A Ka-band to baseband RF Testbed for the SWOT mission

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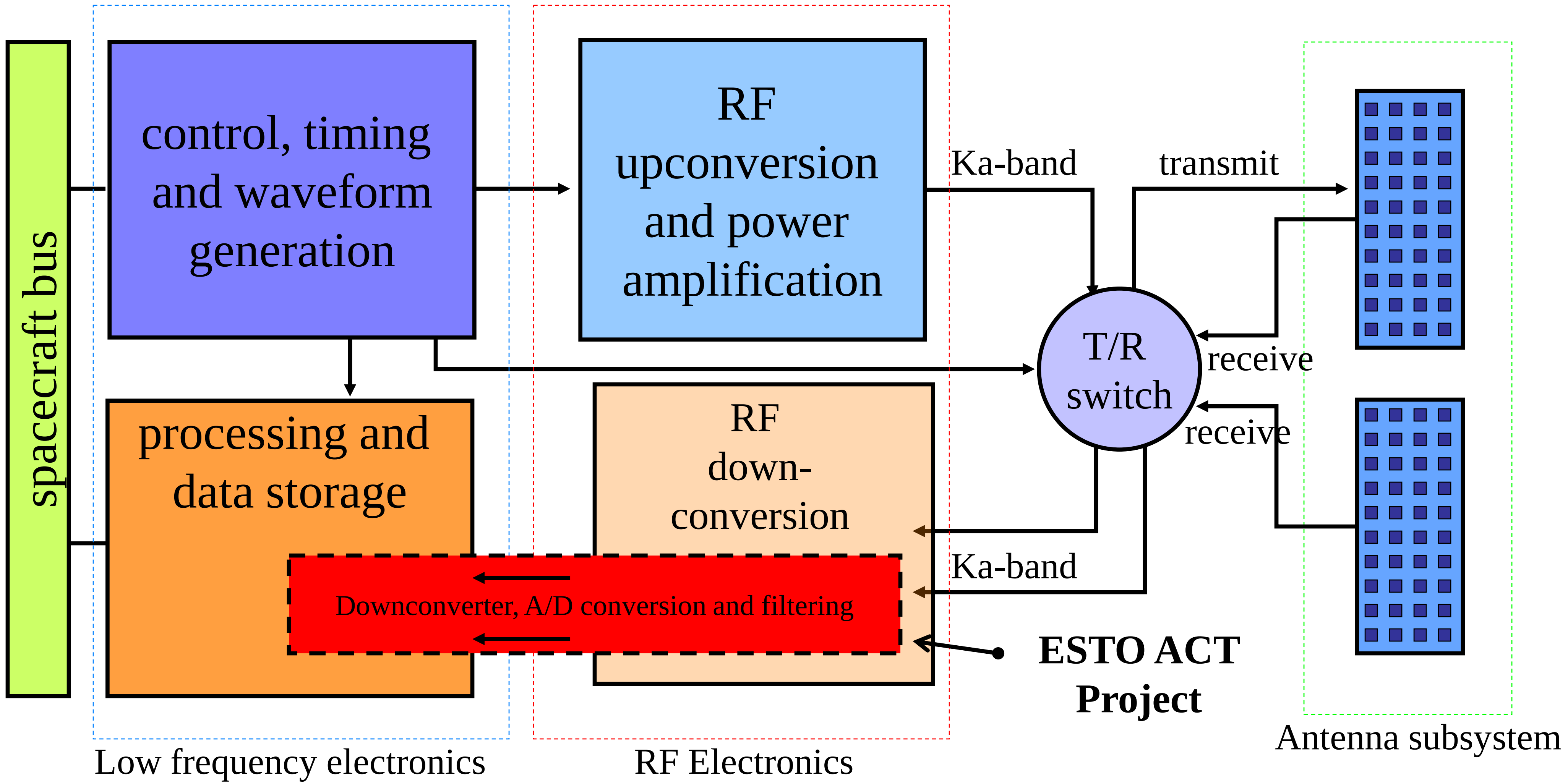
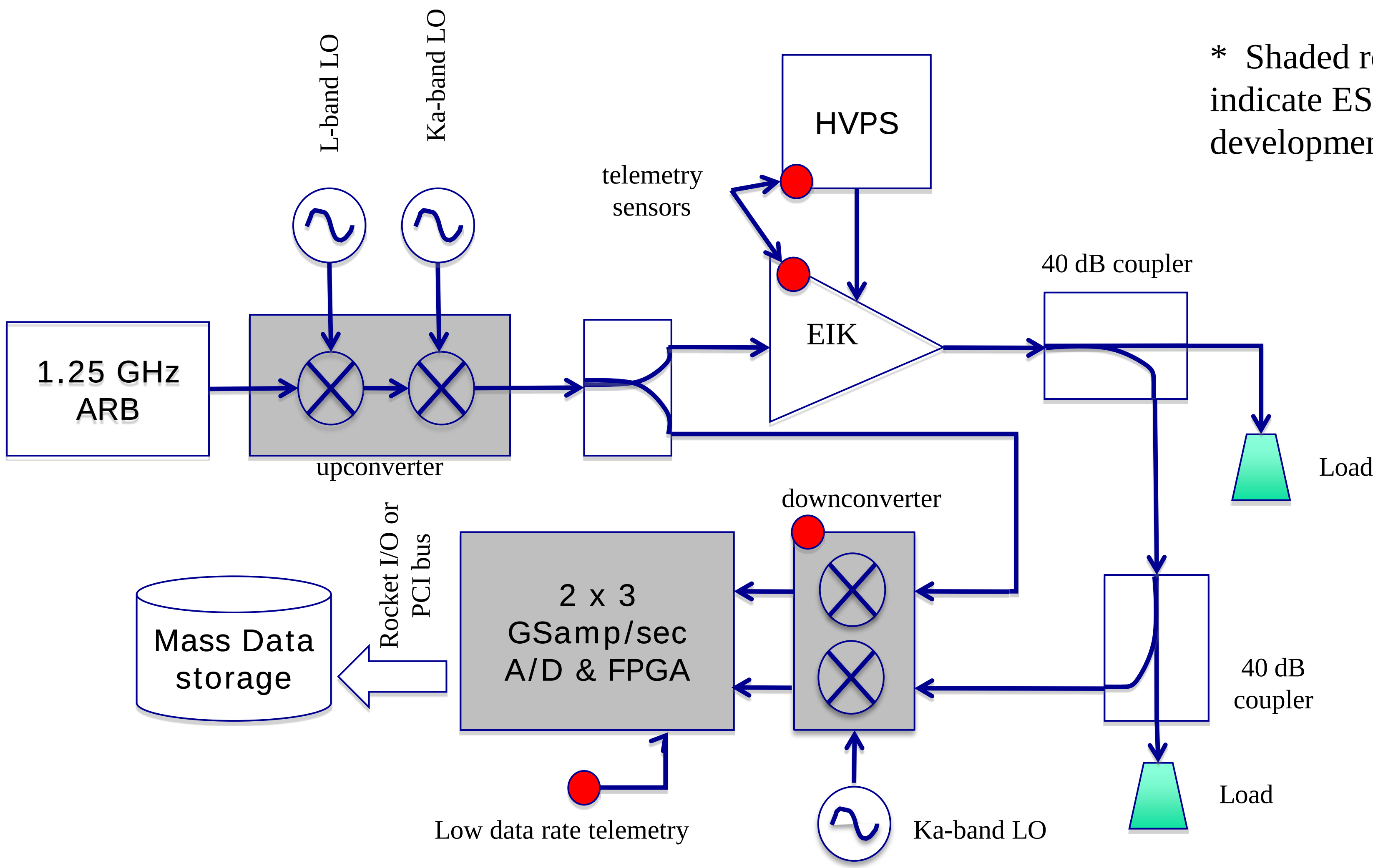
SWOT RF Testbed

- Based on ESTO funded downconverter development to explore receiver topologies and to characterize/compensate for thermal effects
- Additional testbed parts constructed from available test equipment and RF parts
- Ability to perform tests over temperature
- High-speed (2x3GSamp/sec ADC/FPGA Board) for capturing and processing data in real time
- TRL Advancement

Spacecraft block diagram

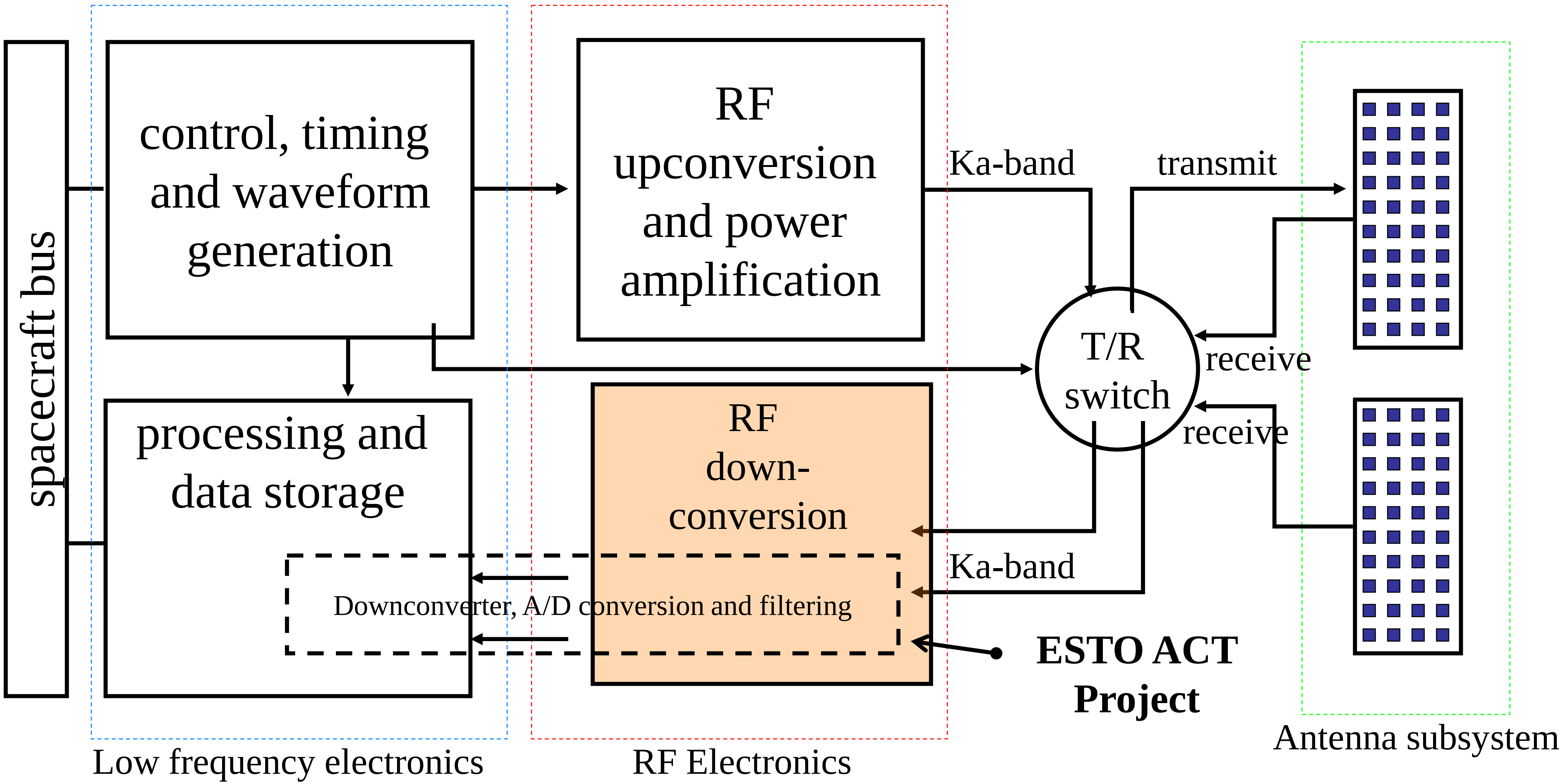


Block Diagram of RF Testbed



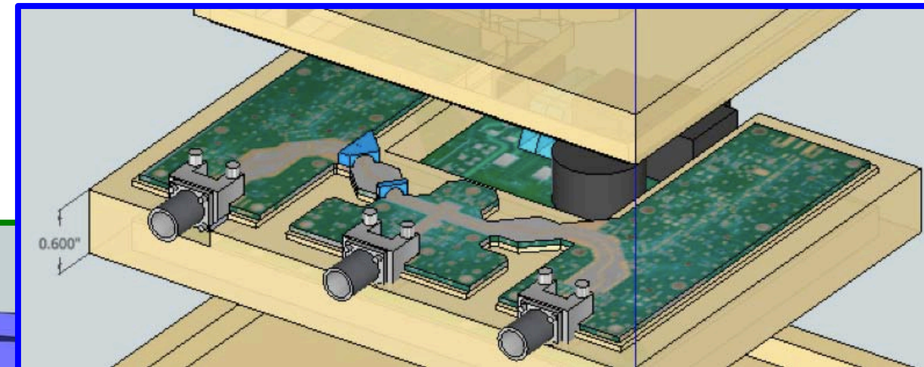
* Shaded regions indicate ESTO funded development components

