Formation Acquisition Sensor for the Terrestrial Planet Finder (TPF) Mission

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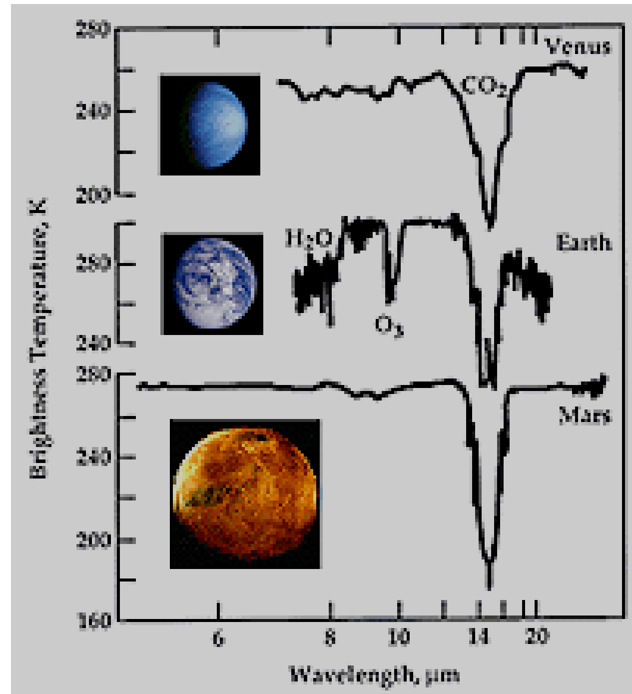
2004 IEEE Aerospace Conference
Big Sky, MO

TPF Mission Overview

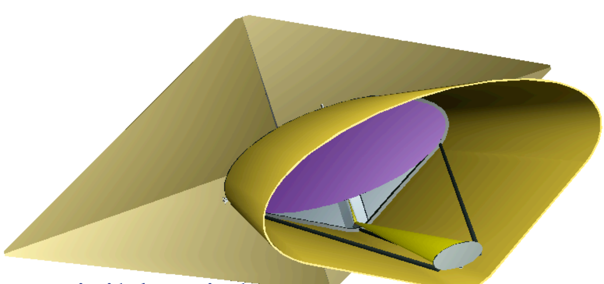
<u>Science Goal:</u>
- Primary objective is direct **detection** and **characterization** of **earth-like planets** around nearby stars
- Secondary objective is general astrophysics

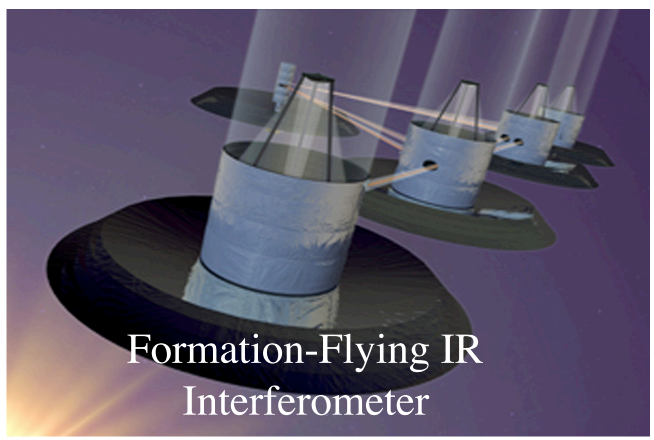


<u>Architectural Candidates:</u>
- Visible Light Coronagraph
- Mid-IR Interferometer
  - Formation Flying
  - Structurally Connected

<u>Mission Duration:</u> 5 years (10 years goal)

