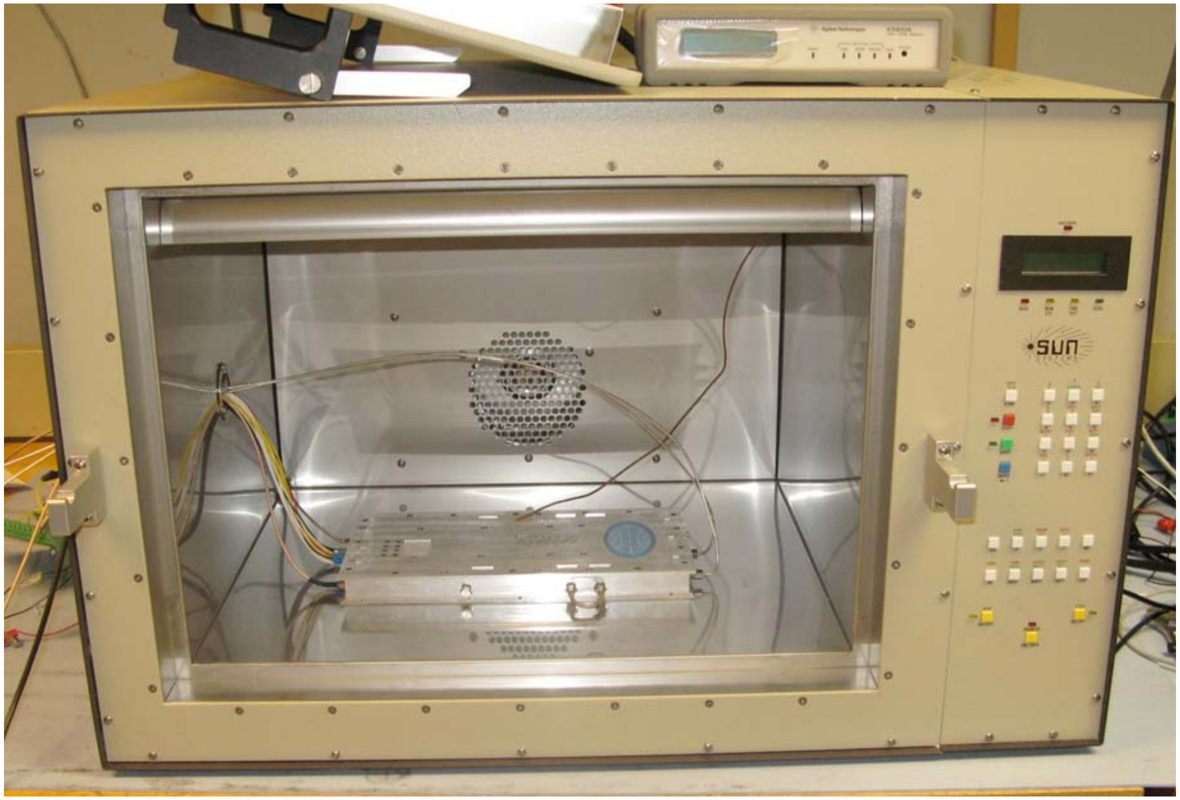
Thermally isolating the downconverter (breadboard model) leads to a 20 mdeg phase error over time.