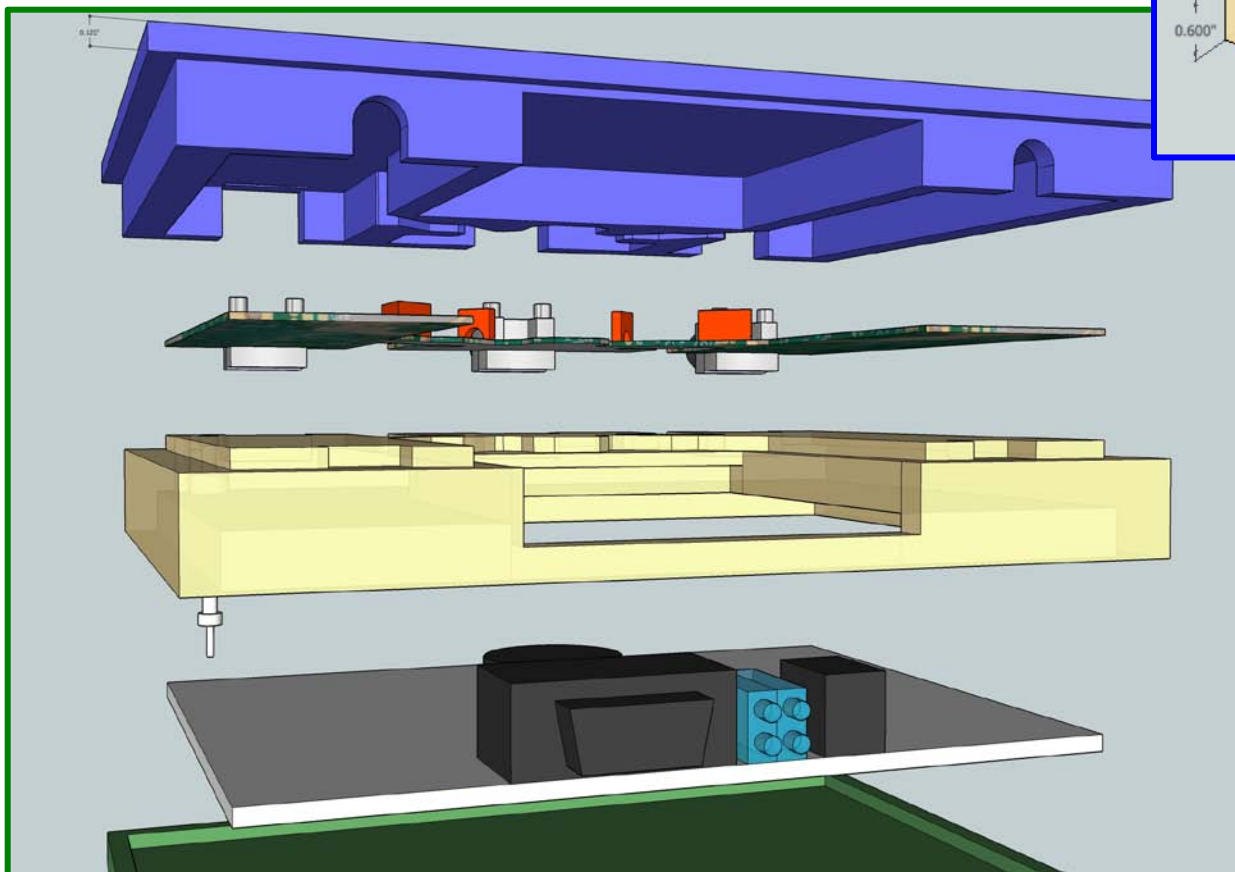
Spacecraft block diagram



Ka-band downconverter development

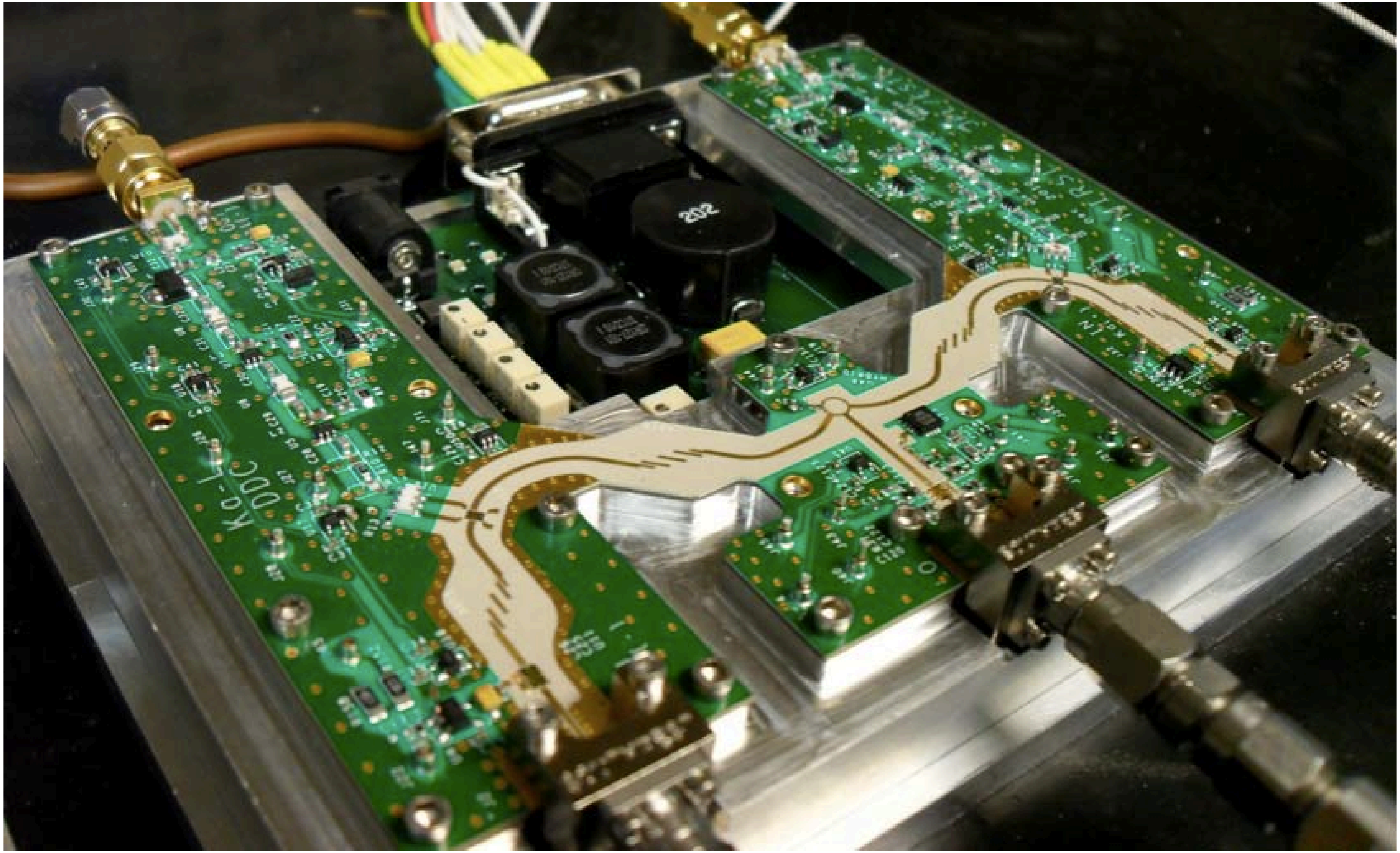
SWOT prototype reciever



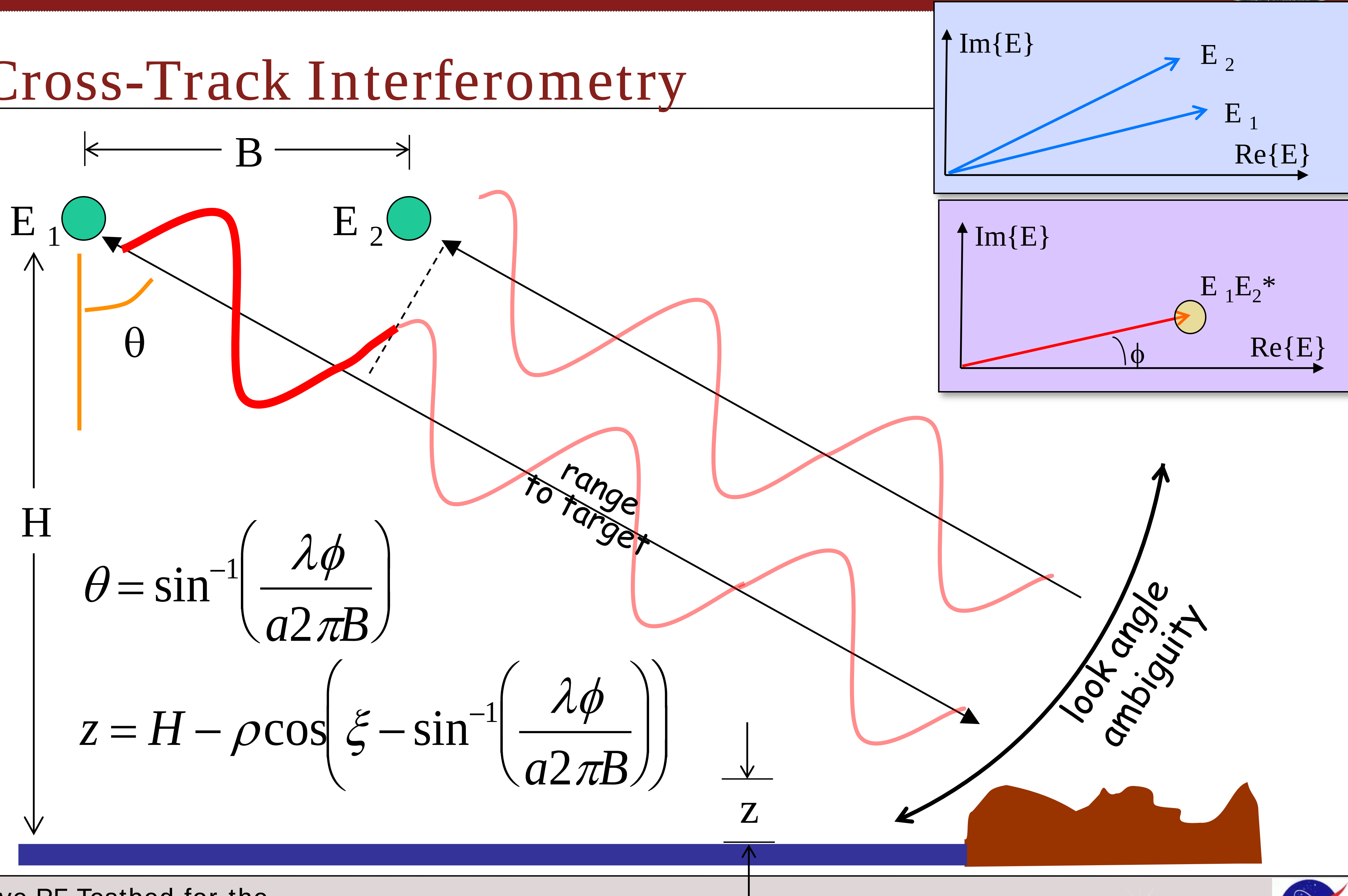


- To improve isolation and thermal management, DC electronics were moved into a secondary cavity
- drop-down walls isolate filter cavities
- between-board connections made with Tusonix through-connectors.
- L-band signal amplified to be directly sampled by A/D converter