<u>Expected Launch Date:</u> 2015


Visible Light Coronagraph

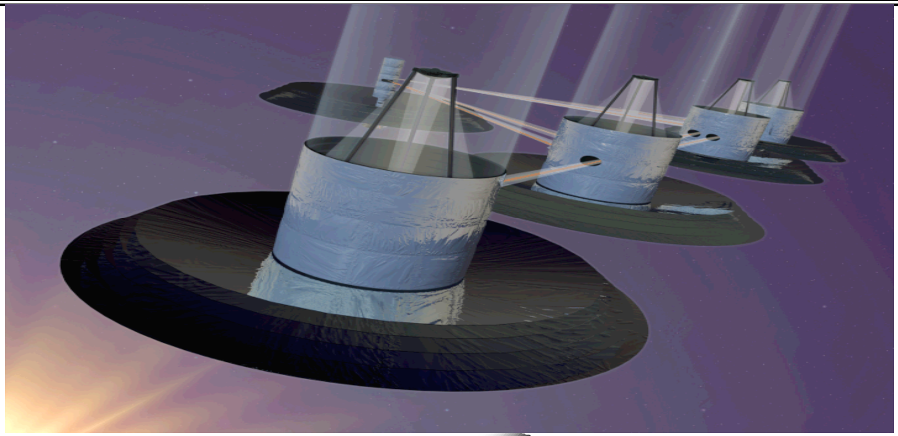

Formation-Flying IR Interferometer

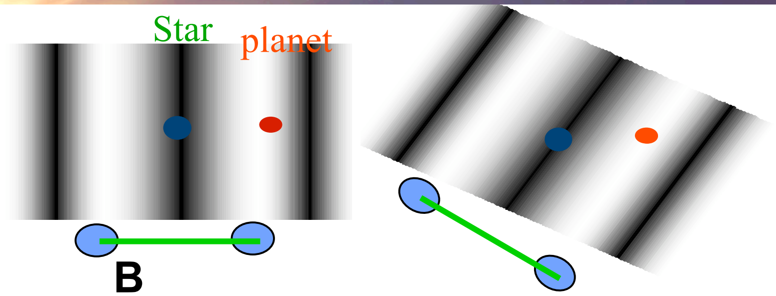

Structurally Connected IR Interferometer

Formation Flying Interferometer (FFI)

FFI Mission Description:

- Formation Flying Interferometer-- consisting of multiple (4-6) telescopes on separate Collector spacecraft flying in closely coordinated constellation with Combiner spacecraft
- Instrument is an Infrared Nulling Interferometer operating at cryogenic temperatures that employs destructive interference to cancel light from a target star and enable direct observation of the star's planets
- Spacecraft separation distance is adjusted to vary the interferometer baseline for optimum viewing of each target





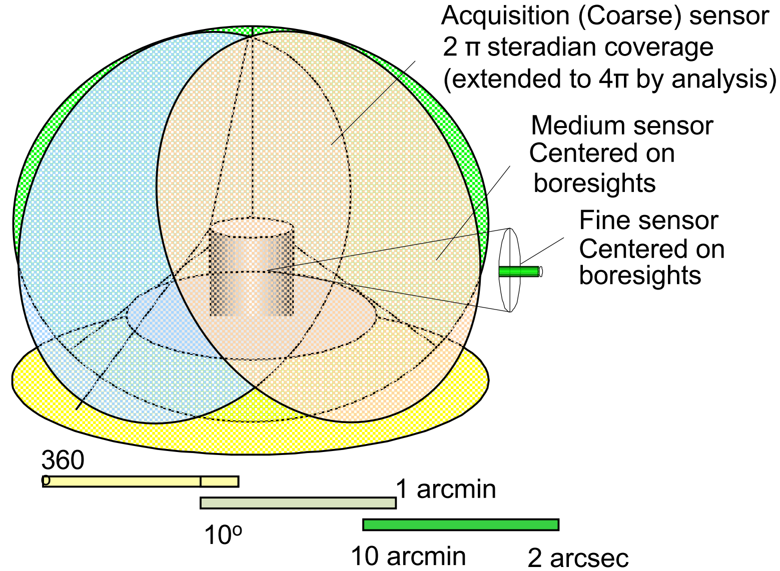
Key Formation Flying Issues:

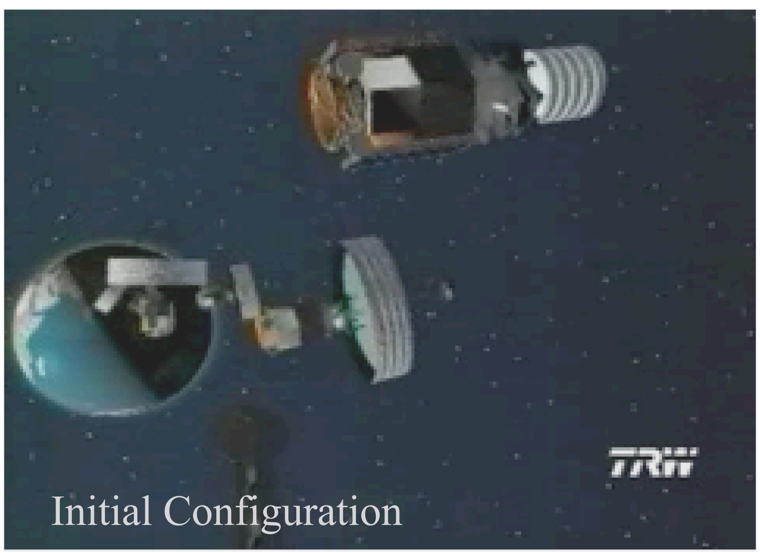
- Lost-in-space Formation Acquisition
- Collision Avoidance
- Precision Formation Control
- Observation-on-the-fly
- Integrated End-to-end System

Purpose of the Formation Sensor Testbed

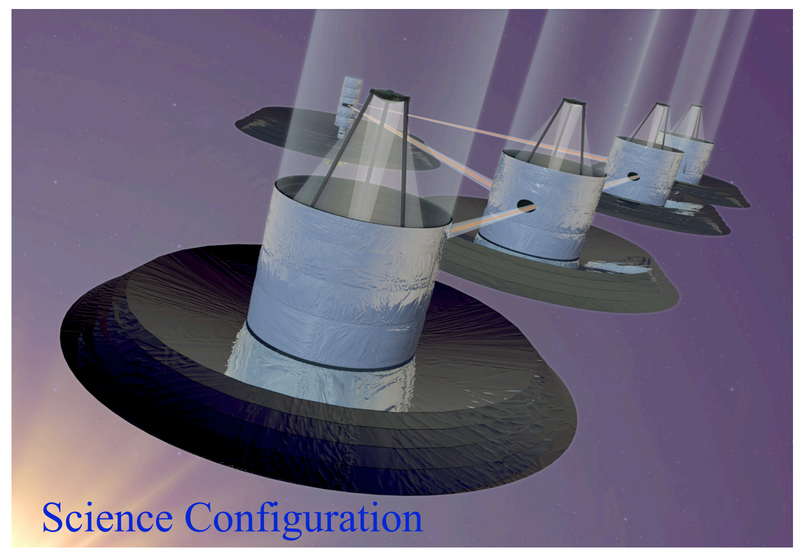
To demonstrate feasibility of an integrated 4π-coverage range and bearing formation acquisition (coarse) sensor that would enables the spacecraft to perform:

- Lost-in-space formation acquisition
- Coarse formation flying
- Collision avoidance in case of single spacecraft fault condition