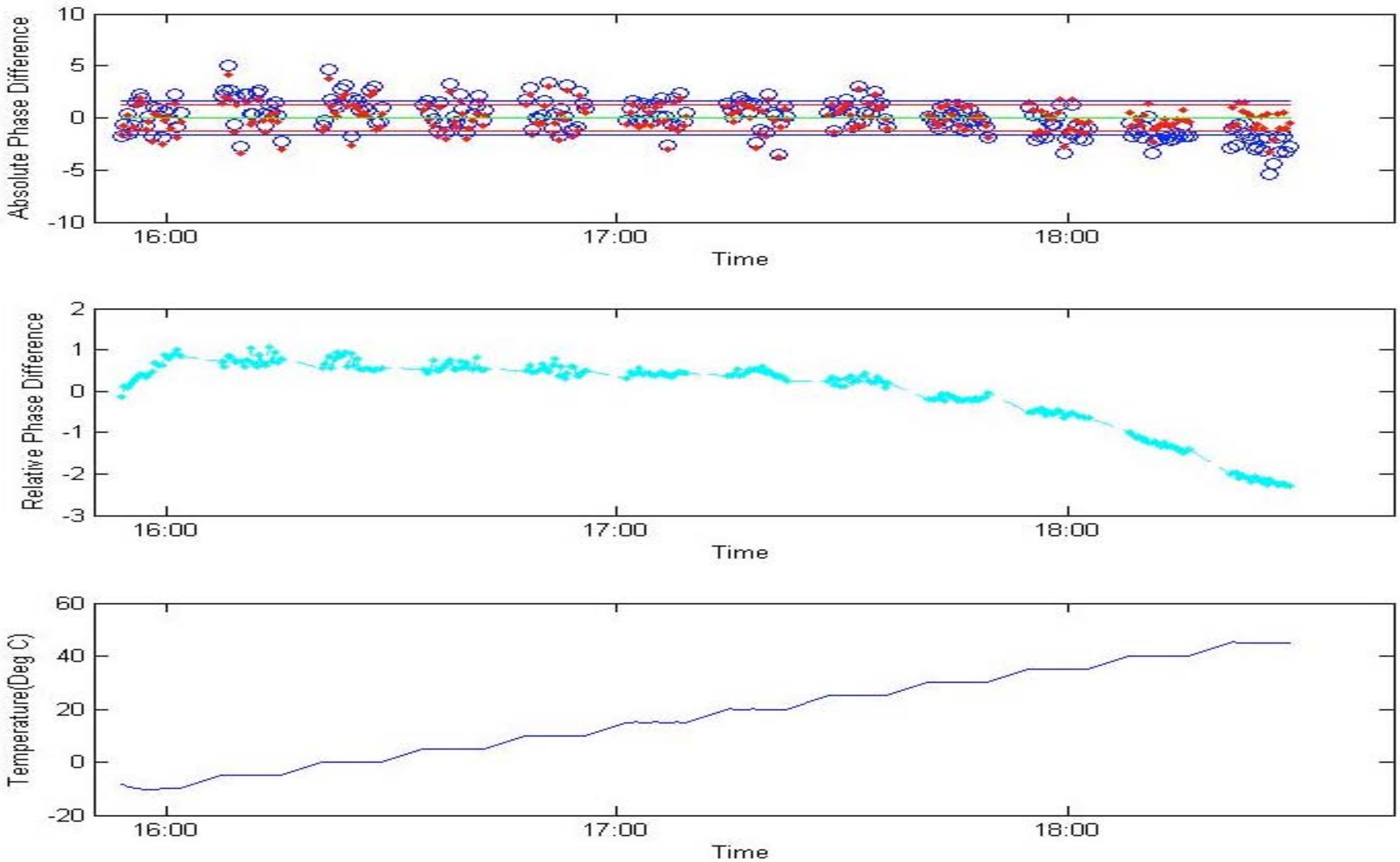
Controlled Thermal Testing

0.25°C/second, 15°C/min; -100°C to 300°C temperature range

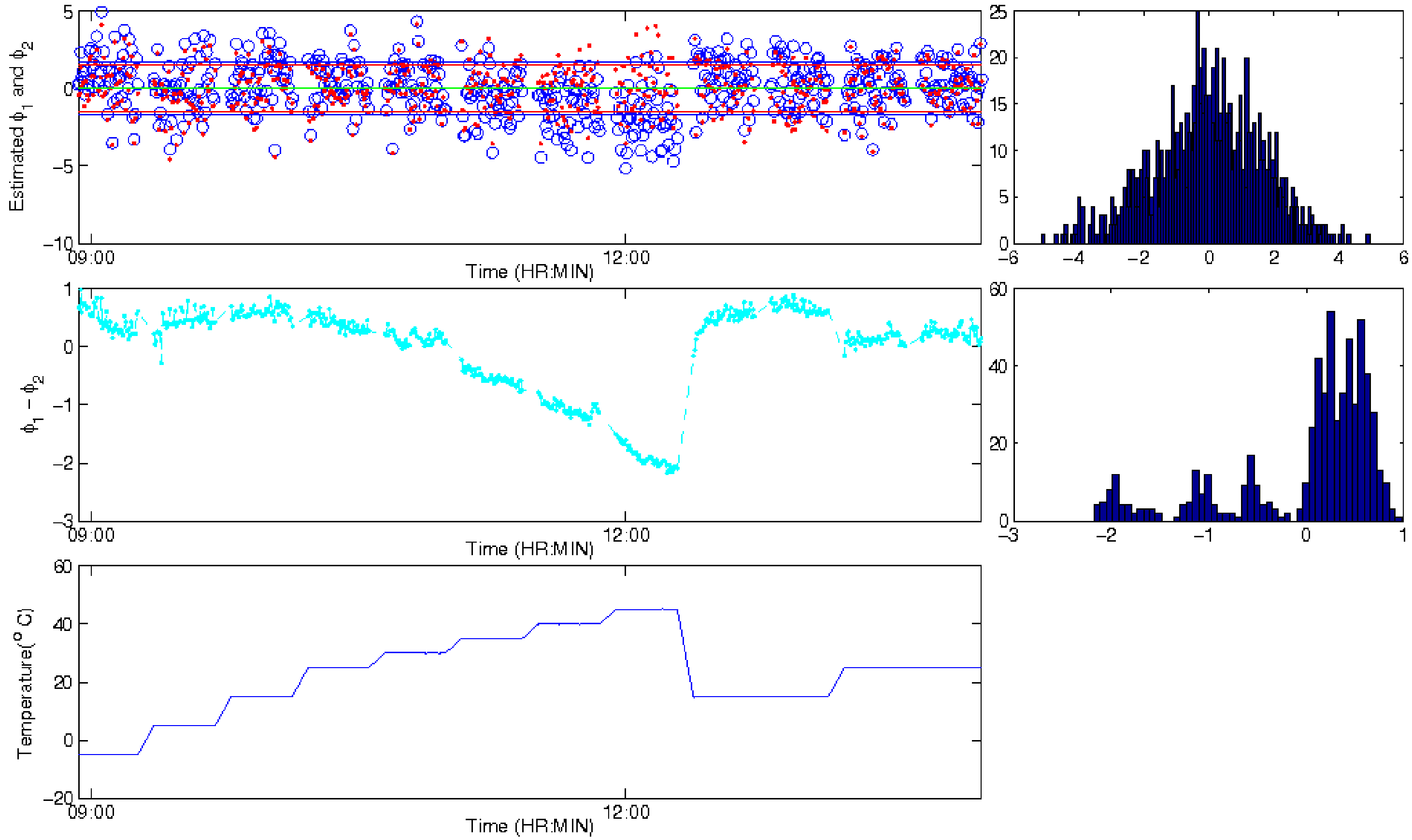
Remote operation via serial port or IEEE-488 bus