Exposed RF subsection undergoing testing



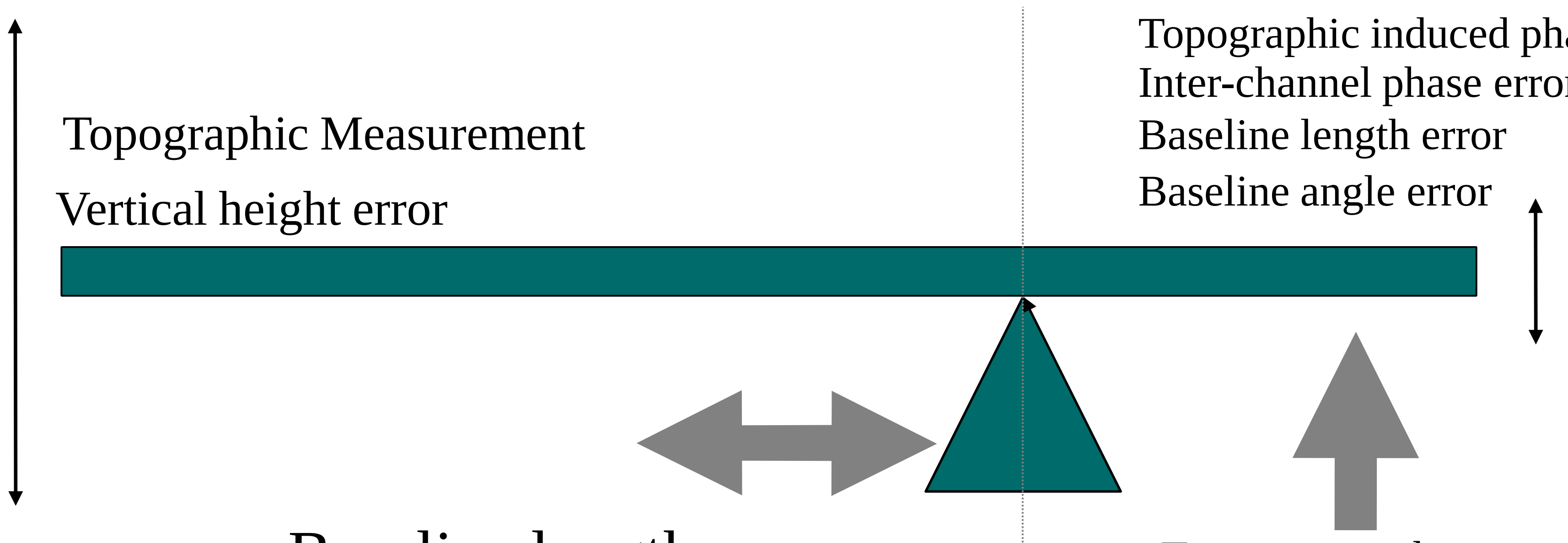
Cross-Track Interferometry



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

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

Engineering Challenge

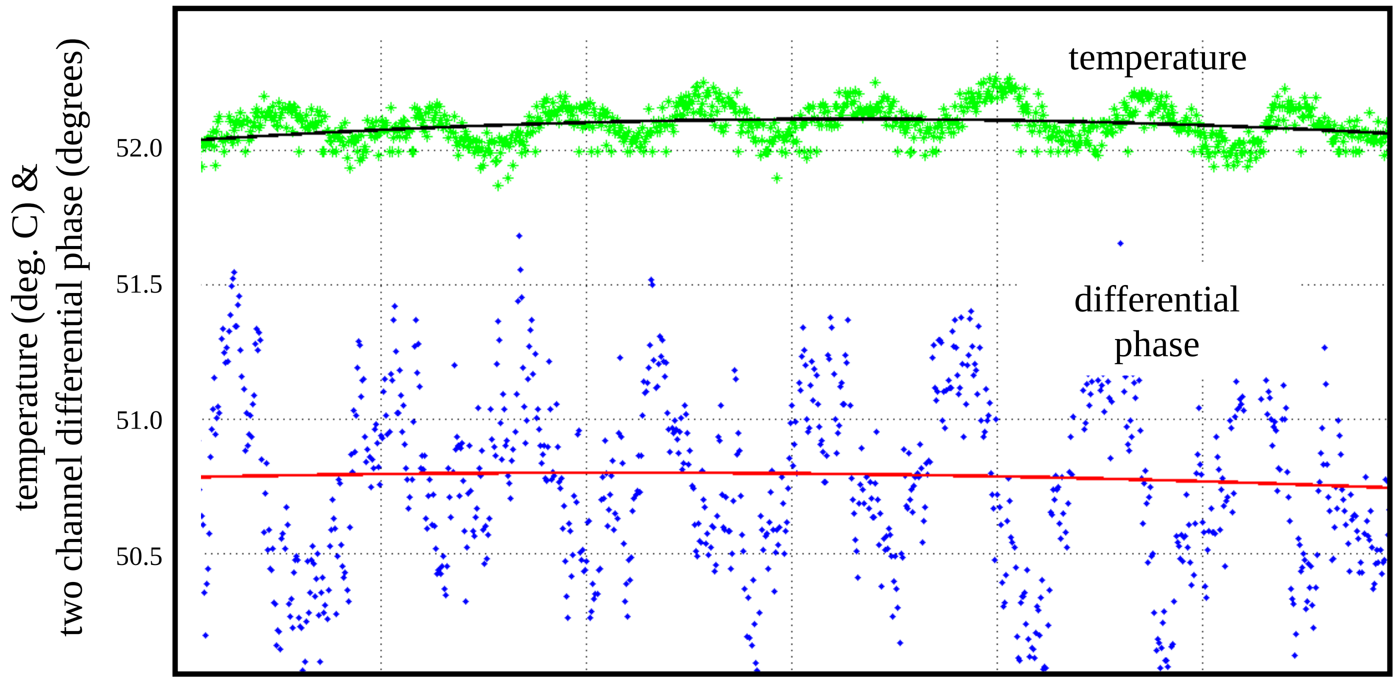


Baseline length

Affects instrument size and weight

- Temperature changes
- Nonlinear operations during downconversion
- Mechanical vibrations
- External interference

Temperature dependence of differential phase

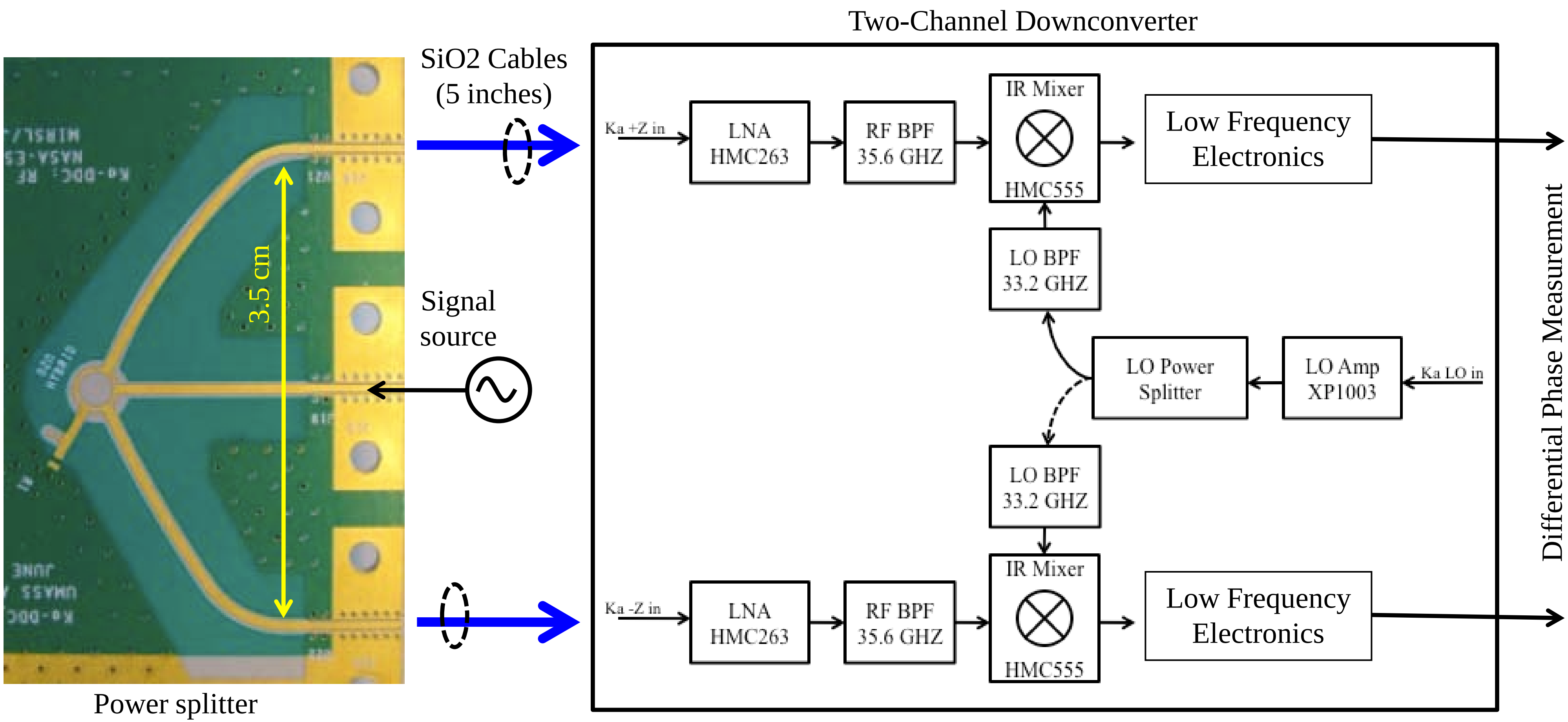


- Concurrent measurements of temperature and differentail phase showed a strong dependence of phase on temperature.
- Temperature fluctuations due to the ambient enviroment. Measurements in a closed environment were much more stable
- Solid lines in the plot indicate a 3rd order polynomial fit to the data.

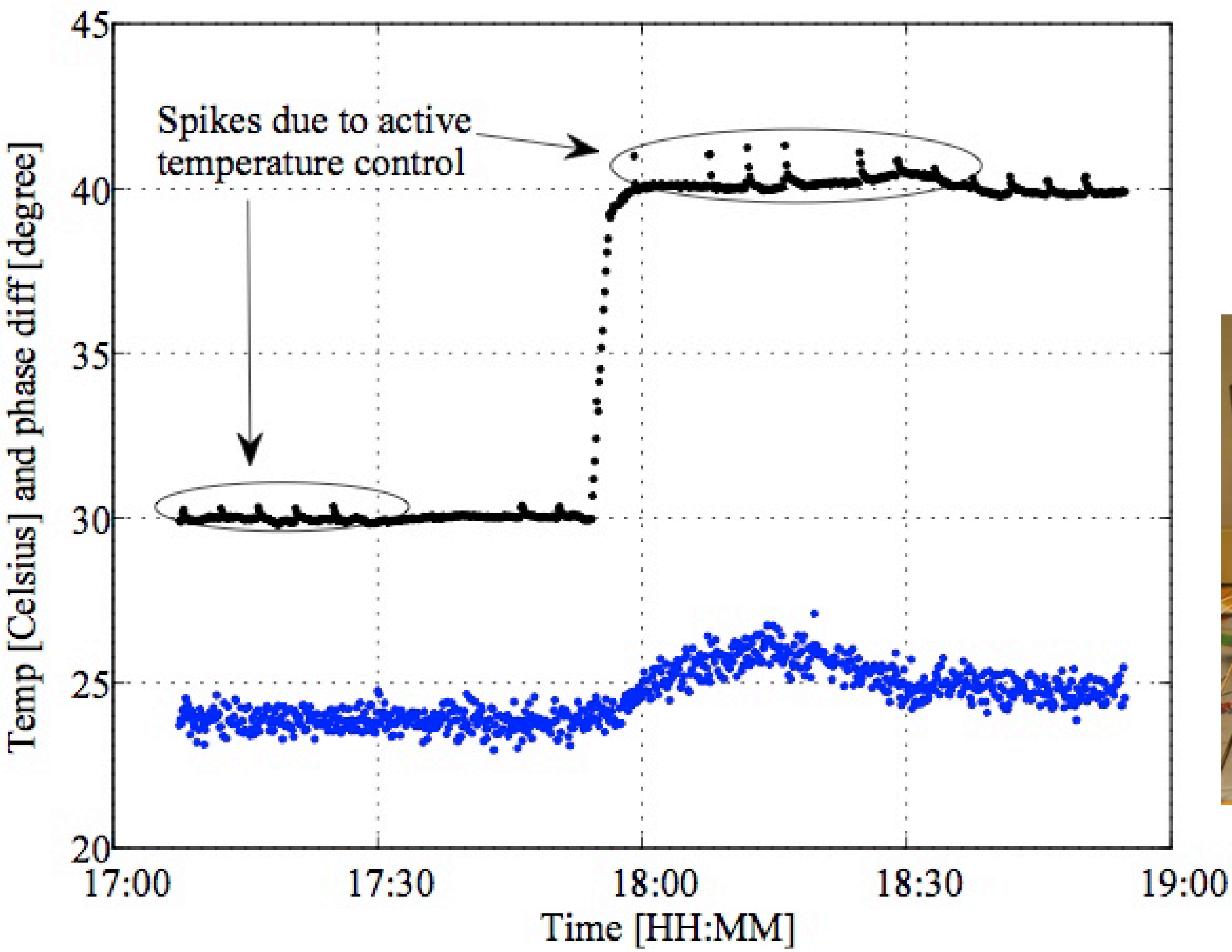
Thermal Analysis

- 35 GHz signals have a wavelength of 8.4 mm.
- Changes in the physical path length due to thermal expansion/contraction, will cause changes in the signal phase as will temperature imbalances in active components
- A one degree phase change is equivalent to 23 μm of electrical path length change. Integrated over 5 cm of total path length, this is equivalent to a 0.05% expansion coefficient, or 5 parts in 10,000.
- Thermal imbalances between the two interferometric paths will thus induce a temperature dependent phase error.
- We are measuring temperature "on-board" so that this phase error may be monitored and corrected in the digital stage.
- Point measures of temperature are unlikely to be sufficient to characterize the phase error, as they do not take into account temperature distributions or the thermal inertia of the chassis
- Thermal modeling will help understand the source of thermal imbalance as it is distributed troughout the system