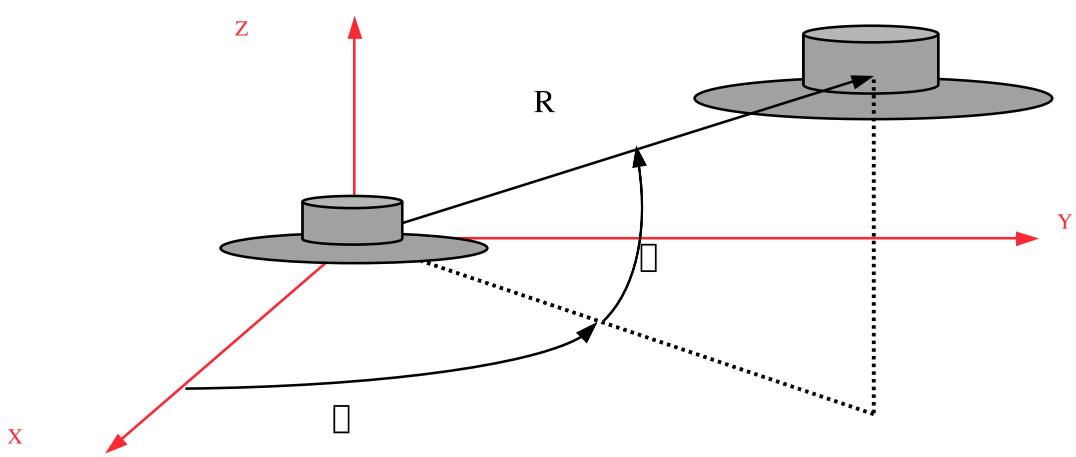


Initial Configuration


Science Configuration

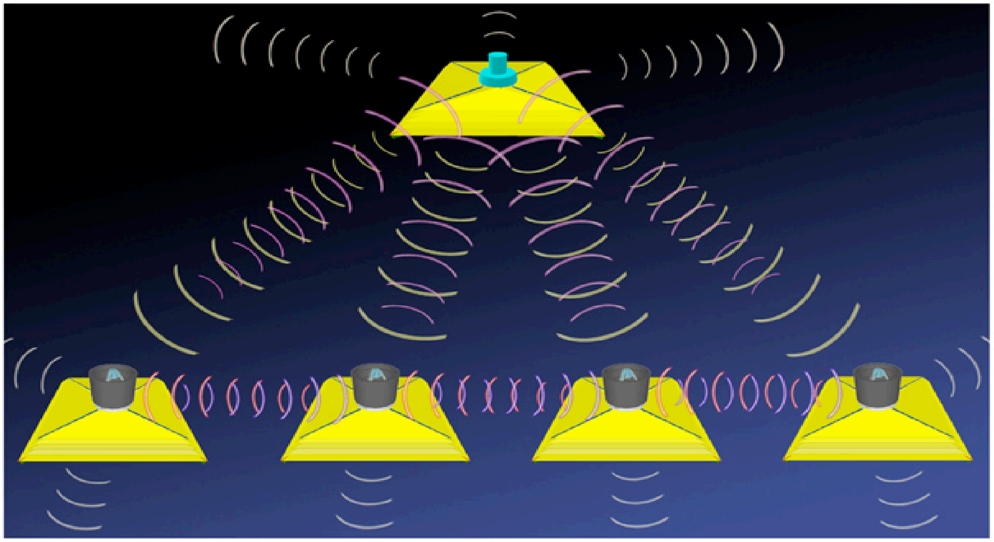
TPF Formation Sensor Testbed Requirements

Formation Sensor Testbed (FST)			
Requirements	**TPF Flight**	**FST**	**Comments**
Performance			
FOV Coverage	4π sr	2π sr	Extend to 4π by analysis
Cooperative Mode			
Operating Range	16 m - 10 km	16 m - 1 km	10 km for evaporation
Range Accuracy	0.5 m	0.5 m	
Bearing Accuracy	1 degree	1 degree	
Non-cooperative mode			**Radar mode**
Operating Range	16–200 m	16–50 m	center to center
Range Accuracy	1 m	4 m	
Bearing Accuracy	30 degrees	-	
Update Rate	1 Hz	1 Hz	



TPF Formation Sensor Testbed Requirements

- 5 spacecraft (scalable)
- Each spacecraft must be able to determine the range and bearing of any other visible spacecraft without prior information.
- Coarse sensor must be able to perform self-calibration without maneuvering the spacecraft.
- The coarse sensor must maintain the integrity of the formation in case of a fault condition (“radar mode”)