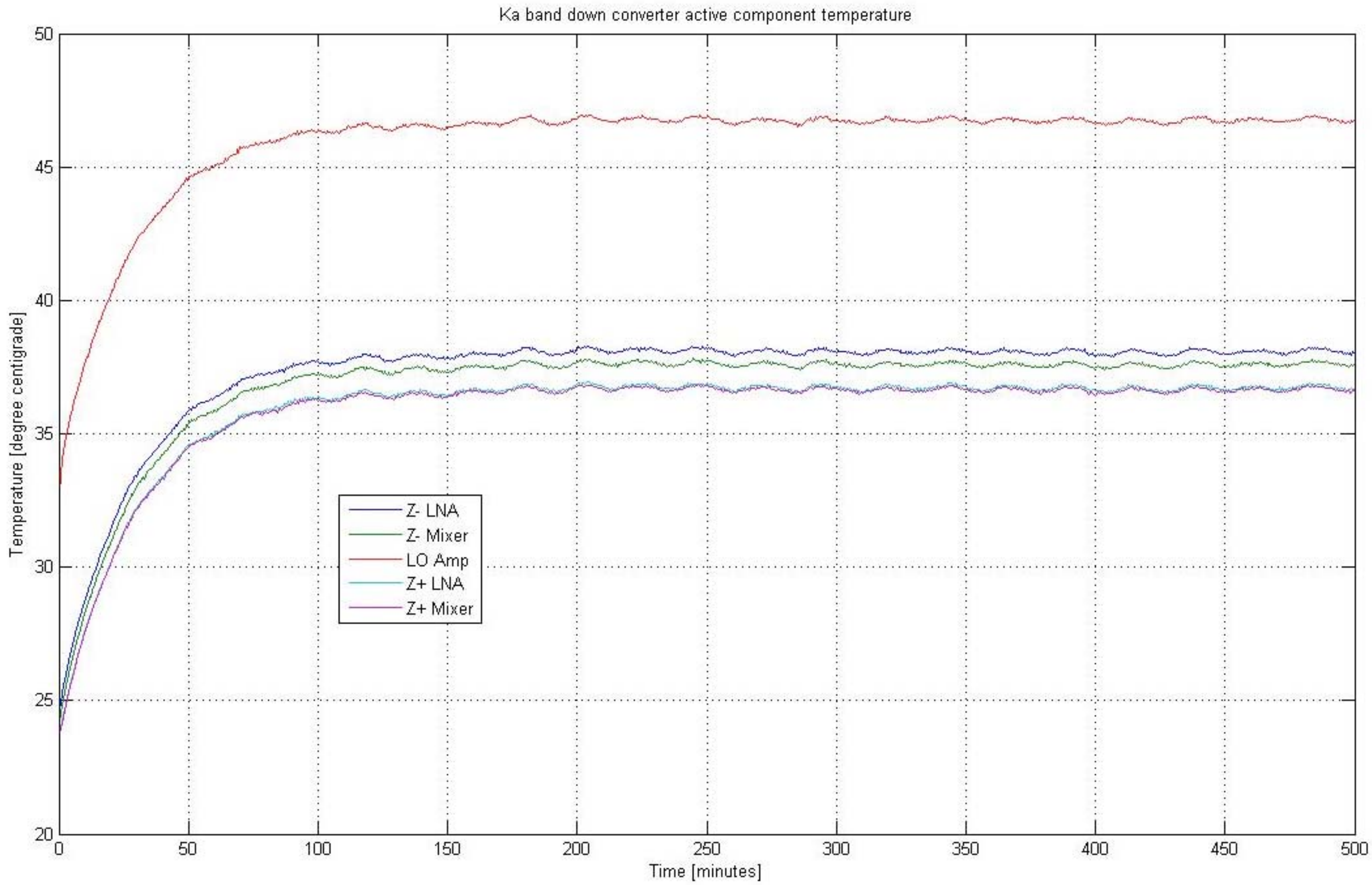
Early thermal test results (-10 to 45 deg C) -- Ku-band