Measurements of Differential Phase

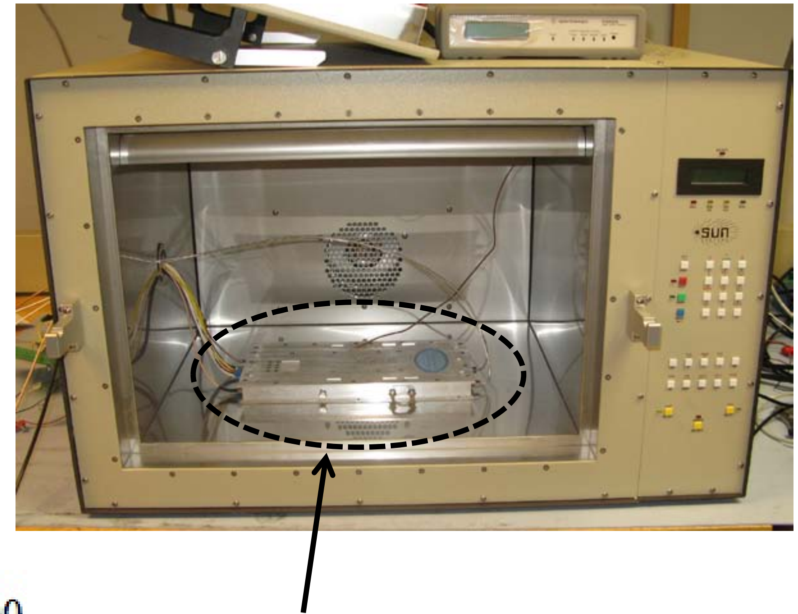


Thermal Testing and Characterization is a tricky affair

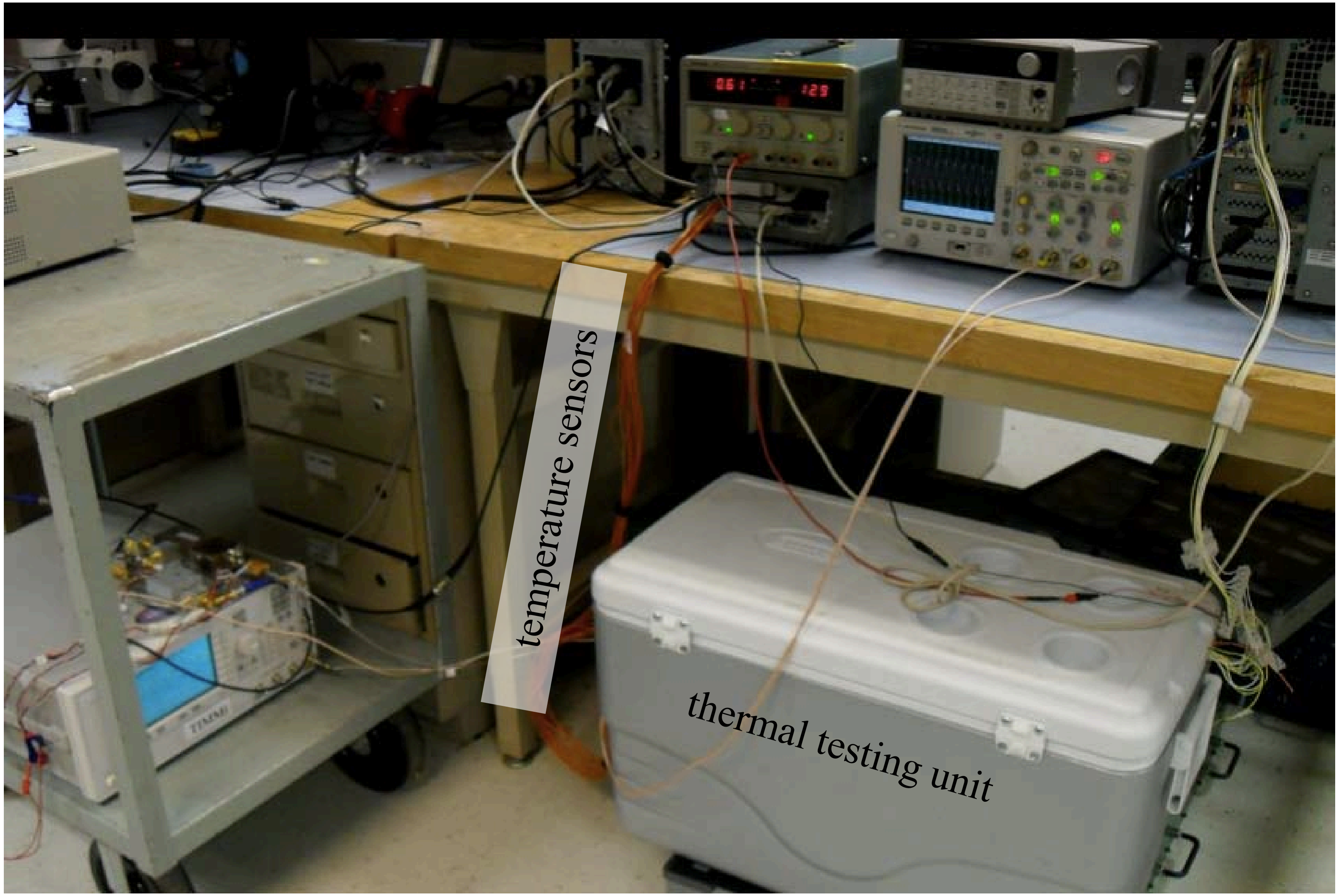


0.25°C/second, 15°C/min; -100°C to 300°C temperature range

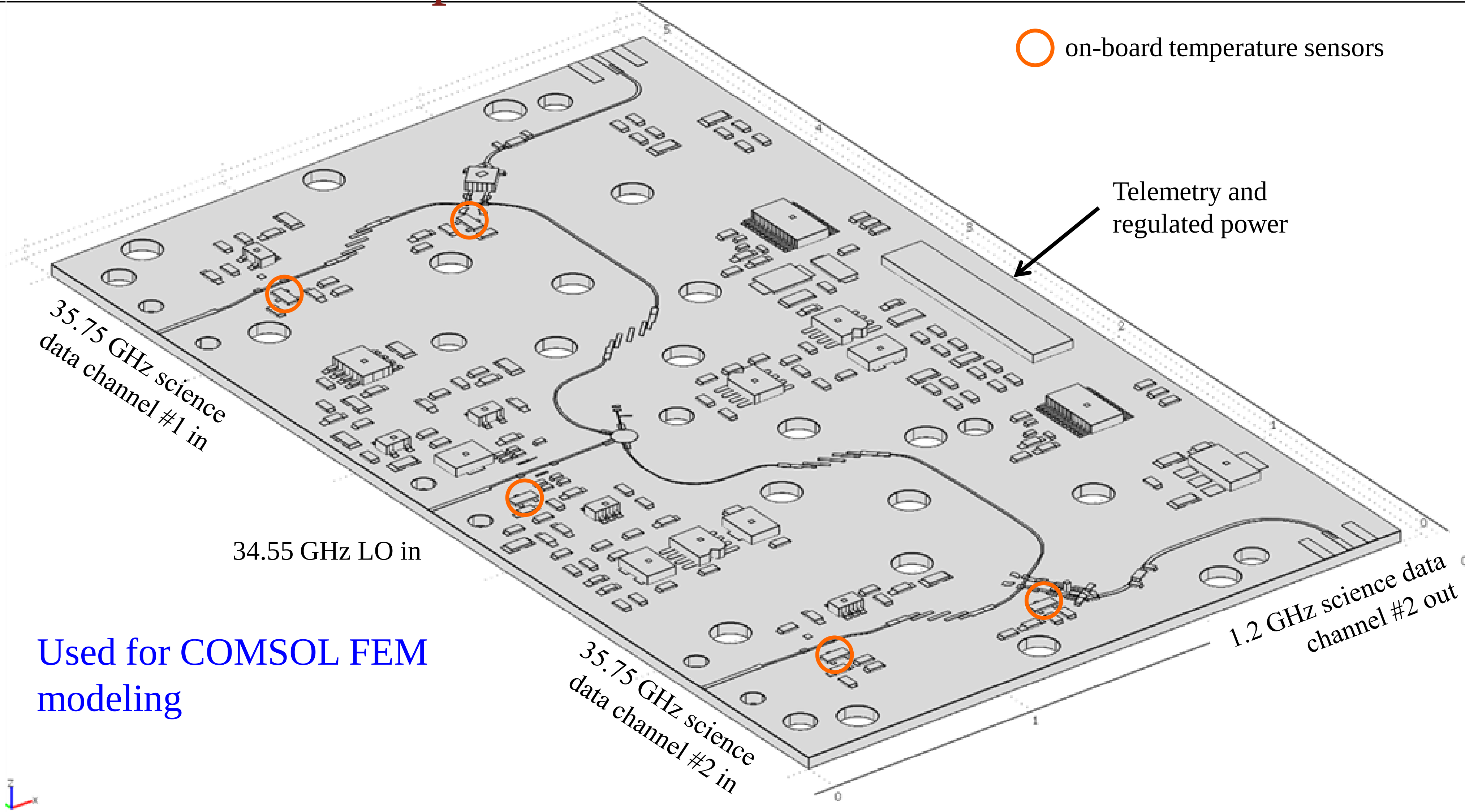
Remote operation via serial port or IEEE-488 bus



