ORCLE Combined RF/EO Aperture

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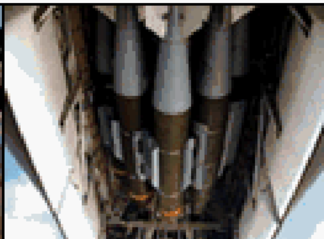

ORCLE Phase I Overview

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Phase I Objectives:

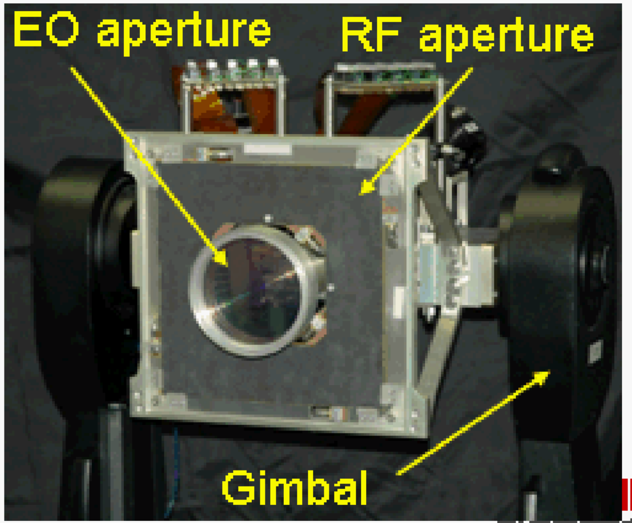
- Develop a combined RF/EO aperture for robust all weather high data rate communications. Specific objectives include
  - **Single** co-boresighted RF and EO apertures that share a common pointing and tracking gimbal mount.
  - RF beam and optical tracking loops **work together** for faster optical acquisition.
  - **RF array** design allows an imbedded, co-boresighted refractive optical system.
  - **Small** volume optical subsystem with a beam director with transmit/receive isolation exceeding 100 dB.
  - **No loss** in performance over separate apertures.

Why This Technology is Important

- Advances ORCLE concept by giving FSO in addition to RF with no net increase in form factor
- Single physical aperture reduces boresight errors and reduces "holes" needed in a/c
- Savings in SWaP
- Co-boresighted apertures simplify handoff between RF and optical communications modes.
- RF aperture is compatible with CDL
- Continuous high resolution RF tracking significantly reduces optical acquisition time

Results From Phase I

- Full system assembled and delivered to customer
- Demonstrated tracking using RF monopulse beam
- Optical beam control subsystem tracking loop tested at RSC
- Control software completed
- Improved OPA connecters implemented
- OPA test fixture



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Operational Concept

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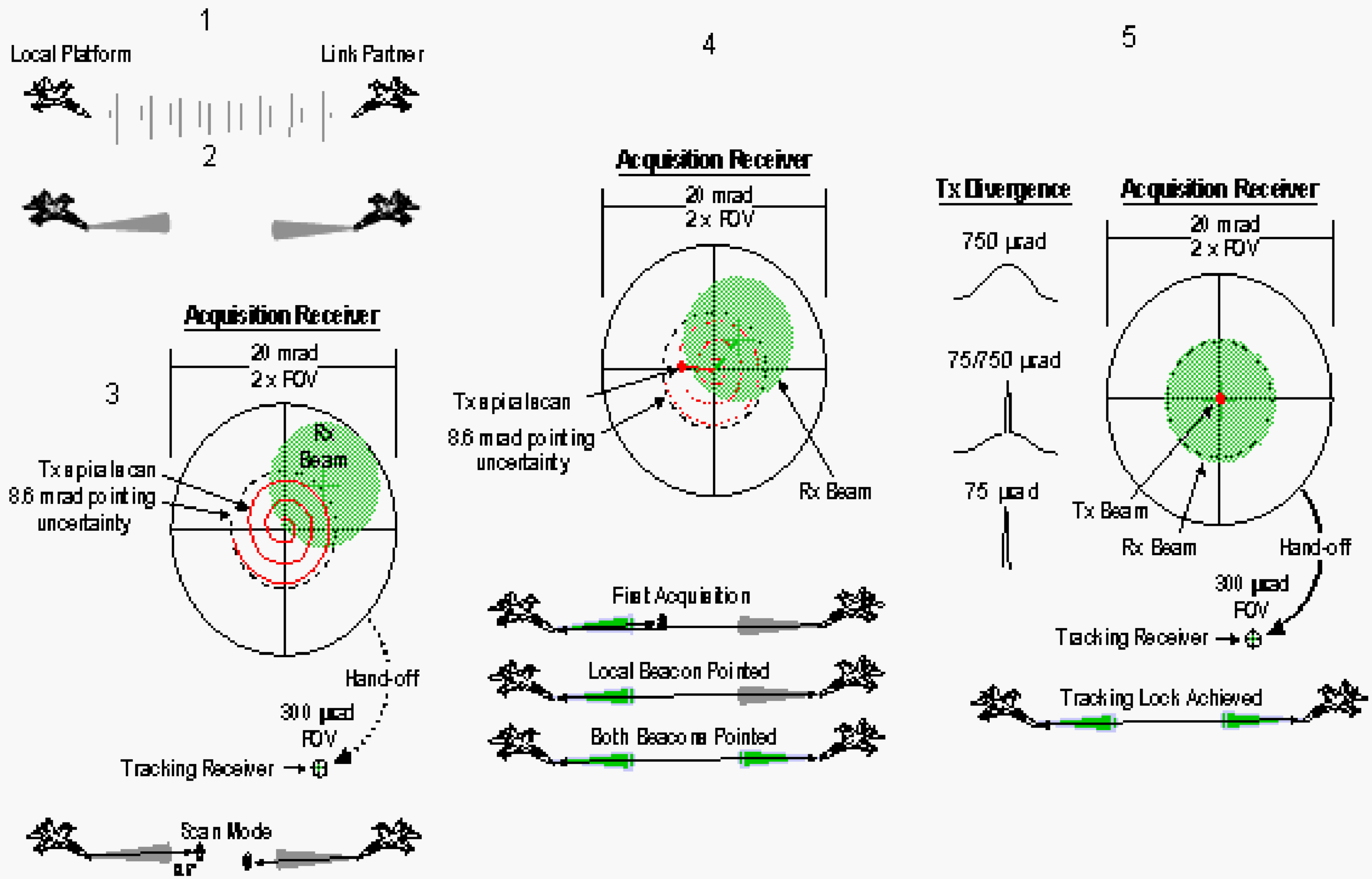

RF subsystem provide coarse pointing data
Optical system provide fine pointing data