More Thermal Cycle Experiments -- Ku-band

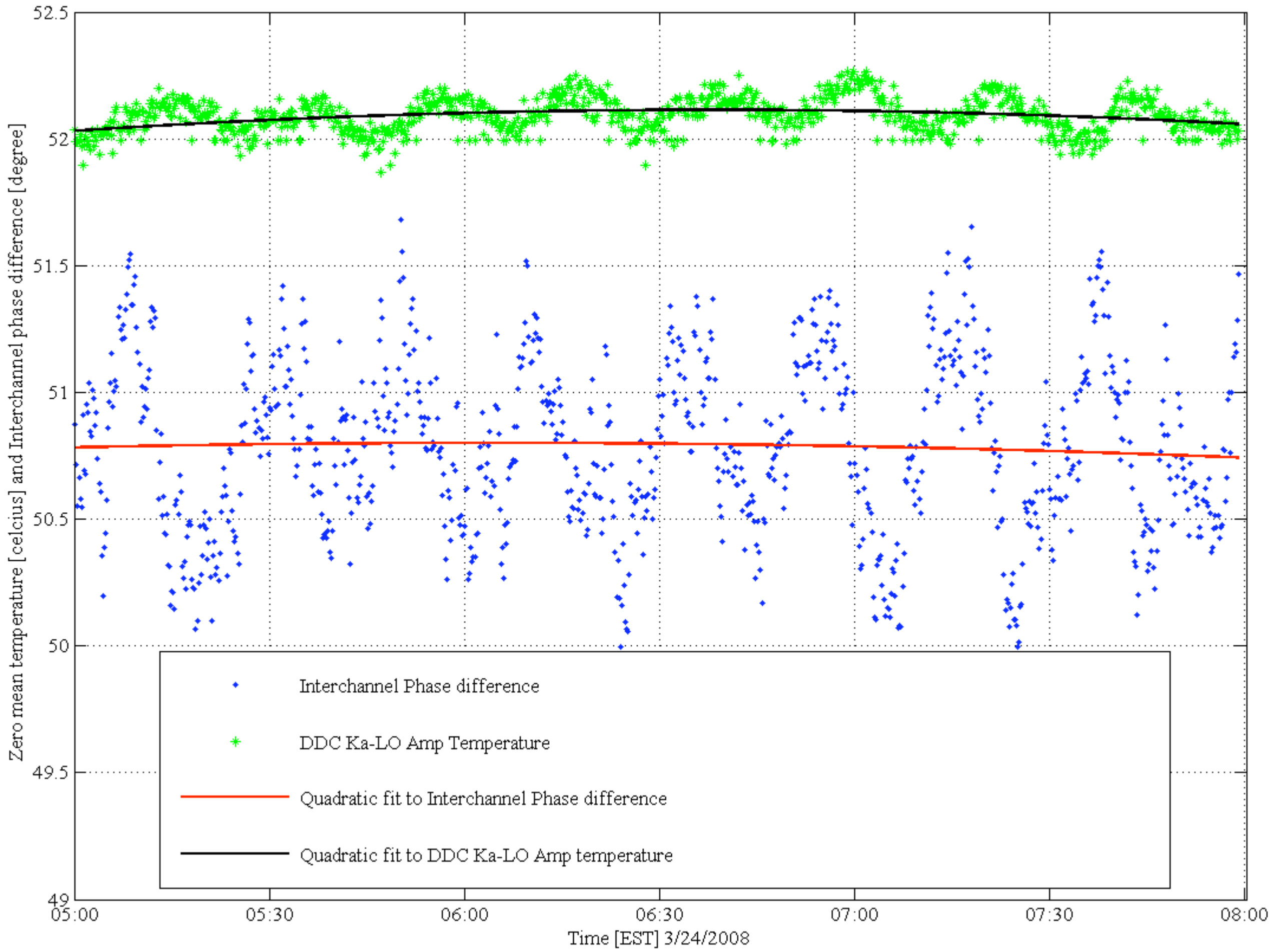


Reaching Thermal Stability (Ka-band)



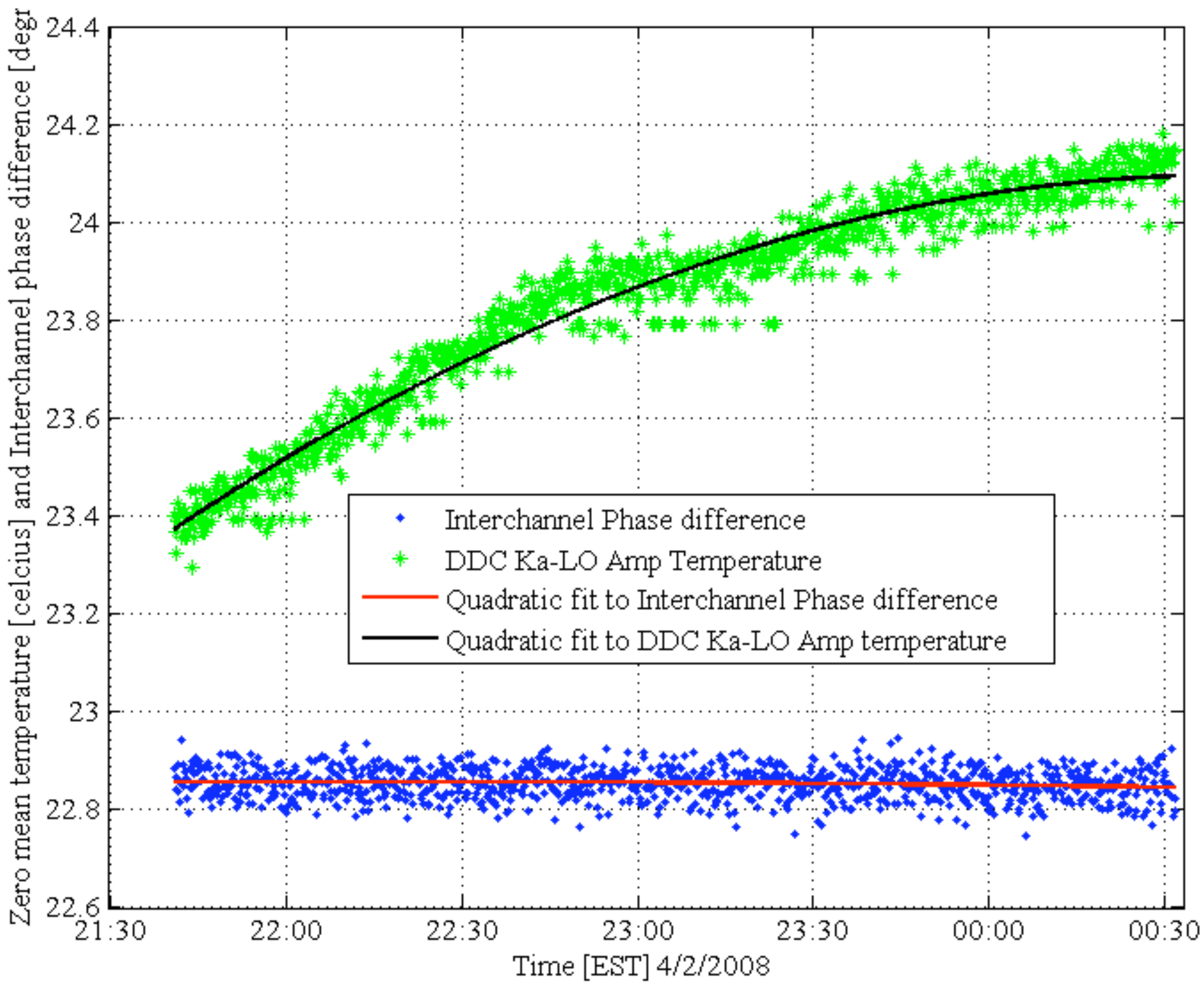
Temperature and Phase Fluctuations in an unprotected environment