"Passive" thermal testing

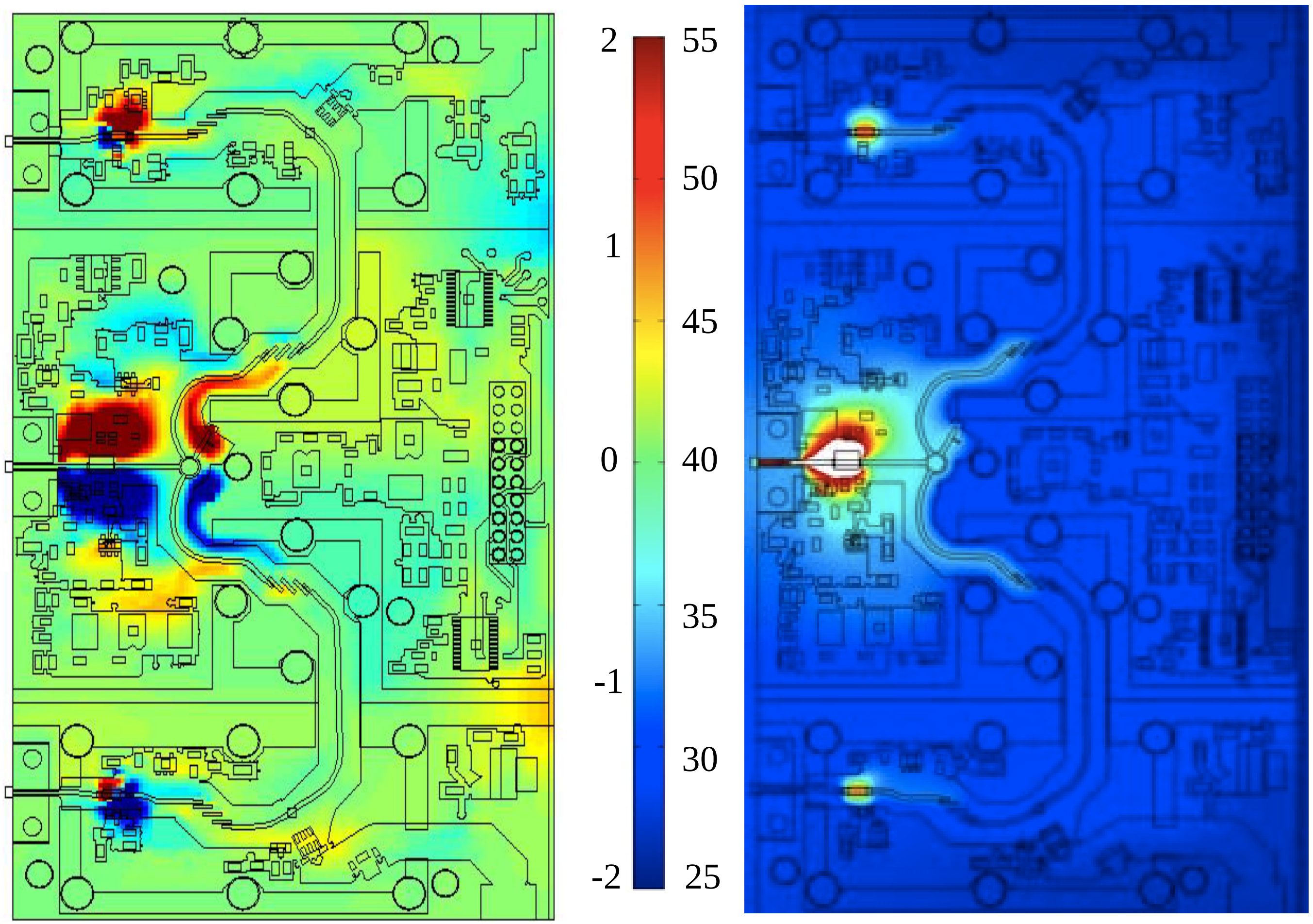


A 3D-relief of previous Ka-band board



Used for COMSOL FEM modeling

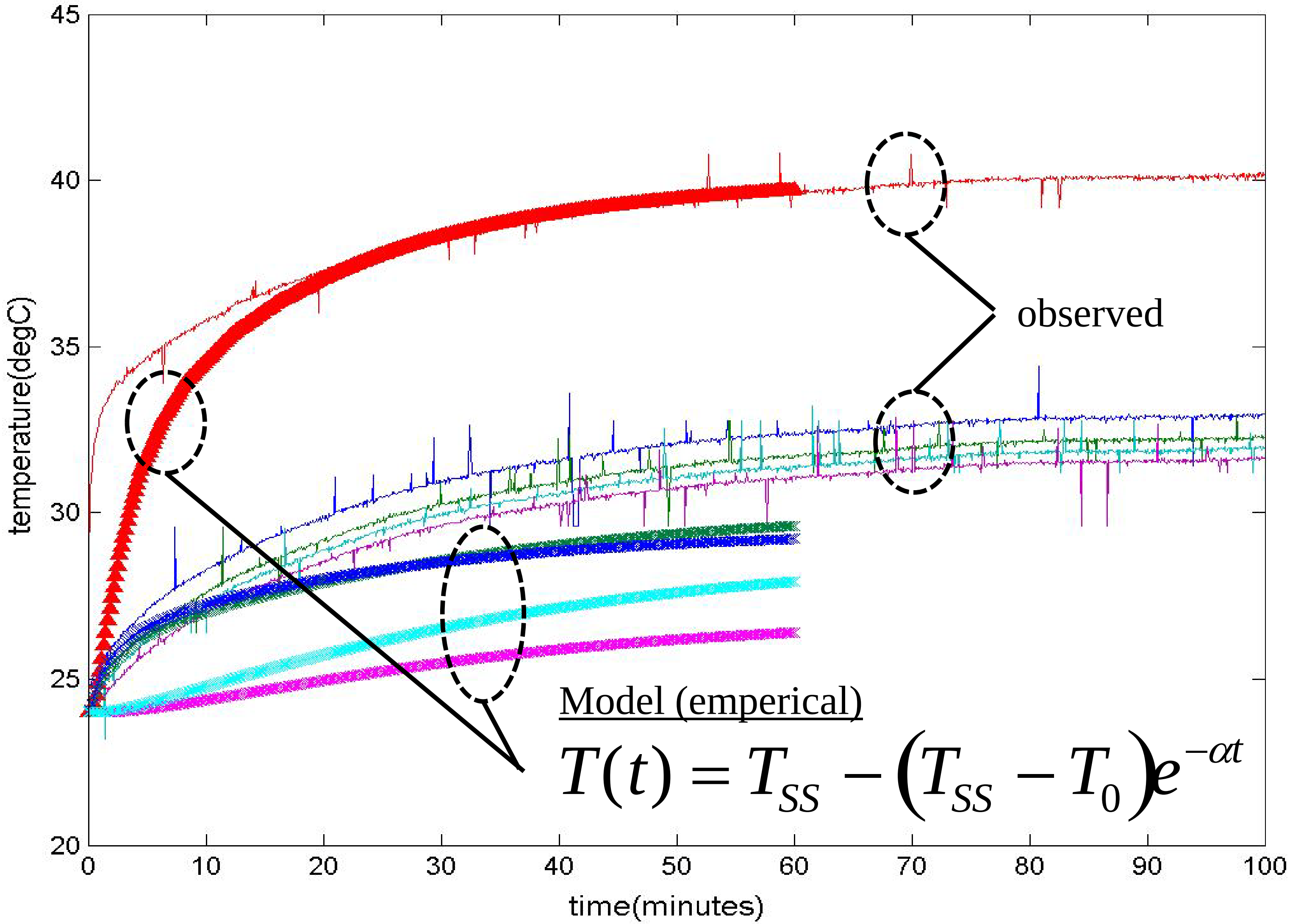
Modeled Thermal Imbalance



Temperature imbalance (°C)   Temperature (°C)

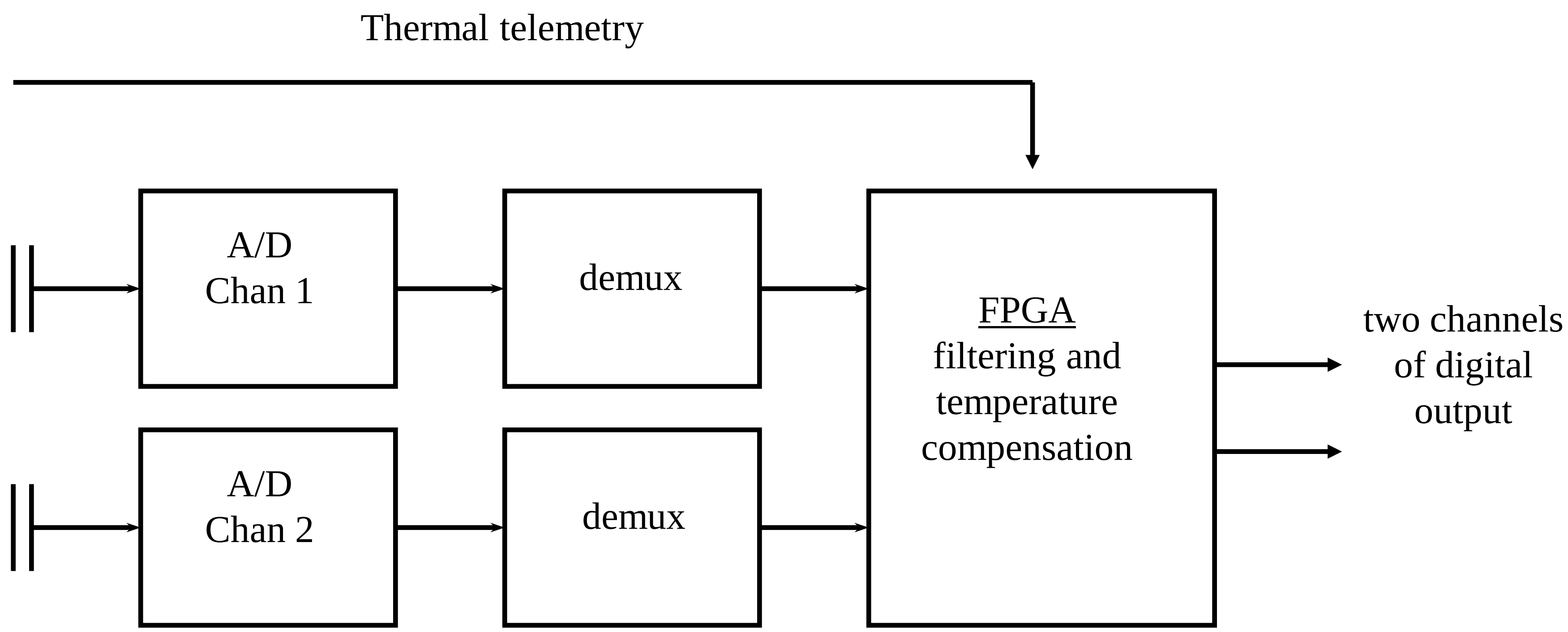
- COMSOL used to solve the heat equation and estimate board temperture and thermal imbalances.
- Thermal assymetry in the downconverter design will lead to an assymetry in the electrical path length.
- While this is not a bad thing in of itself, in a dynamic temperature environment, it will create a bias in the phase measurements, and hence the inferred height.