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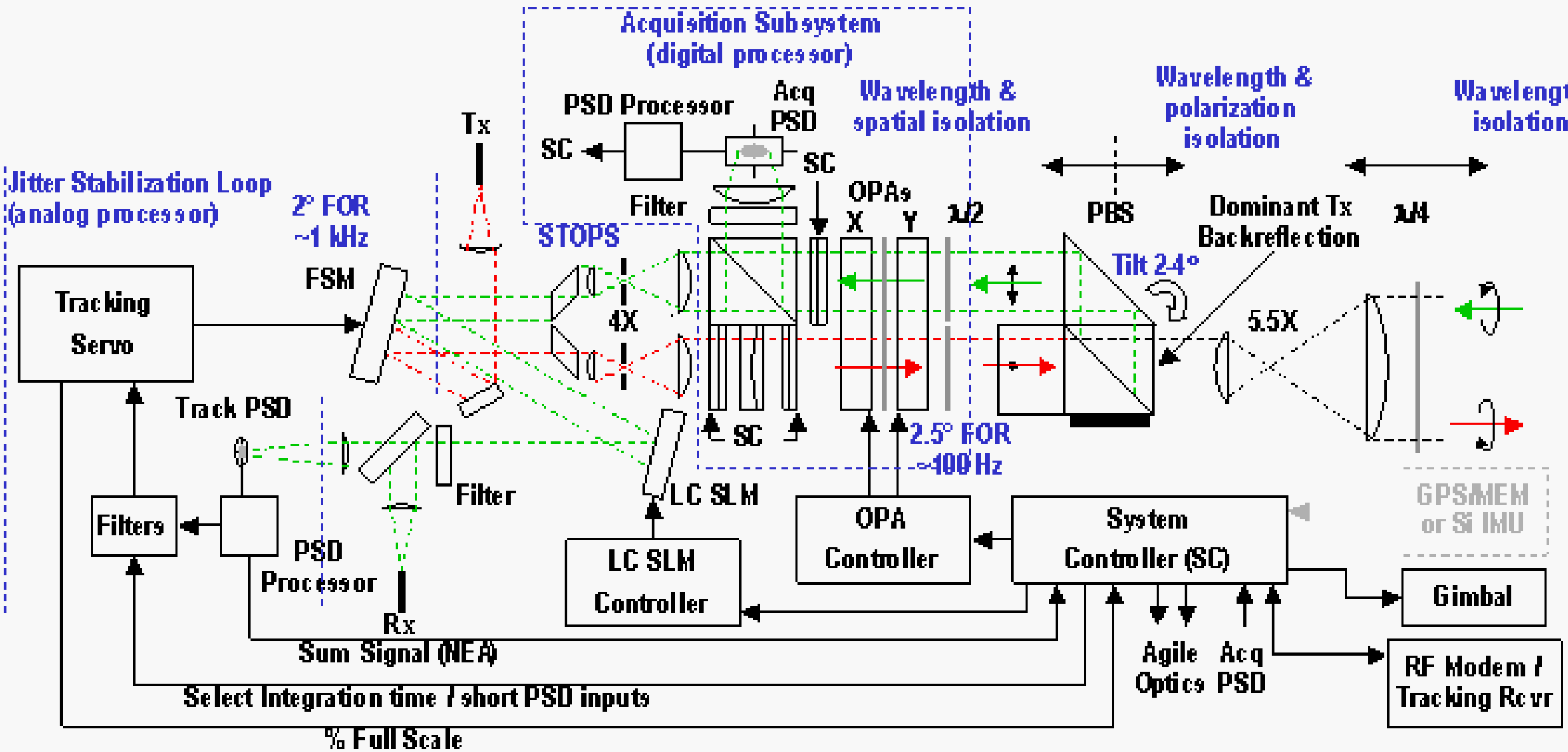

Acquisition Subsystem
(digital processor)
PSD Processor
Acq
PSD
SC
SC
Filter
STOPS
Tx
Wavelength &
spatial isolation
Wavelength &
polarization
isolation
Wavelength
isolation
Jitter Stabilization Loop
(analog processor)
2° FOR
~1 kHz
FSM
4X
OPAs
X
Y
λ/2
PBS
Dominant Tx
Backreflection
λ/4
Tilt 2.4°
5.5X
Tracking
Servo
Track PSD
SC
2.5° FOR
~100 Hz
Filter
LC SLM
Filters
PSD
Processor
Rx
LC SLM
Controller
OPA
Controller
System
Controller (SC)
GPS/MEM
or Si IMU
Gimbal
Sum Signal (NEA)
Agile
Optics
Acq
PSD
RF Modem /
Tracking Rcvr
Select Integration time / short PSD inputs
% Full Scale

ORCLE RF Objectives

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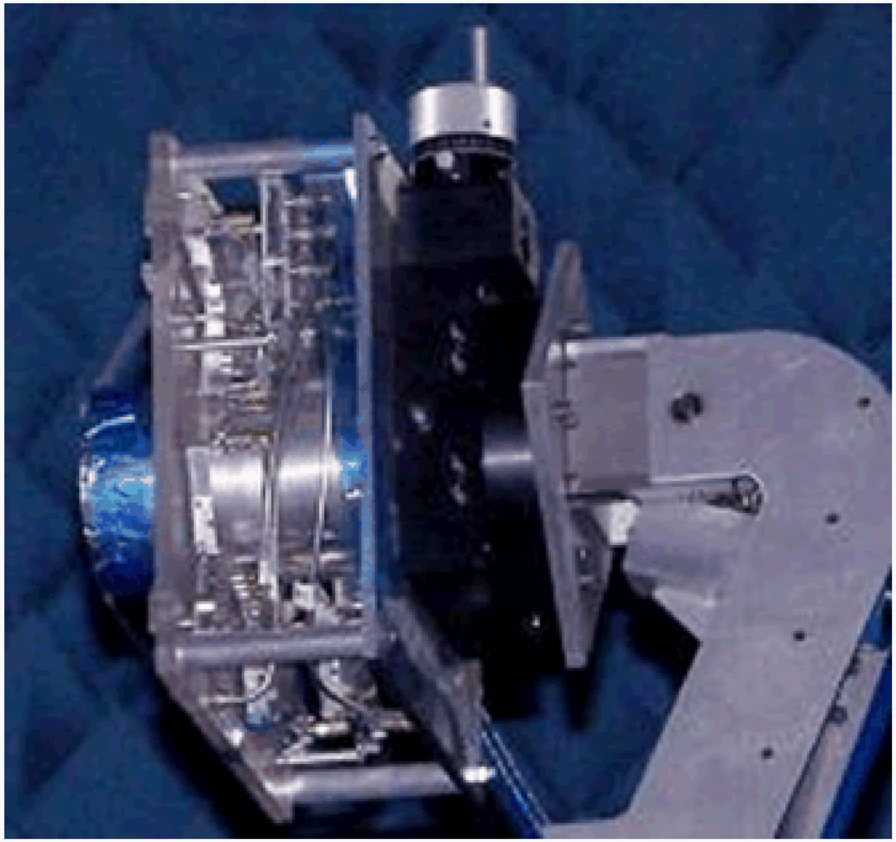
Physically accommodate co-aligned optical system in a single unit

Provide RF monopulse based tracking to provide coarse pointing coordinates

- Goal: ±0.25 Deg. of pointing error

Require compatibility with existing TCDL terminals

- Antenna gain similar to typical airborne TCDL antenna (ATE 9.5" dish)
- Receiver needs to accept the 2 difference signals from the antenna
- ORCLE Effort examined modification to an existing L3 Communication TCDL receiver
  - Changes primarily impact the AMA-module
  - Sum channel is direct replacement for regular TCDL antenna in both transmit and receive modes



Antenna in Dayton Compact Range

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ORCLE RF Antenna

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Circularly polarized EM coupled stacked patch array – 9 inches square on a 10.5 inch dielectric panel

8x8 array of sub-apertures

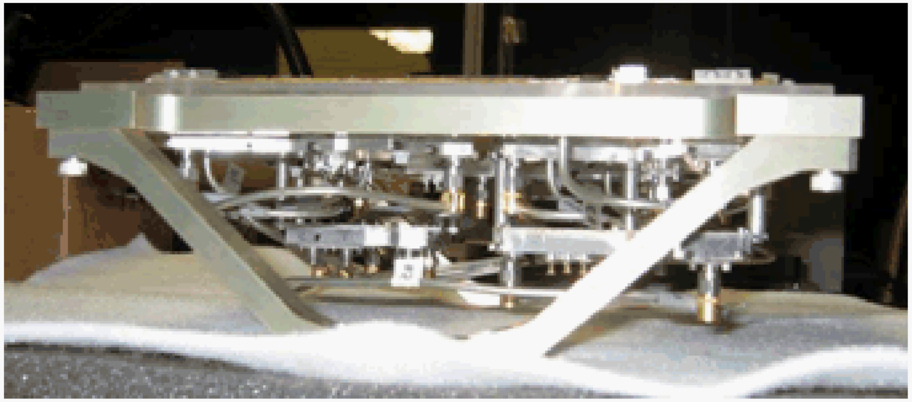
Sub-apertures are 4 active elements with 4 passive elements