Ka-band



Temperature and Phase Fluctuations in a Protected Environment

Ka-band



Ku-band Performance Numbers

Design Constraint	Ku-band DDC planned	Ku-band DDC actual
Signal Bandwidth	20 MHz	20 MHz (adjustable)
Effective Noise Bandwidth	< 30 Mhz	20.3 MHz (adjustable)
Input Frequency Range	13275 – 13295 MHz	33275 – 13295 MHz (nominal)
Operating Temperature	-10 to 50 degrees C	still being tested
Noise Figure	< 4.5 dB	< 3 dB
Output Frequency Range	5-25 MHz	5-25 MHz (nominal)
Channel to Channel Isolation	> 80 dB	~ 70 dB
Input/Output VSWR	< 1.5:1	1.14:1 (worst case)
Relative Channel to Channel Phase Stability	0.050 degrees RMS over BW	0.040 degrees RMS
Receiver Phase Variation over Best Quadratic Fit	3 deg RMS over BW	still being tested
Receiver Amplitude Variation	2 dB over BW	<1.5 dB over BW
Receiver Amplitude Variation over Best Linear Fit	0.3 dB RMS over BW	0.15 dB RMS over BW
Input Signal Range	-100 to –65 dBm	-115 to –44 dBm
DDC End to End Gain	65 to 70 dB	61.2 dB
Image Rejection	> 30 dB	> 30 dB, but still being tested

Ka-band Performance Numbers

Design Constraint	Ka-band DDC planned	Ka-band DDC actual
Signal Bandwidth	20 MHz	20 MHz (adjustable)
Effective Noise Bandwidth	< 30 Mhz	still being tested
Input Frequency Range	34975 – 34995 MHz	34975 – 34995 MHz (nominal)
Operating Temperature	-10 to 50 degrees C	still being tested
Noise Figure	< 4.5 dB	< 3.5 dB
Output Frequency Range	5-25 MHz	5-25 MHz (nominal)
Channel to Channel Isolation	> 80 dB	~ 66 dB
Input/Output VSWR	< 1.5:1	1.5:1
Relative Channel to Channel Phase Stability	0.050 degrees RMS over BW	0.040 degrees RMS
Receiver Phase Variation over Best Quadratic Fit	3 deg RMS over BW	still being tested
Receiver Amplitude Variation	2 dB over BW	<1.5 dB over BW
Receiver Amplitude Variation over Best Linear Fit	0.3 dB RMS over BW	0.15 dB RMS over BW
Input Signal Range	-100 to –65 dBm	-115 to –44 dBm
DDC End to End Gain	65 to 70 dB	70 dB
Image Rejection	> 30 dB	still being tested

TRL Definitions

begin

current

TRL 1 Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept: Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4 Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

TRL 5 System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

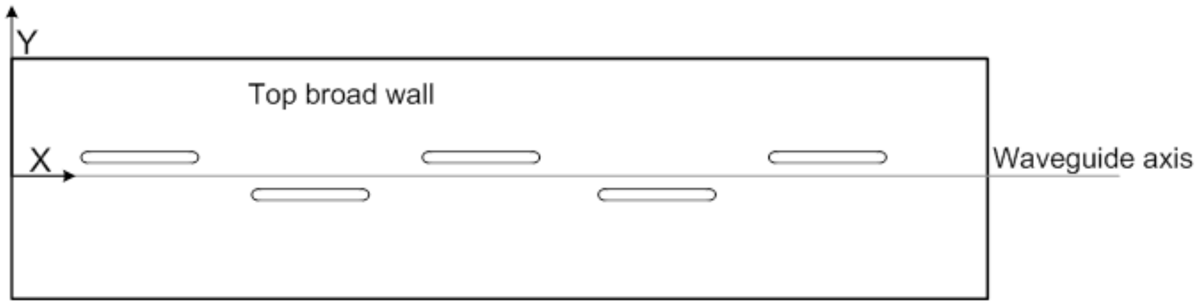
TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space): Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

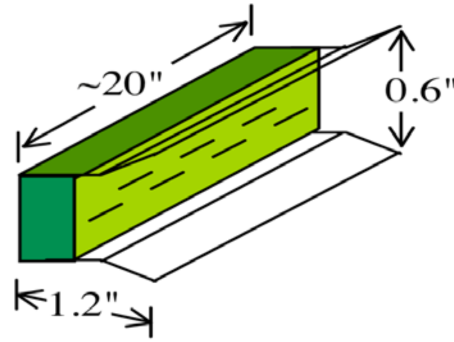
Mission Scenarios

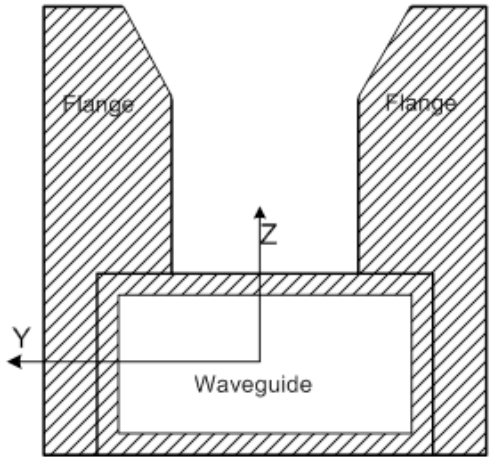
- Enabling Technology: High phase accuracy and low cross-talk two-channel Ku- and Ka-band downconversion to IF.
- Generic capabilities
  - precision polarimetry
  - precision interferometry (along-track and cross-track)
  - index of refraction studies for the atmosphere
- Airborne
  - compact side-looking interferometer for topographic and volumetric depth measurements
- Spaceborne
  - detailed characterization will provide key inputs for mission design and observing scenarios
  - Surface Water Ocean Topography (SWOT)
  - Sea Ice, cold lands process and gravitational satellites