Dynamic Modeling of Temperature

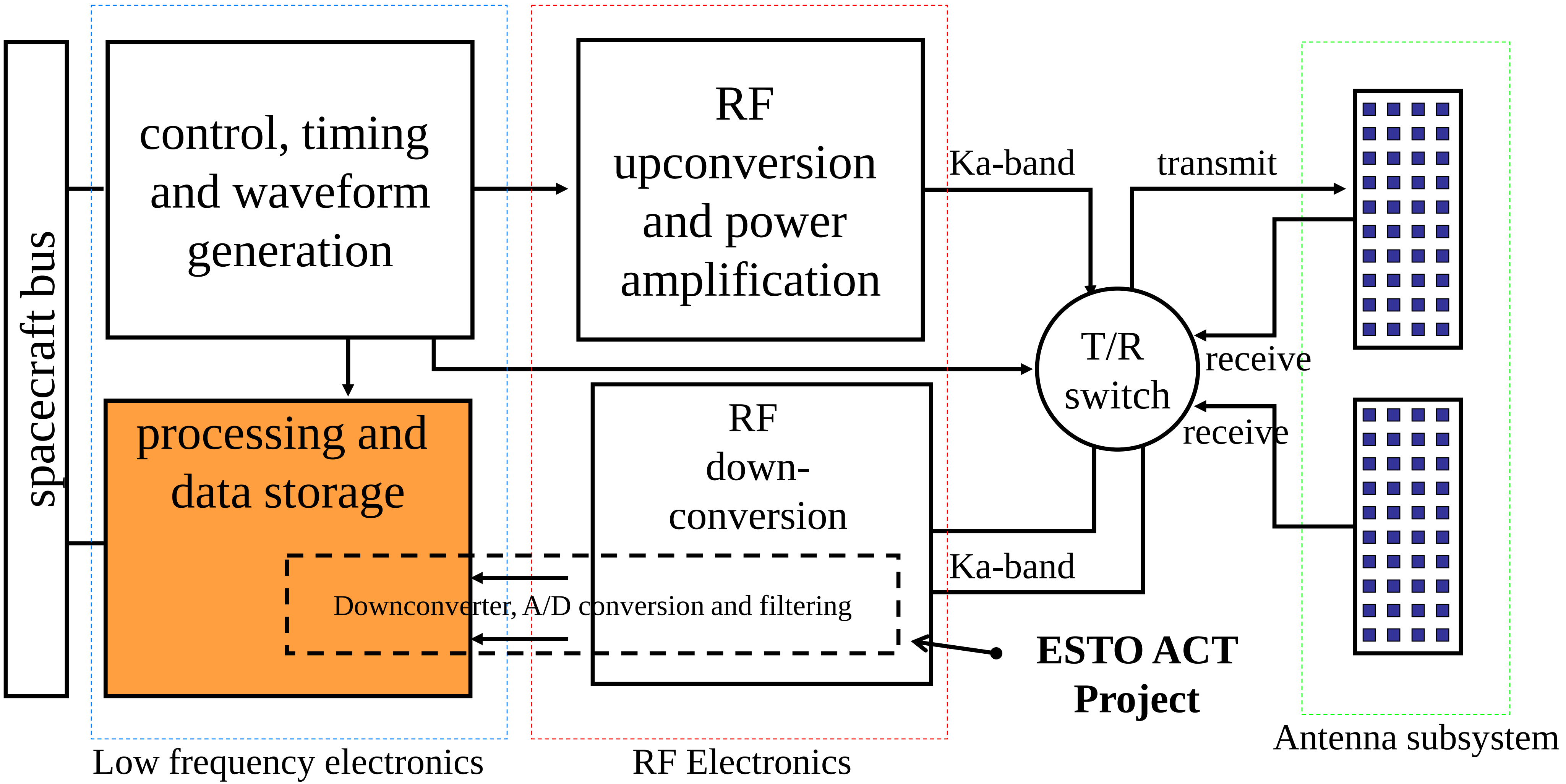


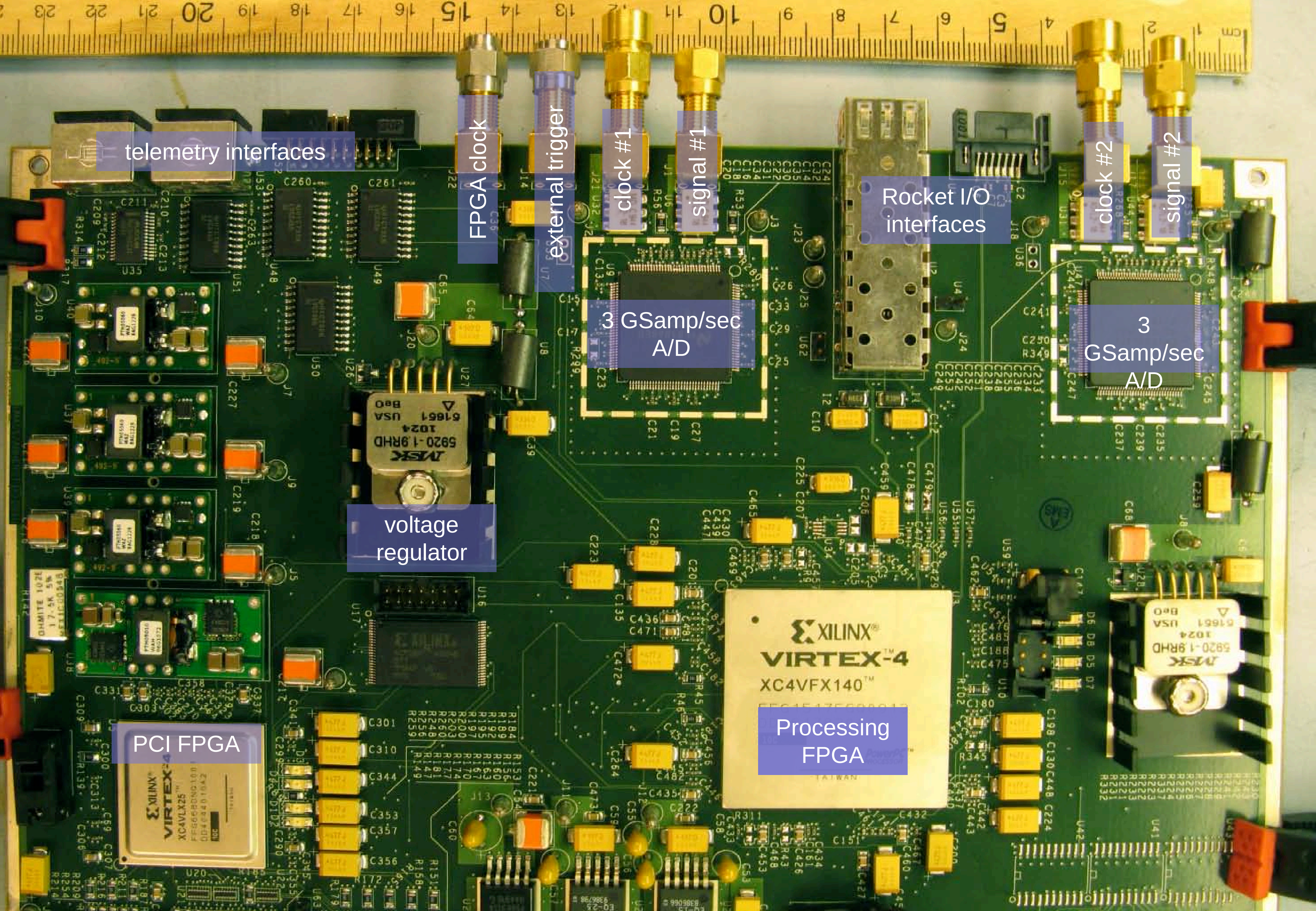
- Dynamic modeling of temperature is challenging because of the complexity of the subject matter
- Absolute accuracy is less important than the ability to capture the low order derivatives
- As modeling improves, we will incorporate the results into the observed phase behavior between the two channels
- Similar model results have been obtained using COMSOL. An emperical model is used currently for tuning the COMSOL model.
- Results will be used to better inform the microwave engineering

Thermal Telemetry combined with Science Data



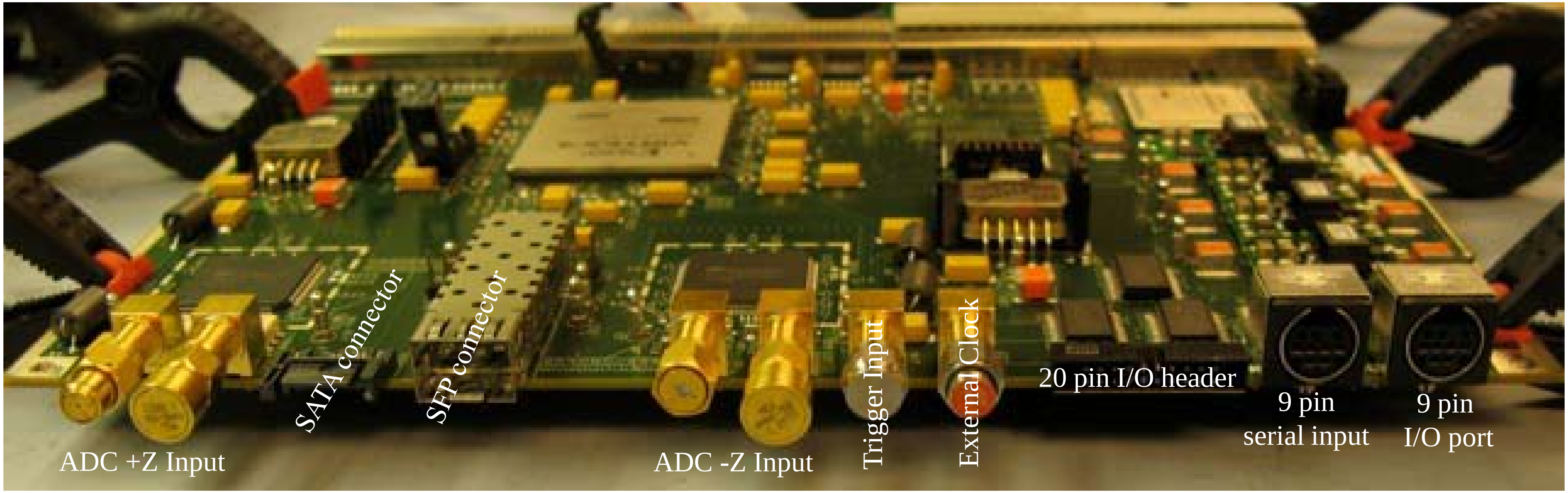
Spacecraft block diagram



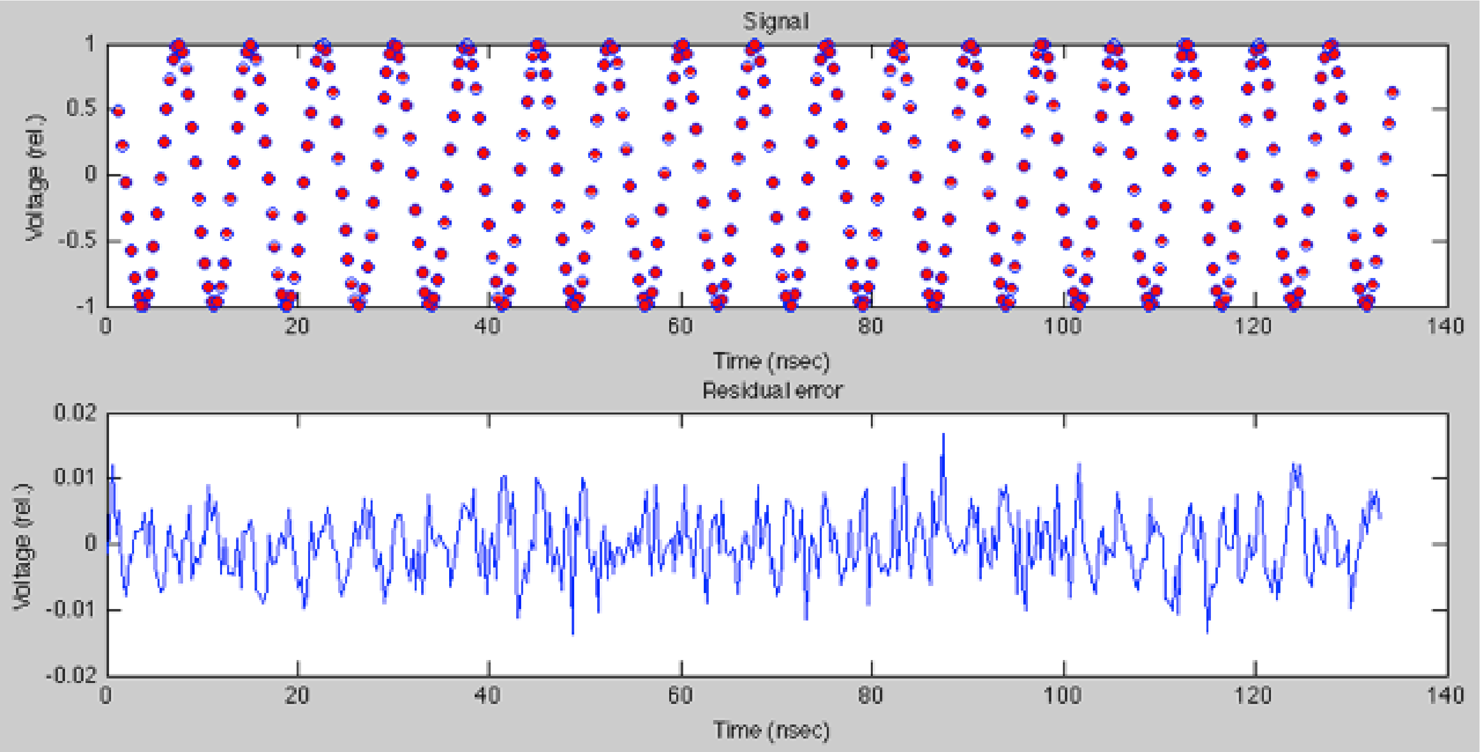


ESTO funded Analog to Digital & FPGA board using all space qualifiable parts

Front Panel Connections

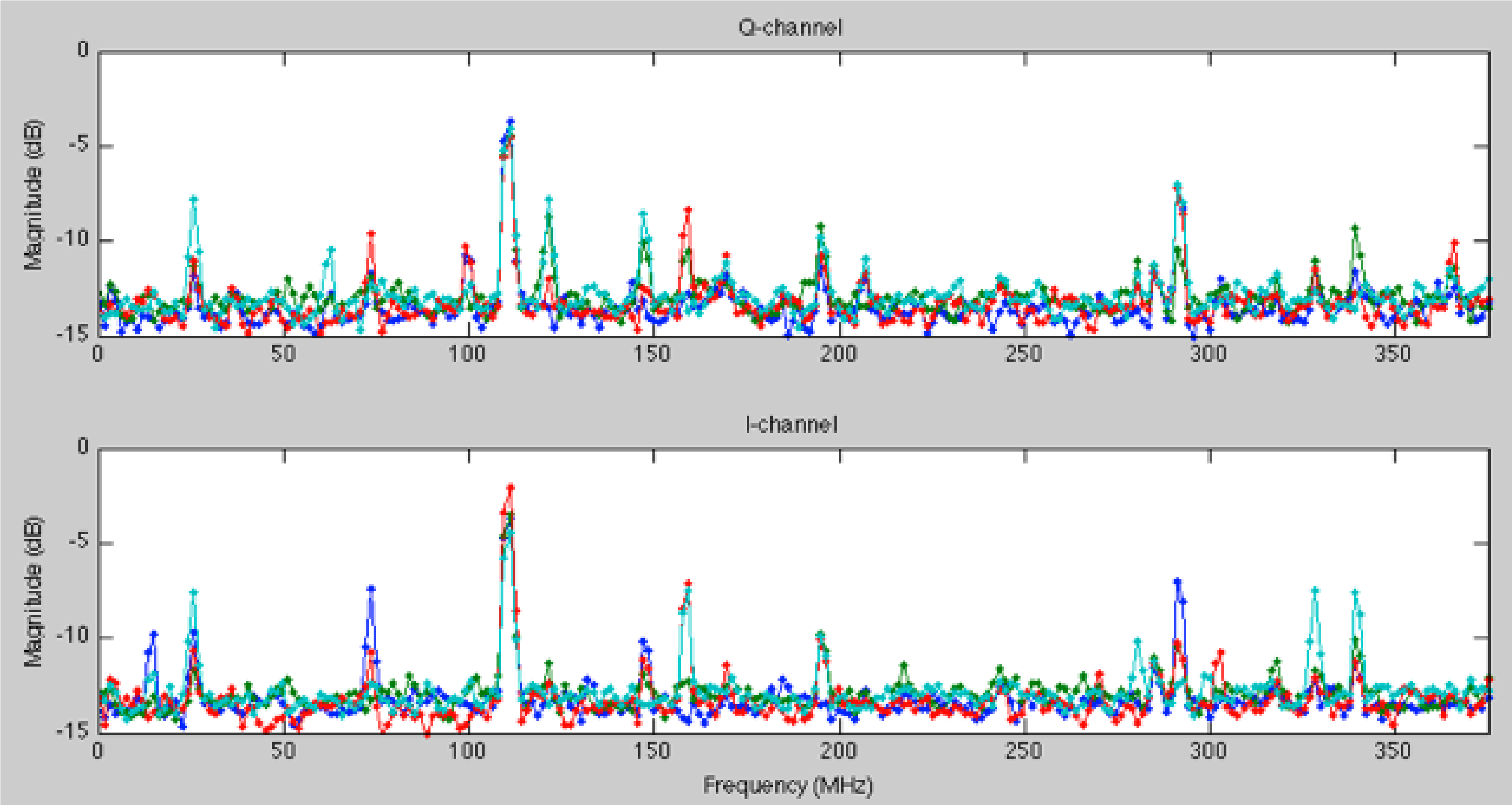


A/D performance validation



- Residual errors are less than 1/100th of the input voltage (~40 dB in power)
- Dominated by quantization errors (7 bits ~ 44 dB QSNR)
- ENOB estimated to be 7 bits, close to the published ENOB of 7.2 bits