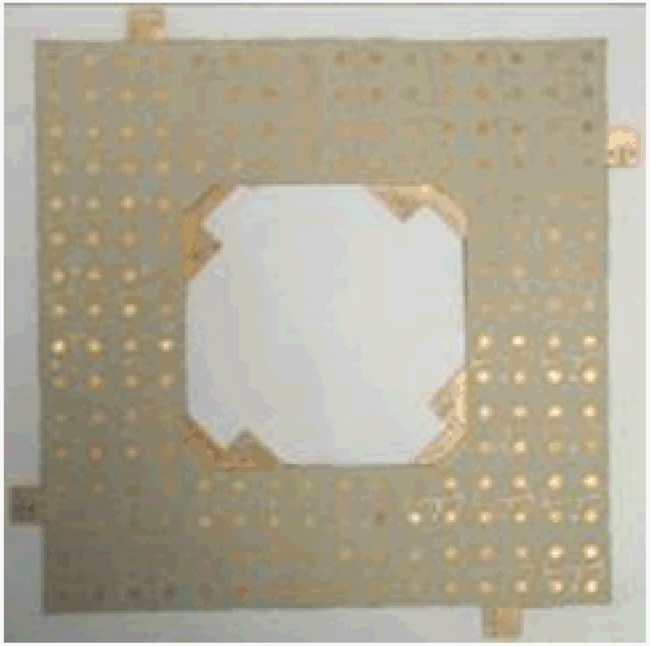
Center 16 elements removed to accommodate optical aperture

Integrated microstrip and waveguide feed network

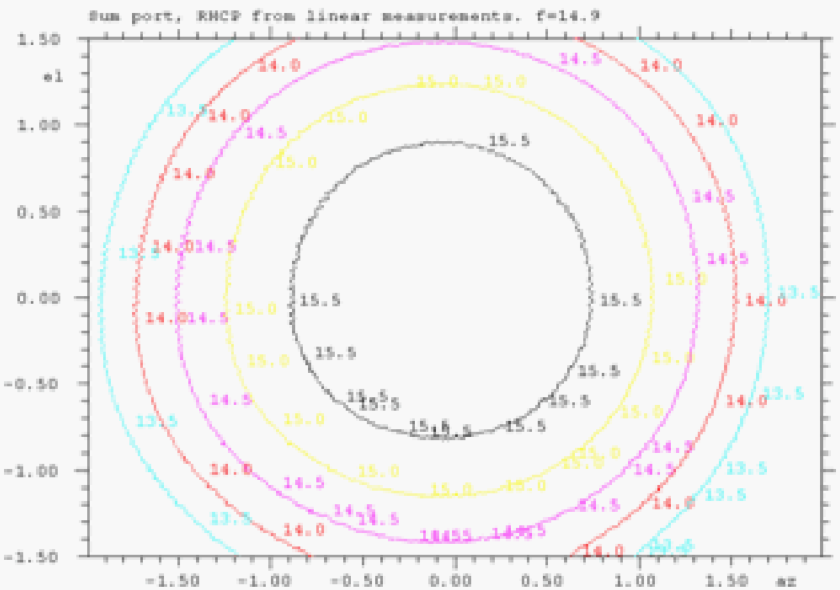
Element feeds organized into 4 quadrants

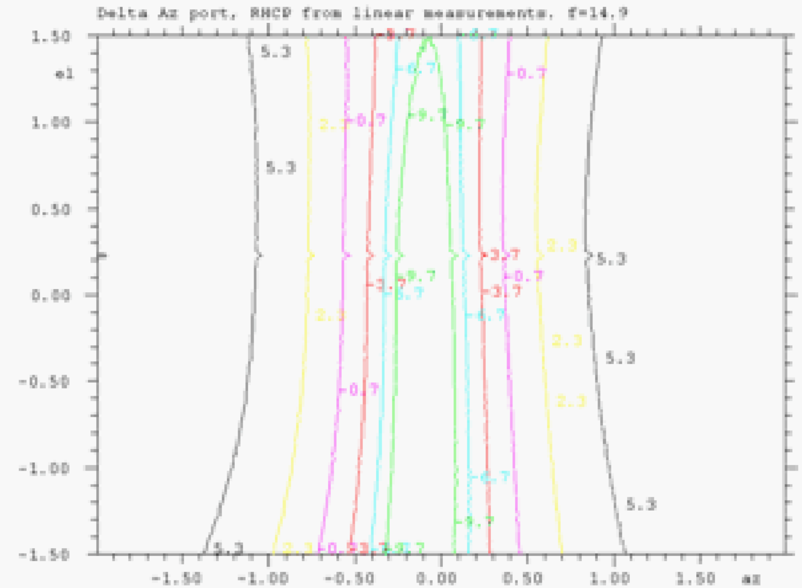
- Sum channel is the sum of all 4
- Azimuth difference is the sum of the 2 left quadrants less the sum of the 2 right
- Elevation difference is the sum of the 2 top quadrants less the sum of the two bottom