TRL advancement

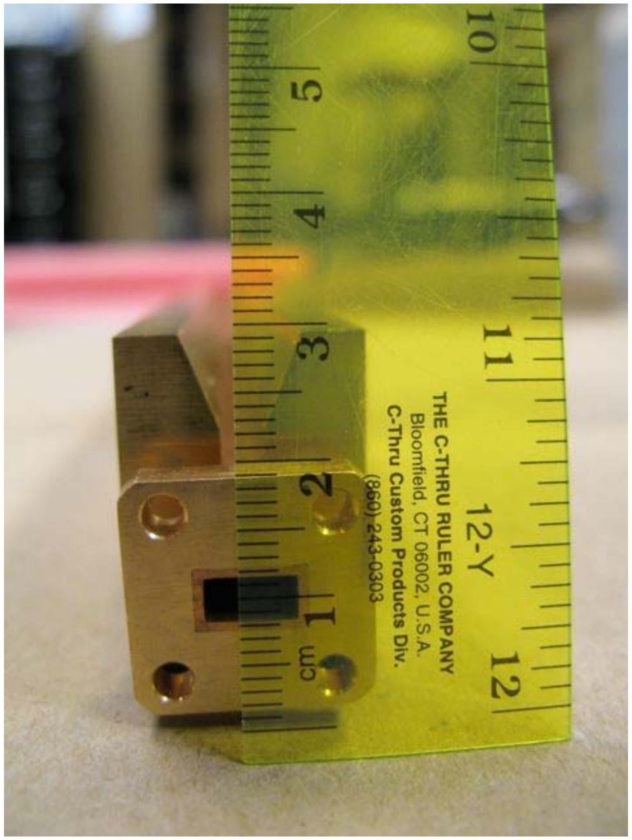
Slotted Waveguide Antenna Design

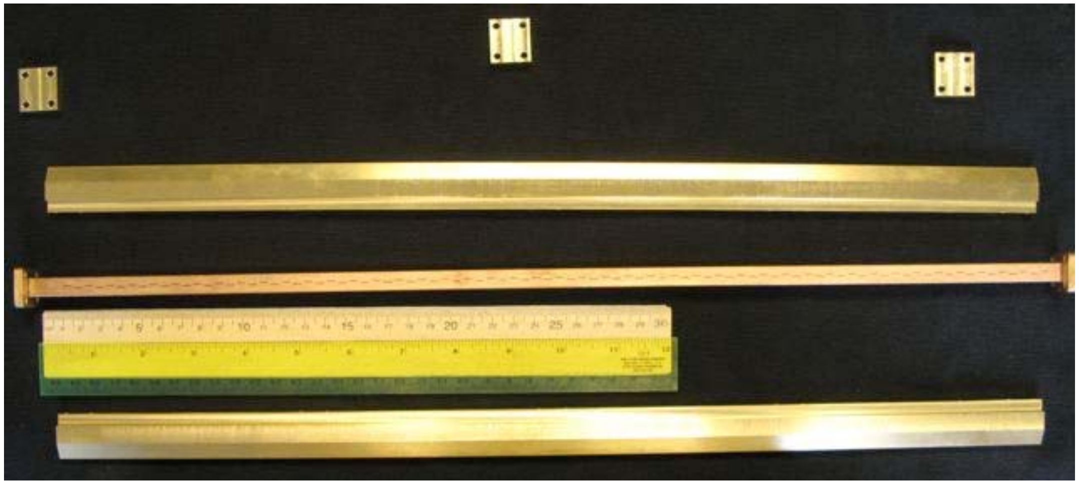


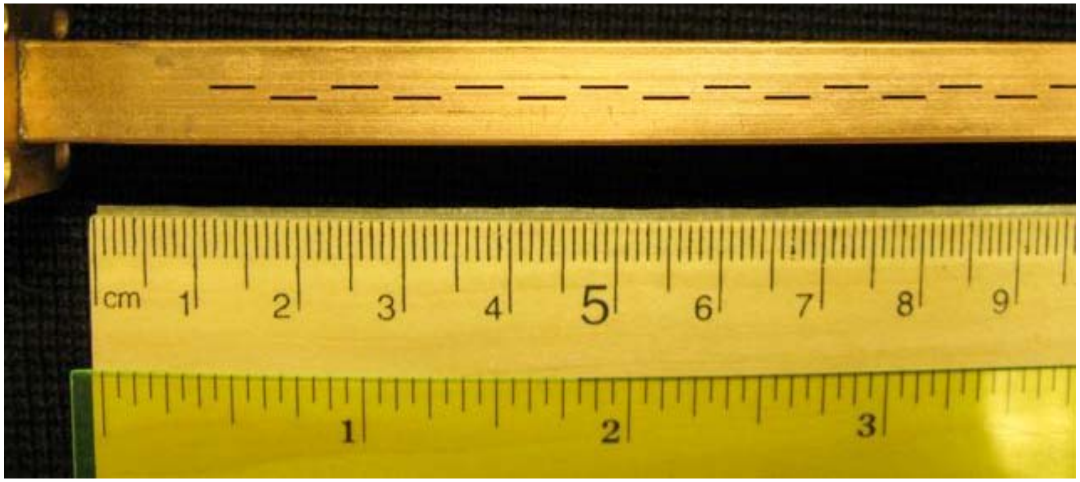




Slotted Waveguide Antenna Implementation

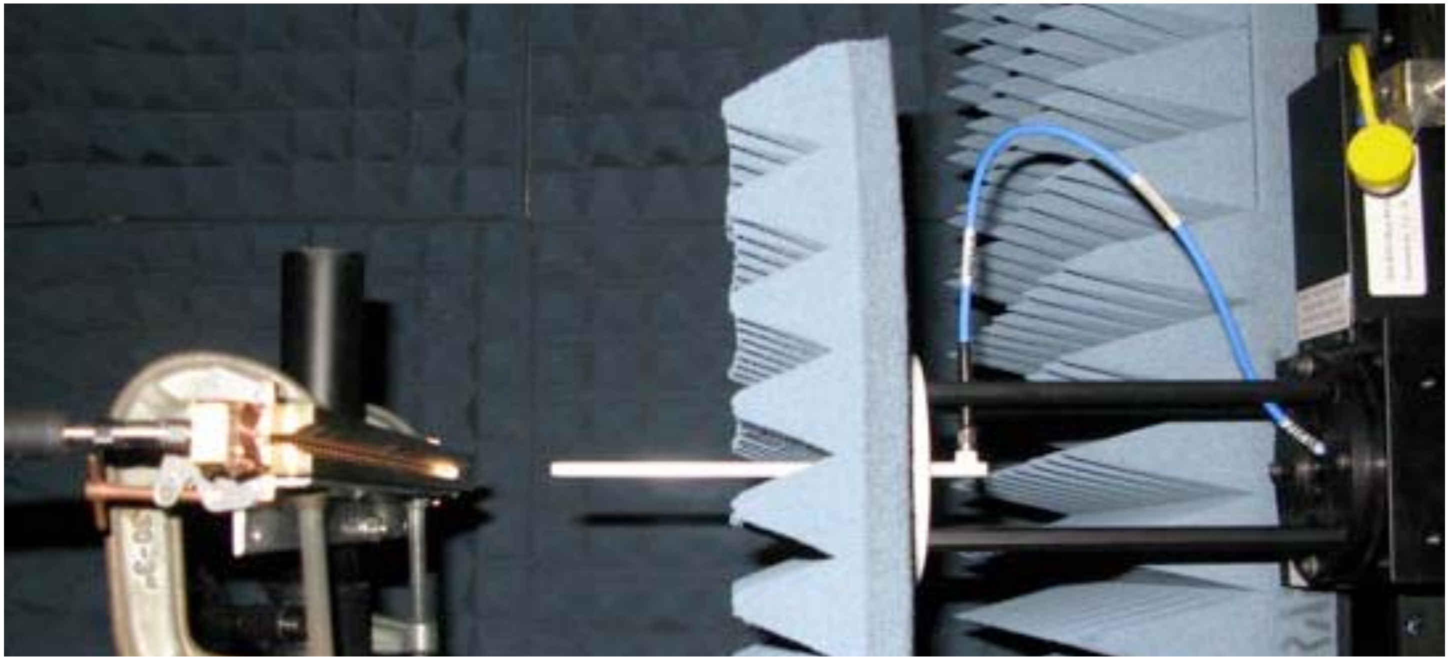