Error Spectra



- Error spectra used to determine periodic signals (e.g. clocks) which may be dominating the observed errors
- Dominant source at 110 MHz not yet identified, yet it is better than specification

FPGA and A/D board outreach

REAL TIME ESTIMATES OF DIFFERENTIAL SIGNAL PHASE FOR SPACEBORNE APPLICATIONS USING FPGAS

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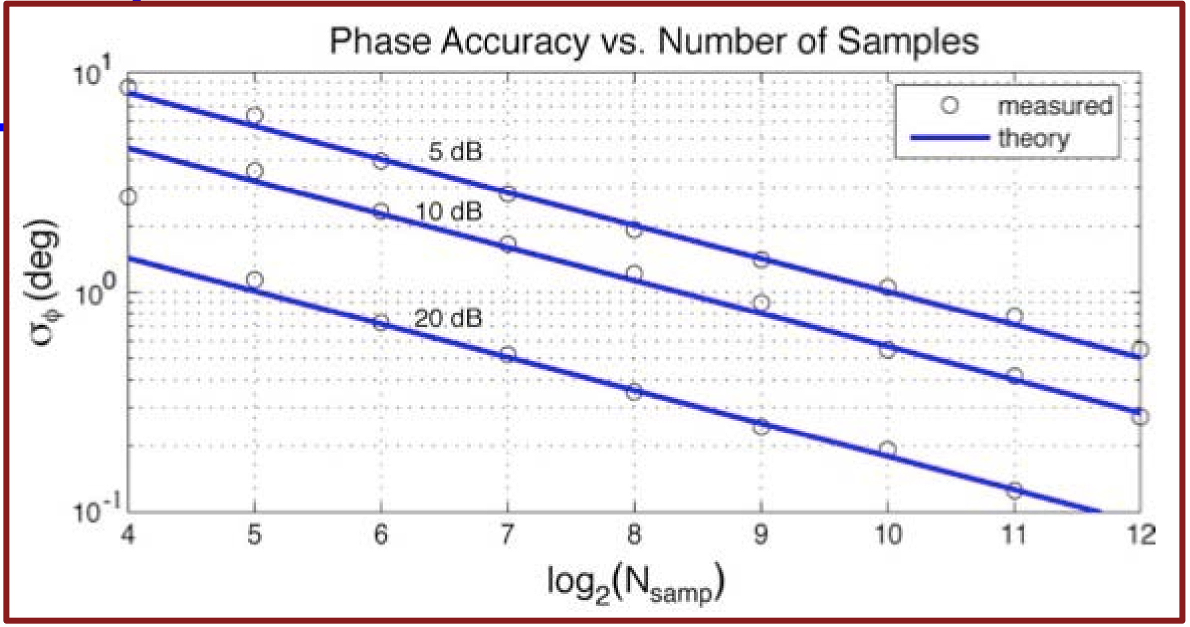
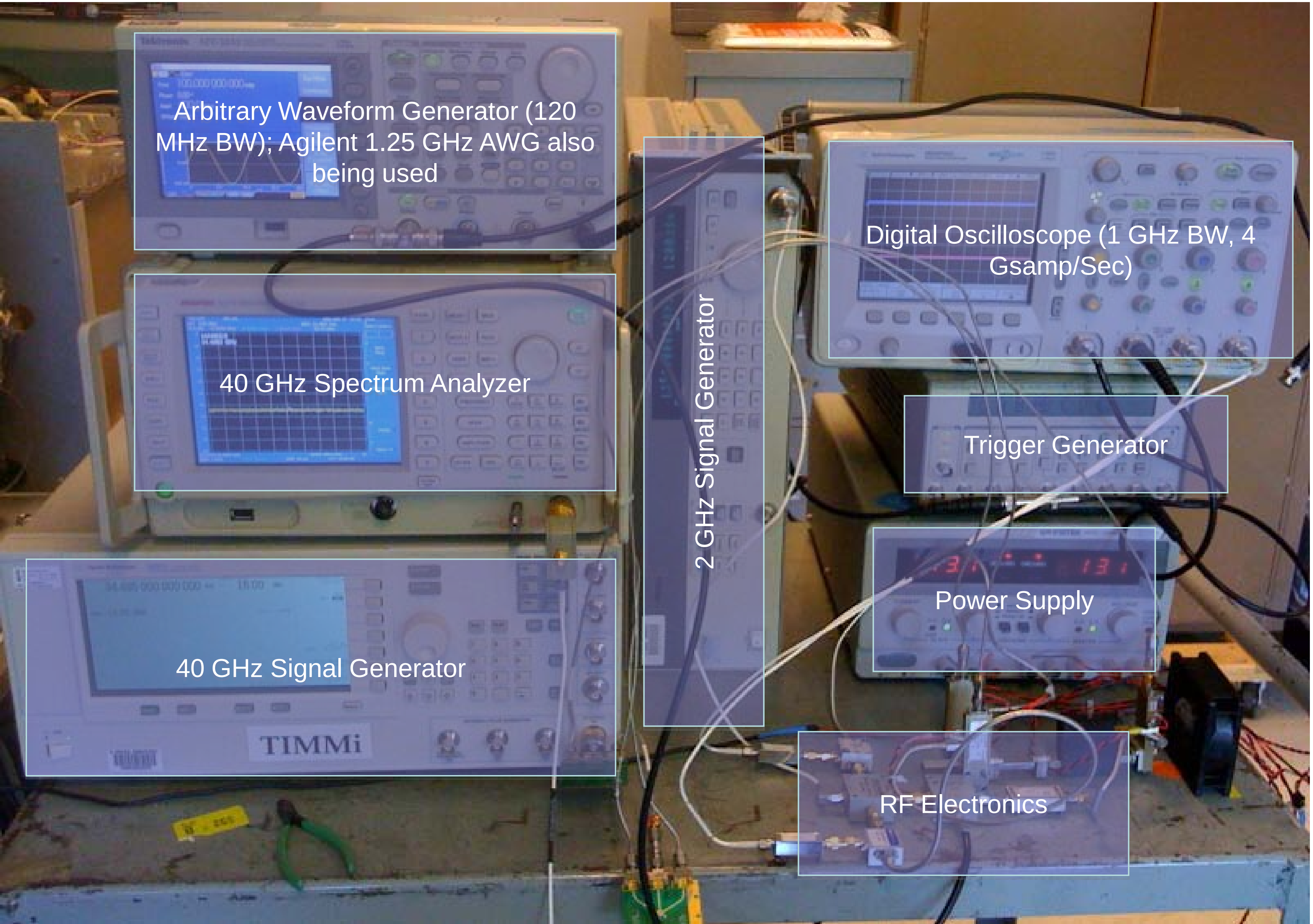
48 DESIGN AUTOMATION CONFERENCE

San Diego, June 5-9, 2011

- Basic form of algorithm
  - Feed a single tone signal into ADC and compare the resultant waveform with reference waveform
  - Differences are used to characterize phase and gain characteristics of the observed waveform



Supporting Test Equipment



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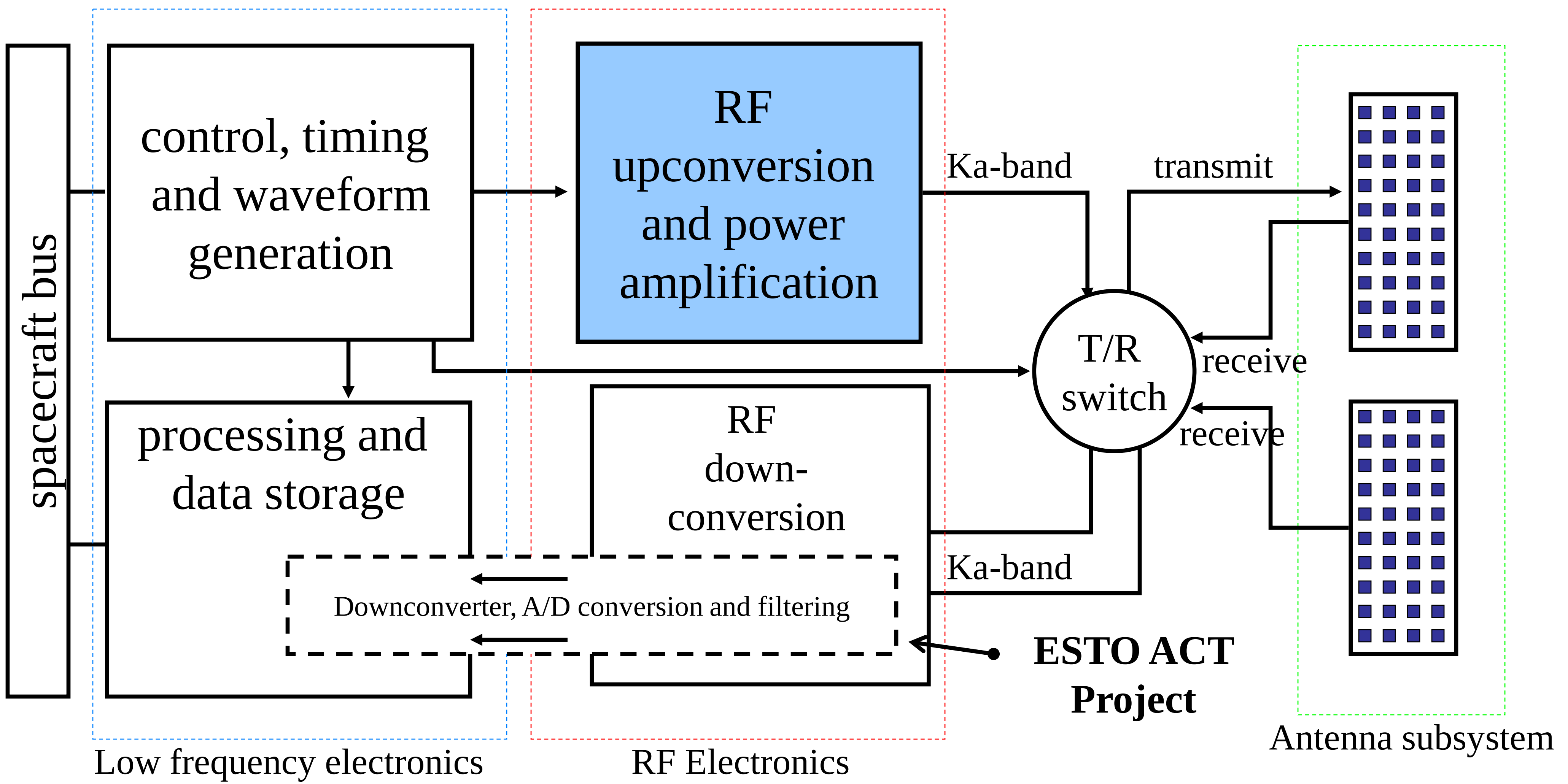
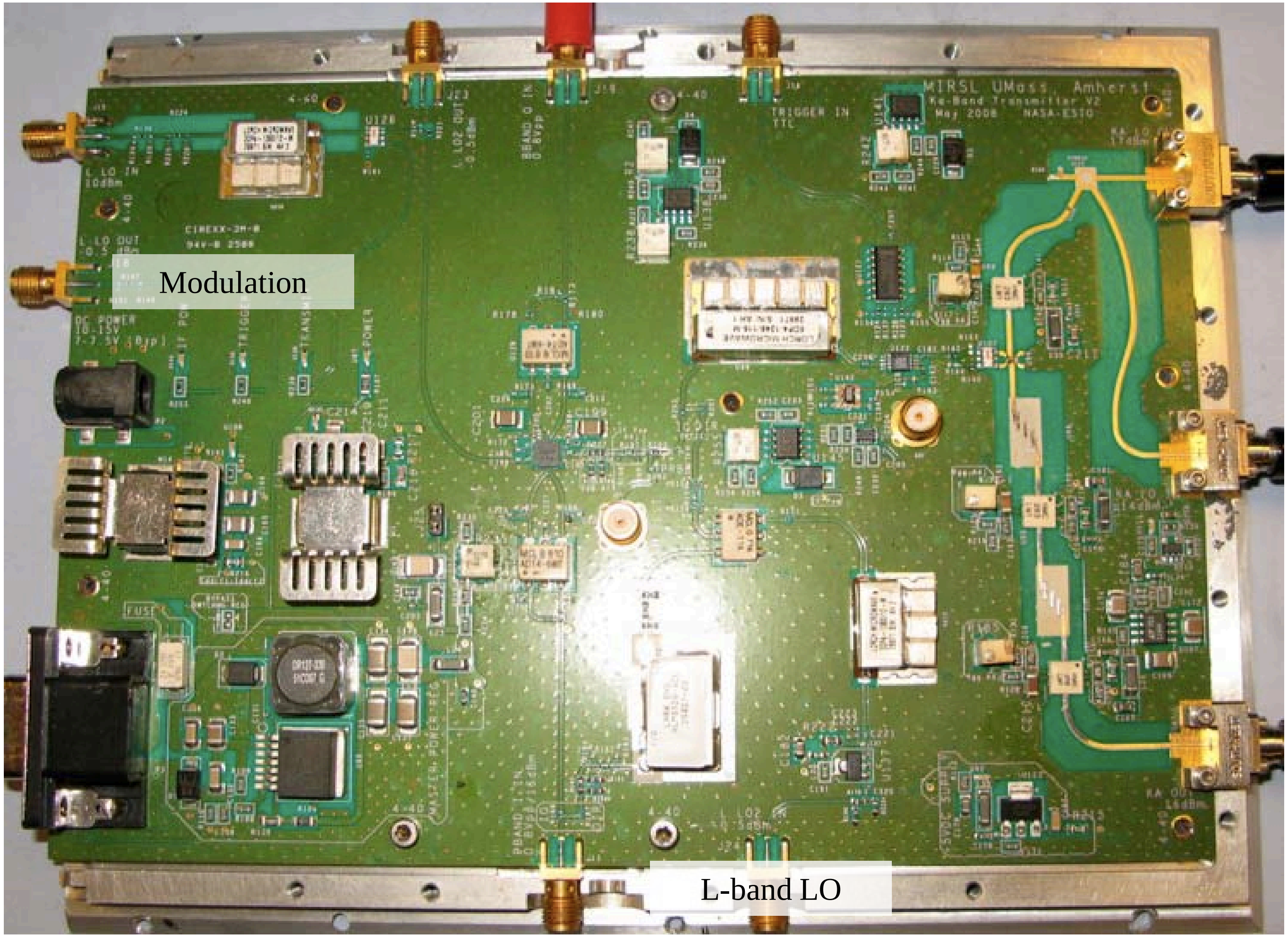