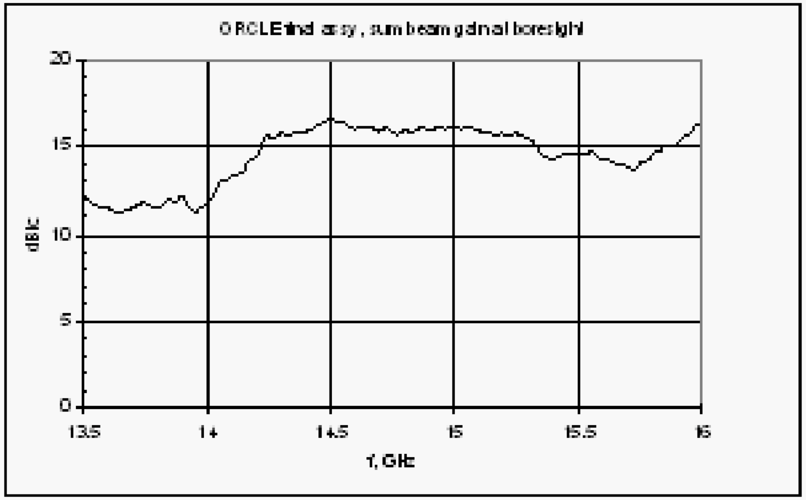


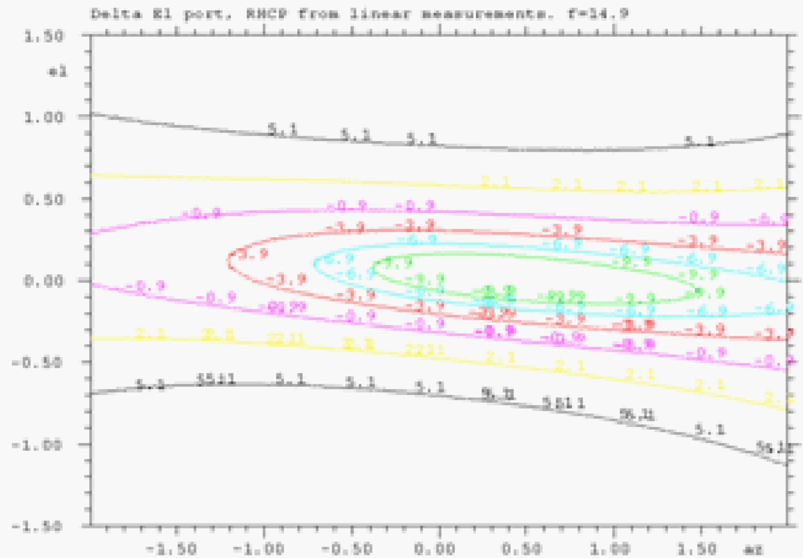


Antenna Performance Results

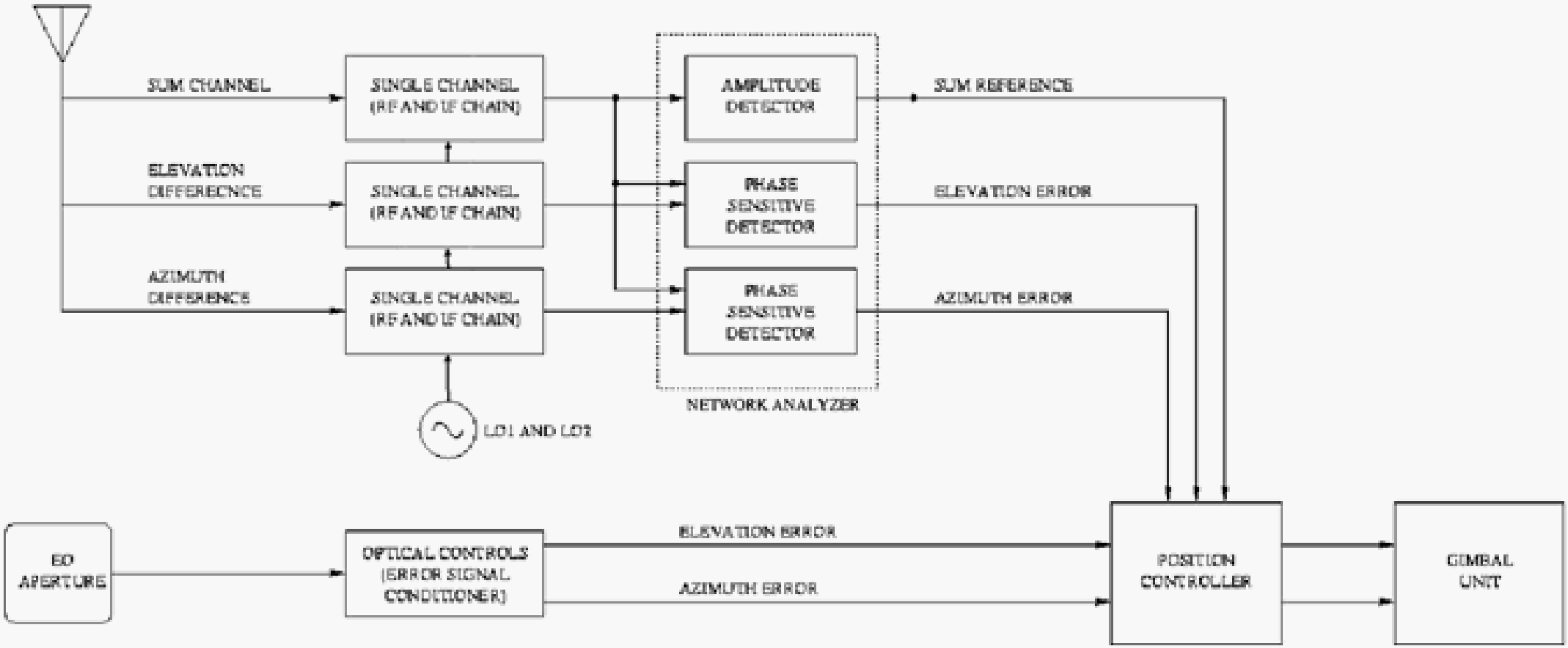








Demonstration Receiver



Low cost receiver to demonstrate ORCLE concept

Based on an Agilent Vector Network Analyzer

Useful for low performance ground based gimbal system

RF Pointing Accuracy Analysis

Primary pointing errors

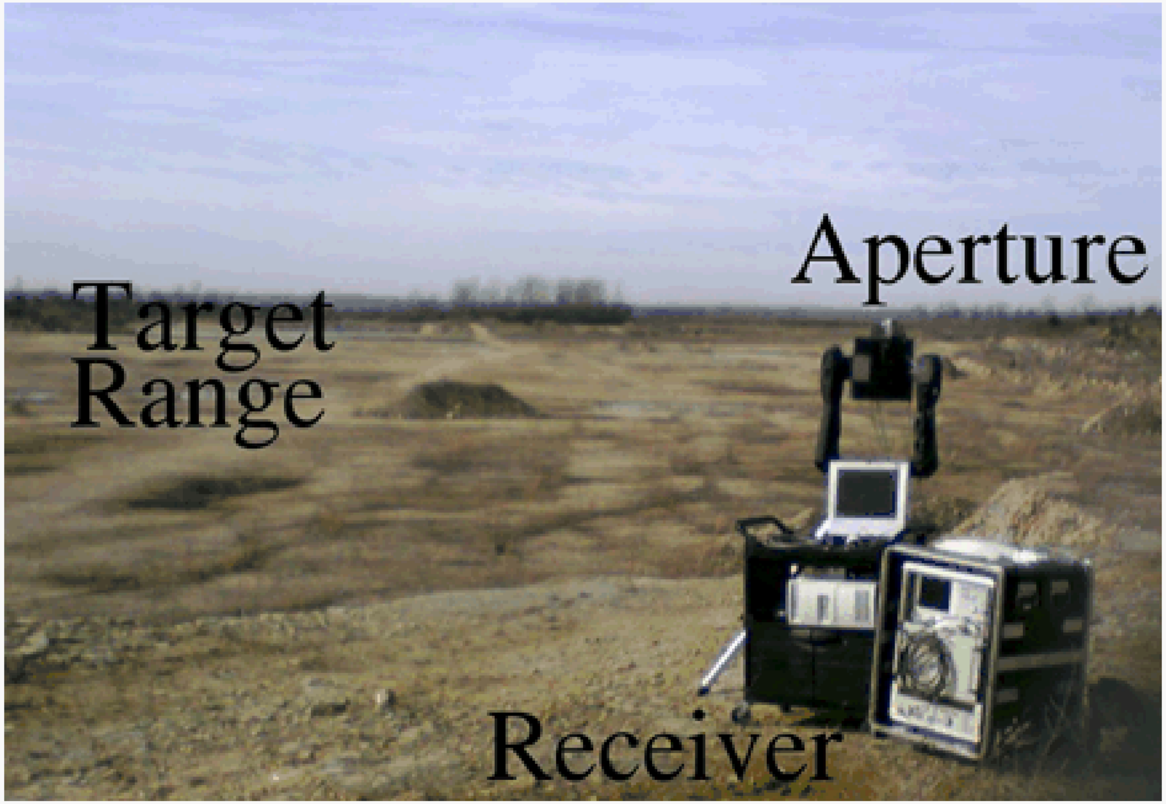
- Error due to SNR
- Multipath / antenna sidelobes
- Gimbal dynamic

Point accuracy based on SNR

- Less the 0.025 Deg. RMS error
- For Gaussian noise model; one sample out of tolerance in 1E162 (200 years of continuous operation)
- Not a limiting factor