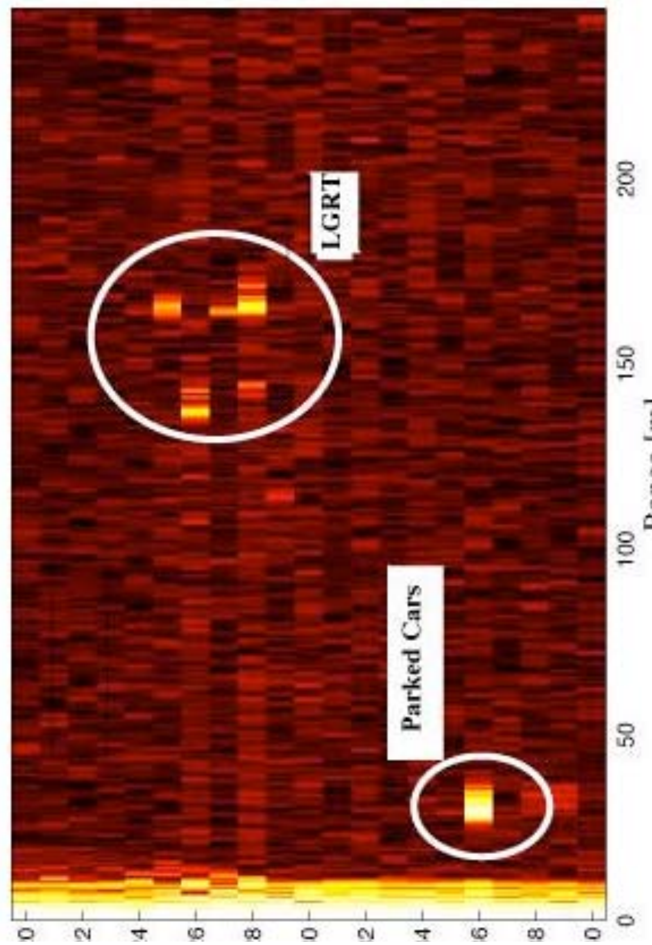


The Ka-band Slotted Waveguide Antenna

- A near-field probe is used to test the antenna performance

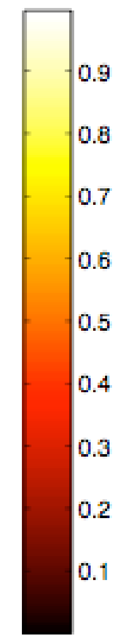


First interferometric results at 35 GHz!