Baseband to Ka-band Upconverter



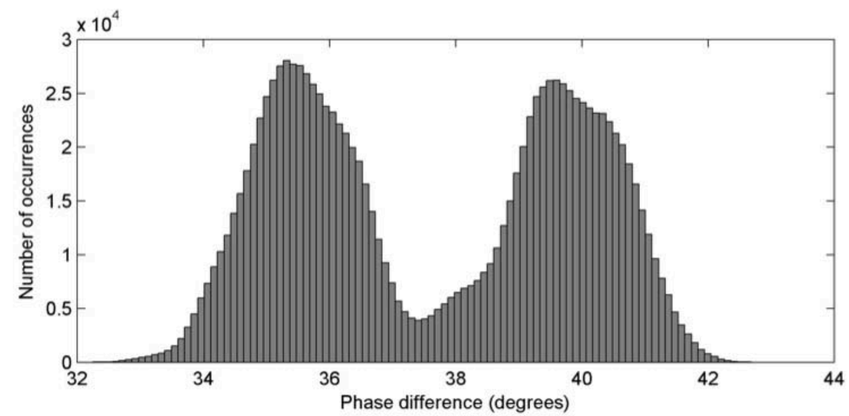
Ka-band LO out

Ka-band LO in

modulated Ka-band transmit signal

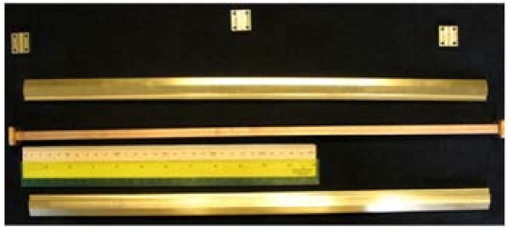
Ka-band EIK (CPI) and HVPS (Pulse Systems)

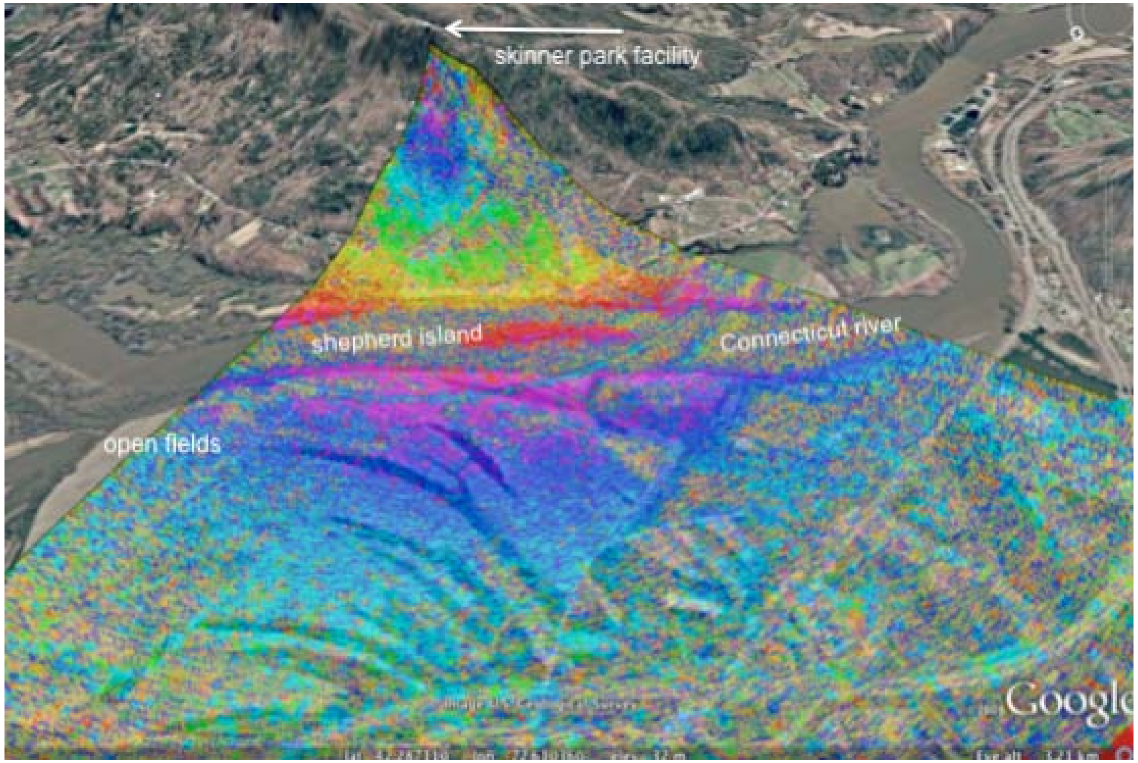
- 1.5 kW 5% duty cycle extended interaction klystron (EIK) amplifier from CPI
- Modulator provided by Pulse Systems
- EIK Demand for large current from the HVPS at the PRF (4 kHz) causes an oscillation in the system phase performance



Advancing the TRL

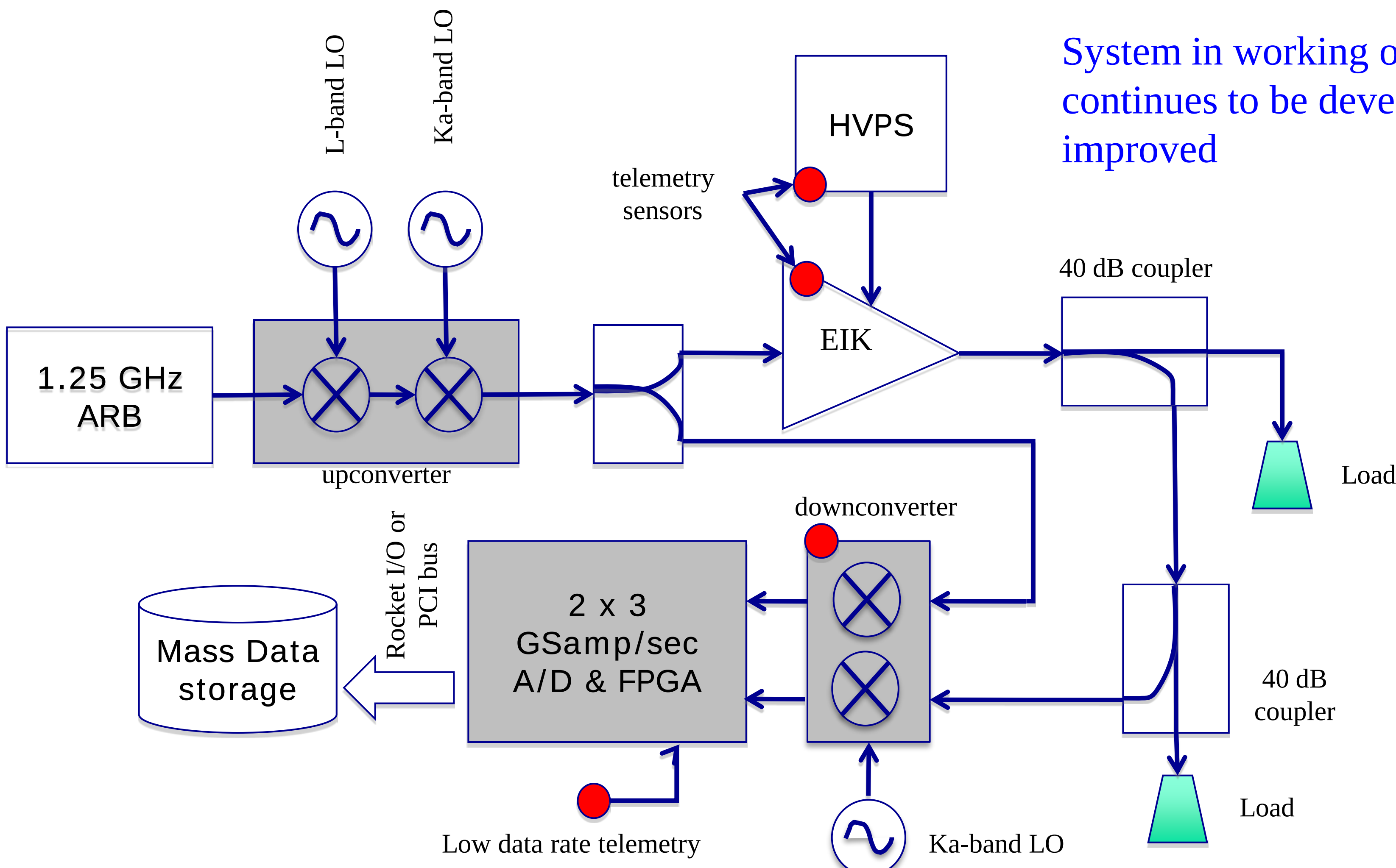
Working interferometer used for TRL advancement, integrated system testing and as a potential SWOT ground validation and pre-flight target characterization.





Block Diagram of RF Testbed

System in working order, continues to be developed and improved



- We are continuing our expertise in Ka-band microwave technology development
- Integration of RF hardware with digital subystems allows detailed analysis of error in components and across the system
- Measurement accuity sufficient for measuring milligree variations in the propagation path
- Hardware components are valid across a variety of NASA mission types (e.g. GRACE II, SWOT)

Questions?