Multipath and antenna sidelobes will limit accuracy

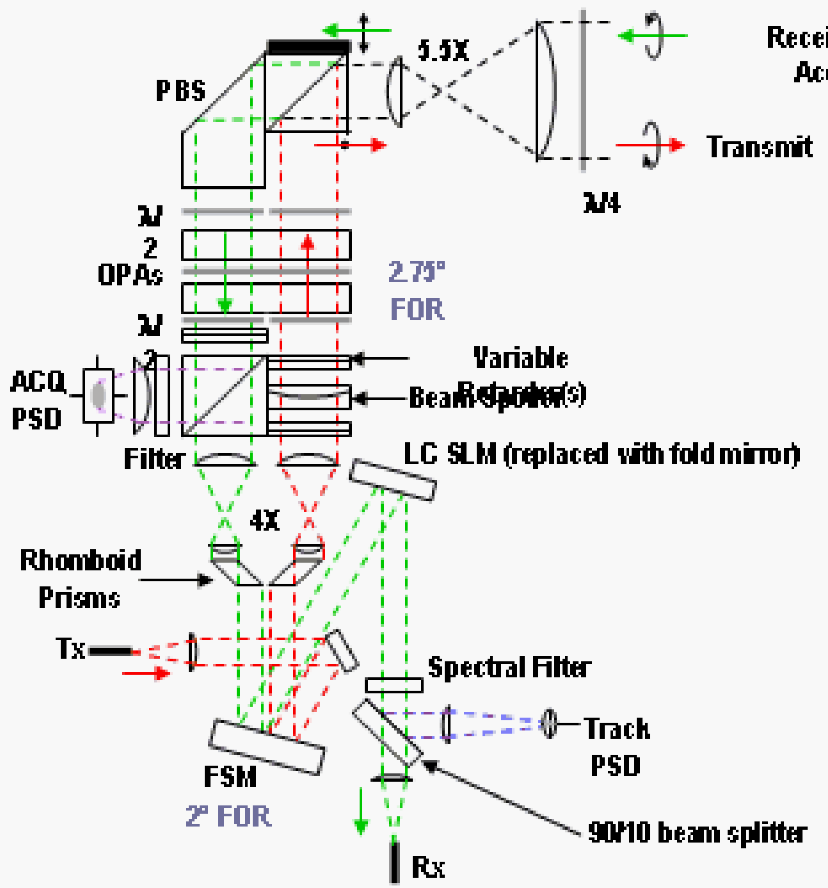
Effects that are minimal on an airborne platform