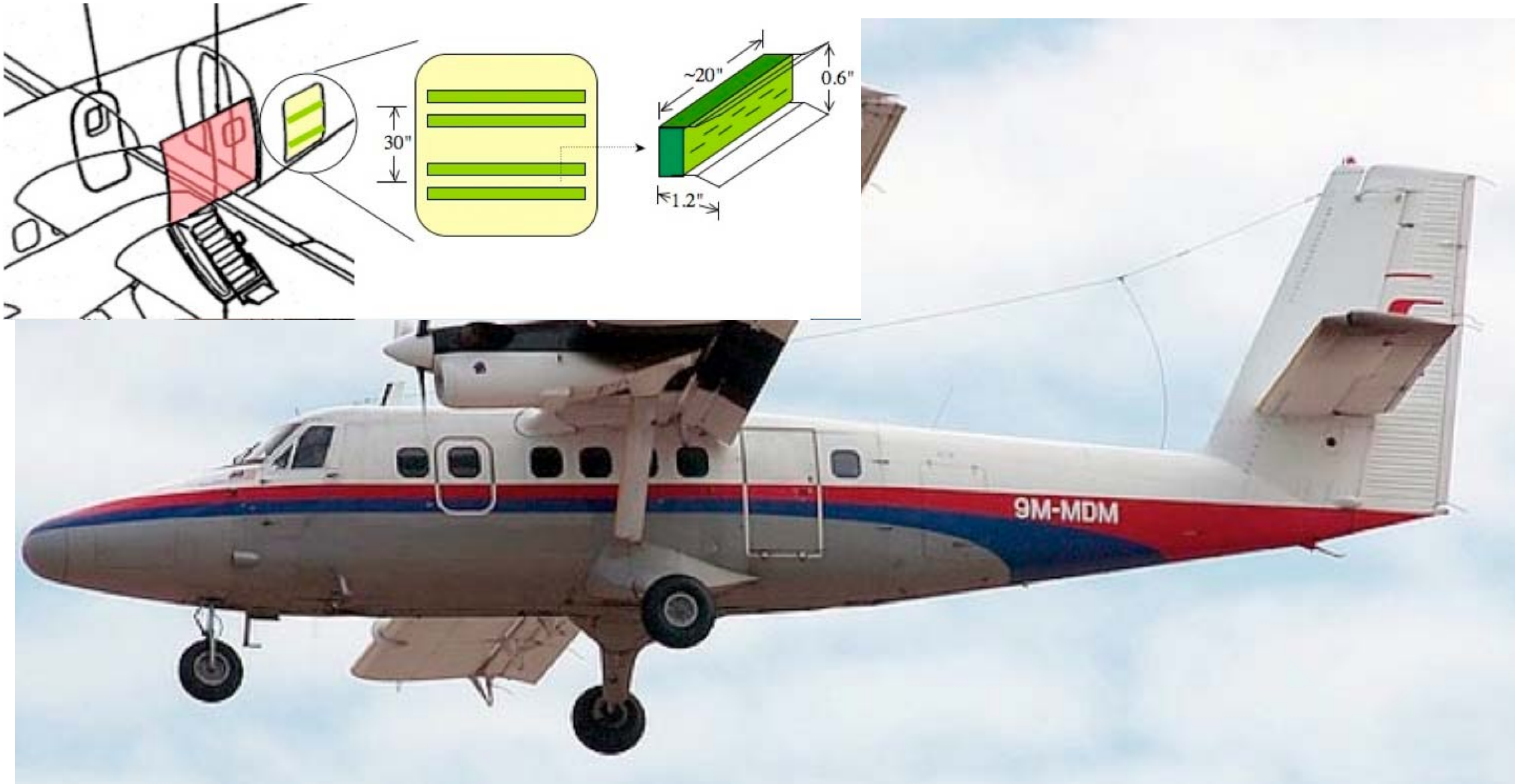


Interferometric correlation magnitude

$$\rho e^{j\phi} = \frac{\langle E_1 E_2^* \rangle}{\sqrt{\langle |E_1|^2 \rangle \langle |E_2|^2 \rangle}}$$



Potential for an Airborne Platform



Academic Output

- Two date, the project has generated:
  - Four Masters degrees (two continuing on for a PhD, another working at NASA-Marshall)
  - One Journal Paper (IEEE MTT), One in progress, One book
  - Four undergraduate projects

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES

IEEE MTT, 55(10), 2007

Variable Precision Two-Channel Phase, Amplitude, and Timing Measurements for Radar Interferometry and Polarimetry

Paul Siqueira, *Member, IEEE*, Razi Ahmed, John W. Wirth, and Alex Bachmann

DESIGN AND DEVELOPMENT OF A KA-BAND INTERFEROMETER FOR CRYOSPHERIC APPLICATIONS

Harish Vedantham, 2008

RADAR SYSTEM CHARACTERIZATION: MATHEMATICAL MODELS, SIMULATIONS AND VERIFICATION

VDM Verlag Dr. Müller

Razi Ahmed, 2006

DESIGN AND DEVELOPMENT OF TIMMI - AN INTERFEROMETRIC RADAR

A Thesis Presented

by

KARTHIK SRINIVASAN VENKATASUBRAMANIAN

September 2007

End