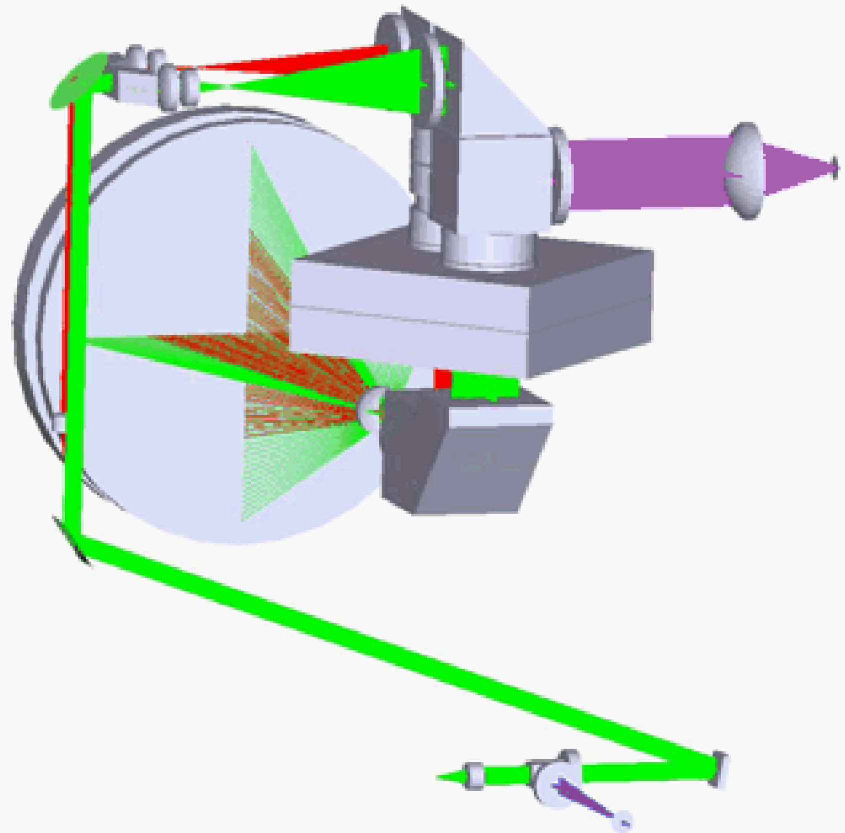


Testing of RF Aperture at quarry site

Achieved ±0.15 Deg. of pointing accuracy

Optical Layout





Hardware

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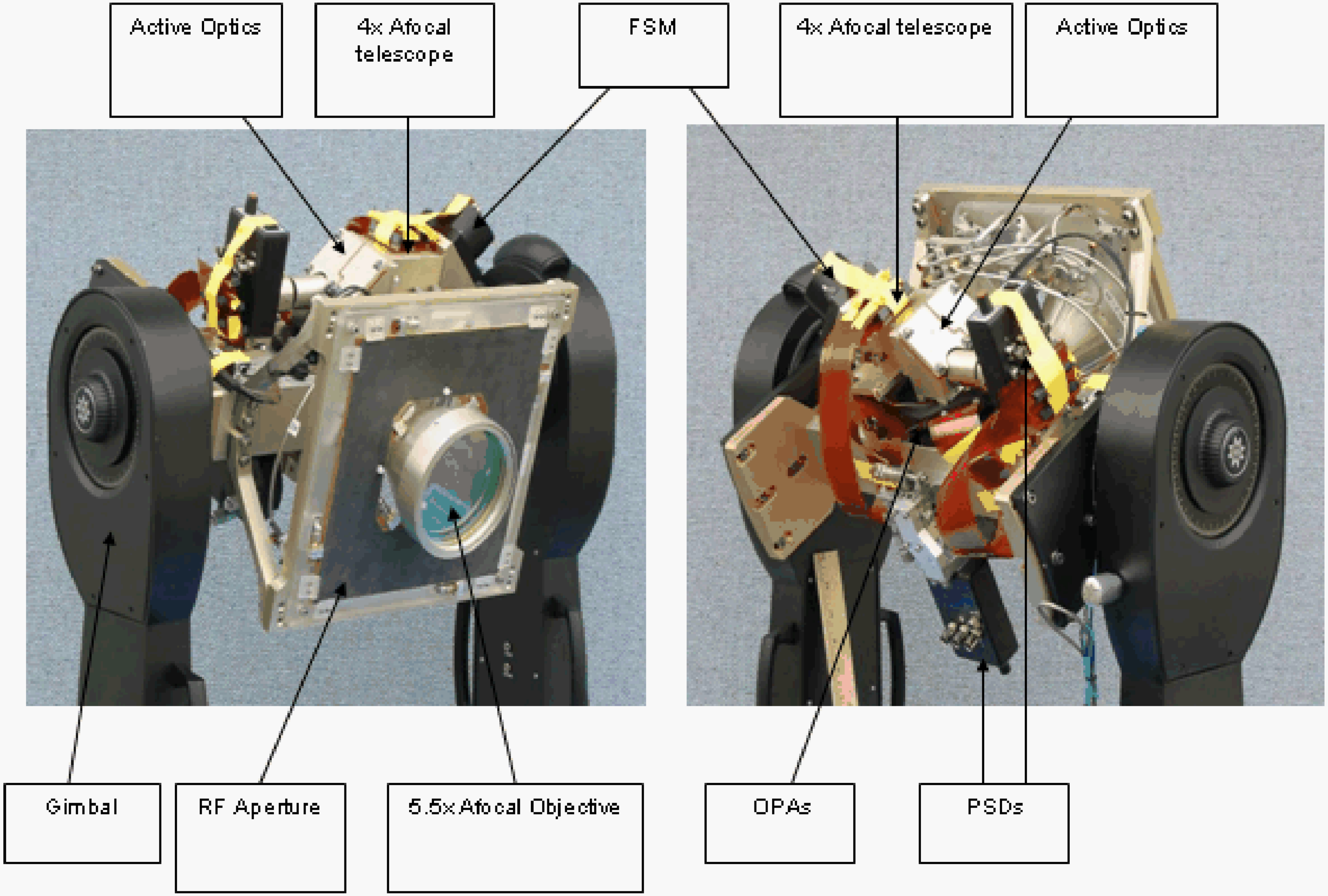
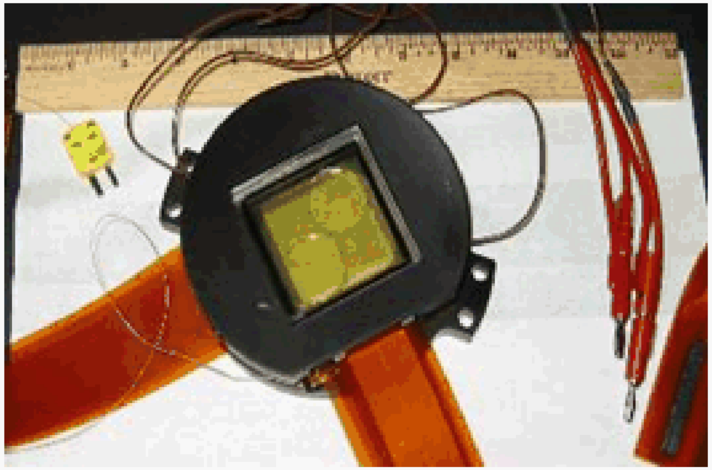
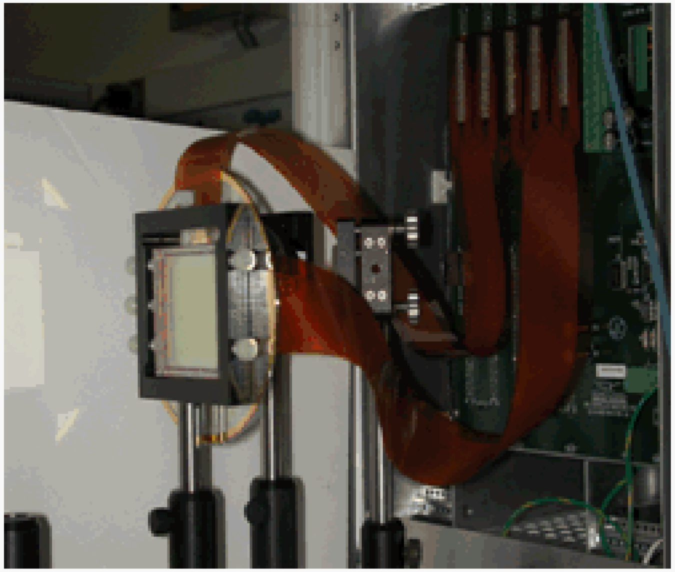


Steering efficiency of one OPA in the current aperture is lower than expected.

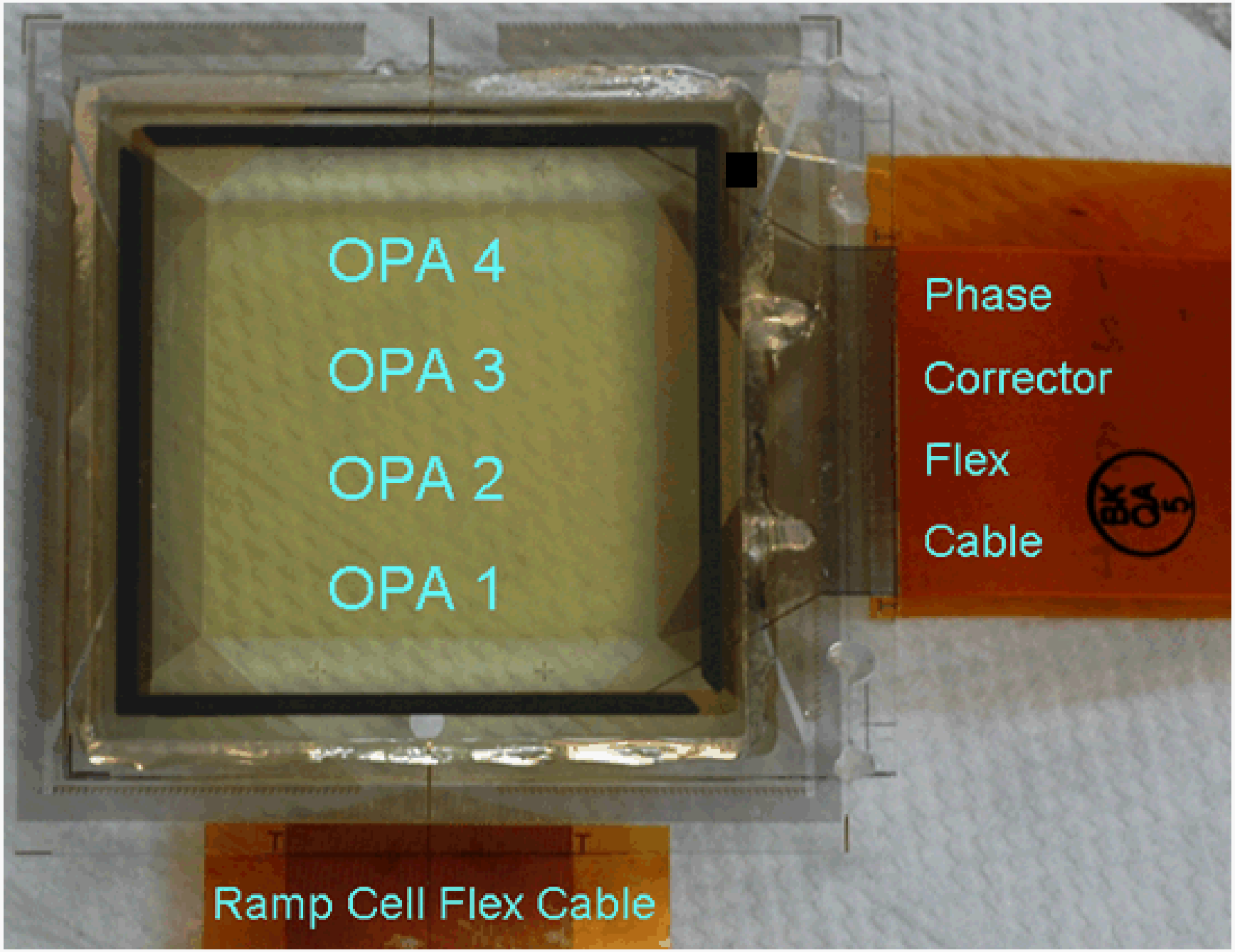
We would replace one OPA to correct defective aperture

- Complete processing of all unfinished parts from phase I
- Test performance
- Install new OPA unit in aperture #1
- Verify aperture #1 system performance





OPA nomenclature



Active Optics – OPA disassembly

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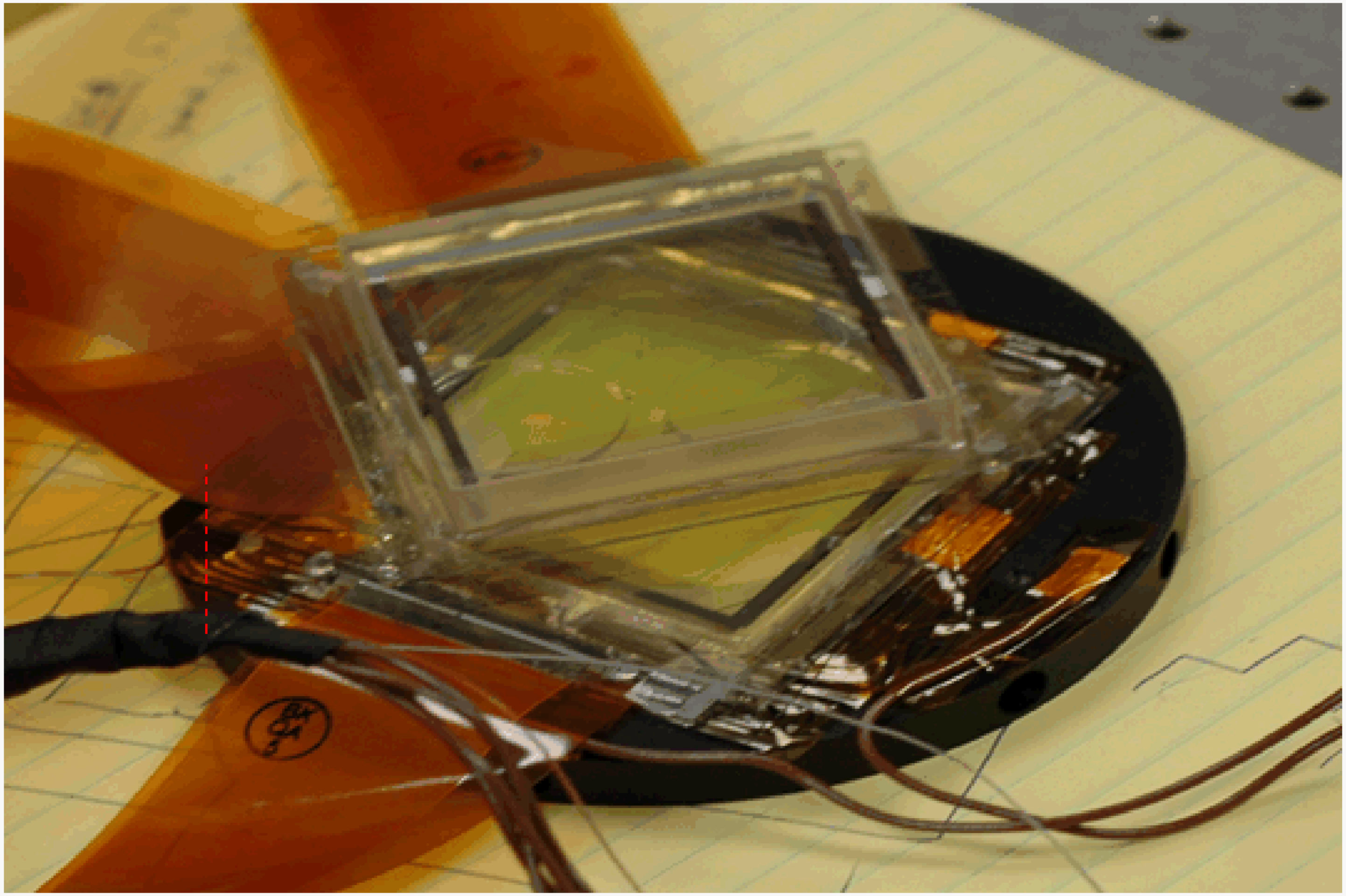

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OPA replacement

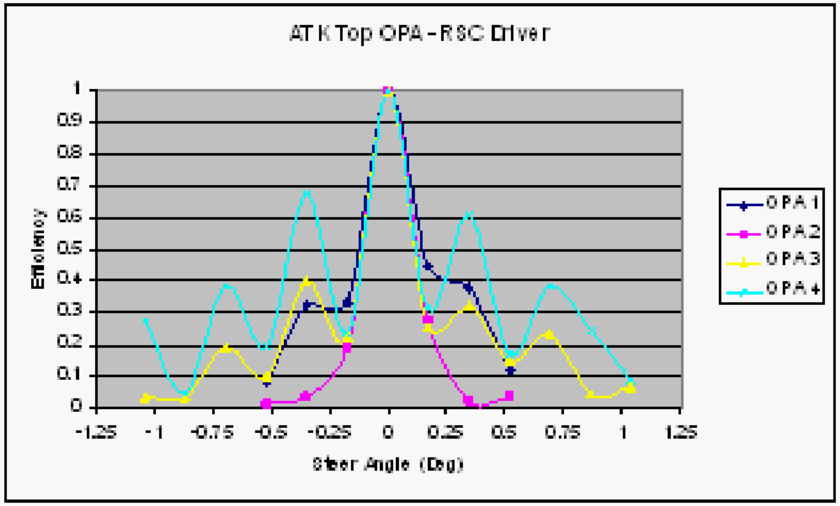
Removed and measured separately

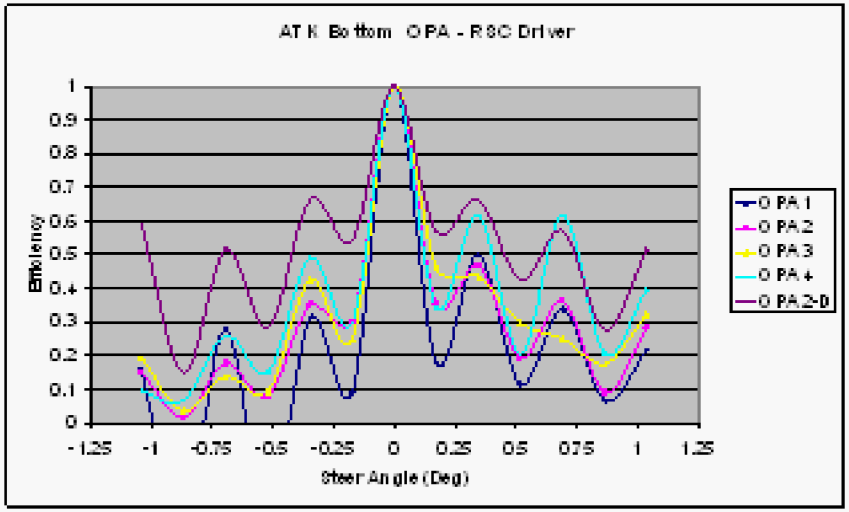
Top OPA

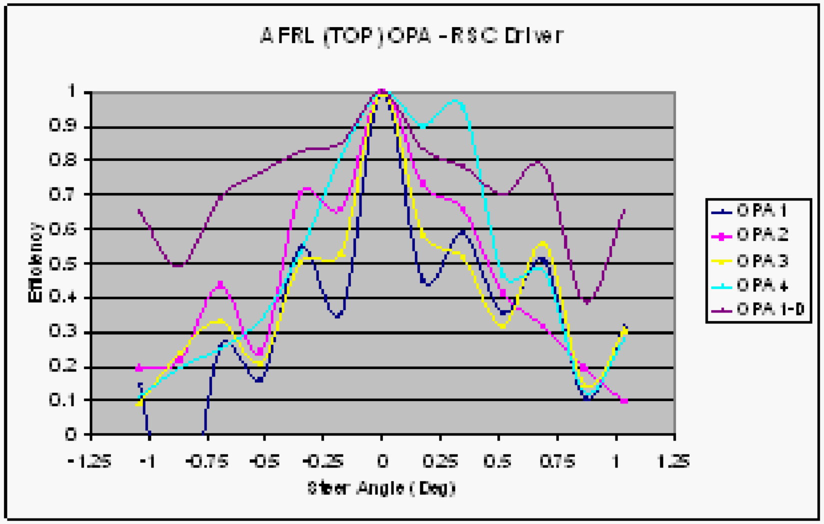
- Half functional Phase correctors (Tx)
- Poor at non-magic angles
- Replaced with AFRL OPA

Bottom OPA

- Better, but still poor at non-magic angles



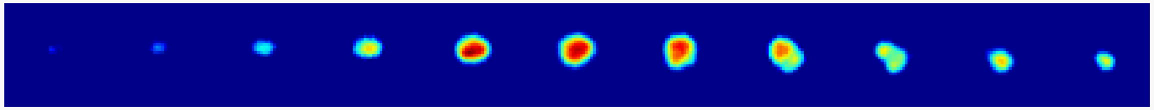




System Performance

Fully closed loop operation has not been successfully demonstrated.

- **RF pointing/tracking operates as expected**
  - Sidelobes are an issue
- **Optical performance is lacking**
  - Poor OPA performance makes it difficult to track beam
  - FSM loop performance has not met expectations



  - Manufacturing errors in the diamond turning process in 5.5x telescope objective
- **Software complete but not tested due to optical hardware performance issues**

Opportunities

Continue work on Phase I aperture

- Complete system testing
- Implement new FSM controller
- Implement SLM beam correction
- Implement RF modem
- Debug system operations code

Apply lessons learned to build 3rd GEN system

- New layout with separate OPAs
- 2nd GEN OPA drive electronics
- "Final" system form factor
  - All electronics on ORCLE head
  - SRC-7 processor

Test full ORCLE system in the field

- Complete system with 2 heads to work out system dynamics and best operational modes
- Real world distances and data

ORCLE Next Steps Implement Window Aberration Correction with SLM

Real world implementation of ORCLE on a platform requires a window

- Window introduces aberration into the beam path that changes with pointing angle
- Less energy gets focused onto receiver
- Shorter range capability

Two step approach

- Utilize a fixed optic to minimize range of wavefront aberration
- Use commercial Spatial Light Modulator (SLM) to remove angle dependent residual aberration (designed in during Phase I)

SLM also has potential to mitigate other slowly varying wavefront aberrations

ORCLE Next Steps Test RF aperture with TCDL station

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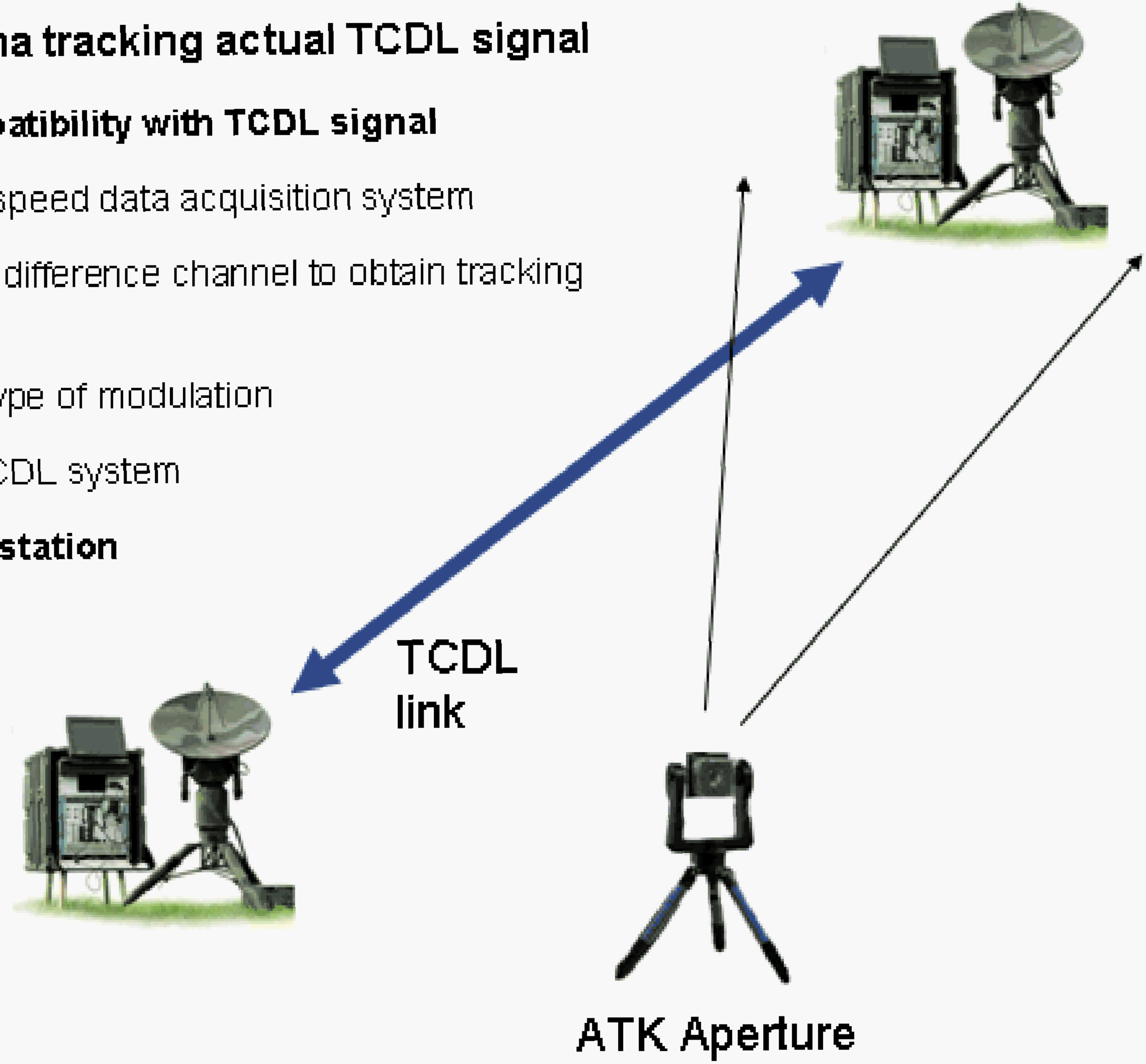
Demonstrate ATK MR antenna tracking actual TCDL signal

Modify Phase I receiver for compatibility with TCDL signal

- Replace VNA with COTS high speed data acquisition system
- Correlate sum channel to each difference channel to obtain tracking error
- Track in band signal with any type of modulation
- Approach is compatible with TCDL system

Test against the AFRL/SN TCDL station



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Real world testing of systems for extended periods

- Locate at site where paths of 1 - 20 km are available
  - Fixed site to fixed site
  - Fixed site to mobile site
- Operate for weeks at a time
- Operate using windows for aberration generation
- Operate under varying weather conditions to facilitate real world RF/optical link switching
  - Collect meteorological data
- Operate under real world RF environment

Current plan is Fallon NAS, NV

- Many possible locations that allow peak to valley and peak to peak scenarios
- Can do mobile tests from mountain peak to truck on valley floor
- Many electronic warfare sites at test complex for real RF environment testing