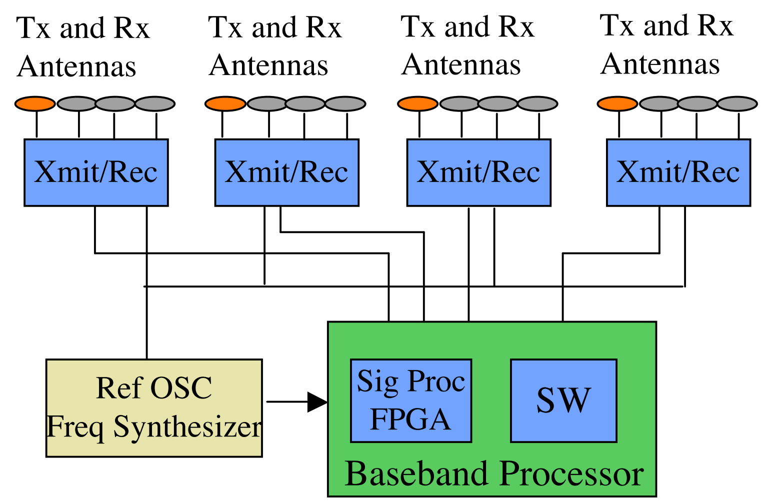


Range and Bearing-angle Links

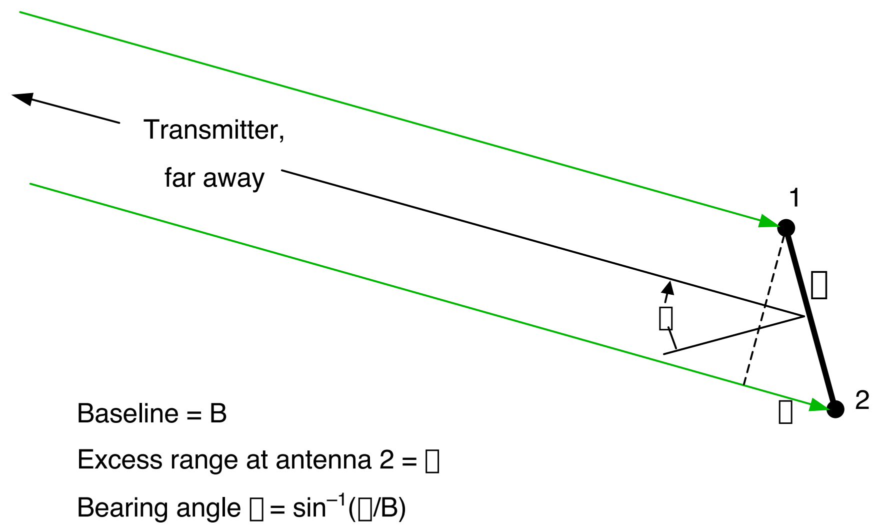
Design and Features

An RF sensor based upon the Autonomous Formation Flying (AFF) sensor

- Integrated range and bearing sensor
- RF sensor to achieve 4π-steradian coverage
- Multiple sets of transmitting and receiving antennas to do ranging and bearing-angle measurements for a target spacecraft in any direction
  - 1 transmitting antenna
  - 3 receiving antennas
- Configurable baseband processor can perform multiple functions
  - Pseudorange and phase measurements
  - Local diagnostics and estimation
- Integrated radar for collision avoidance
- Integrated inter-spacecraft comm.

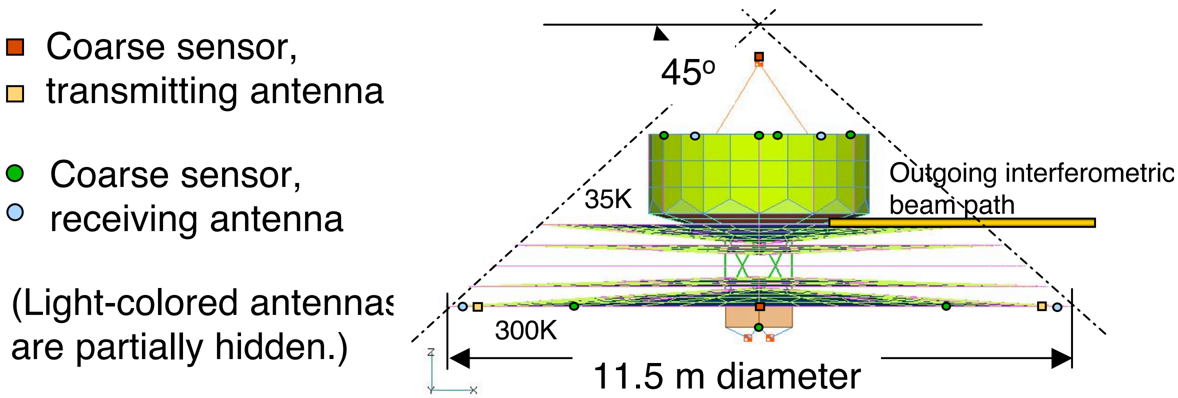


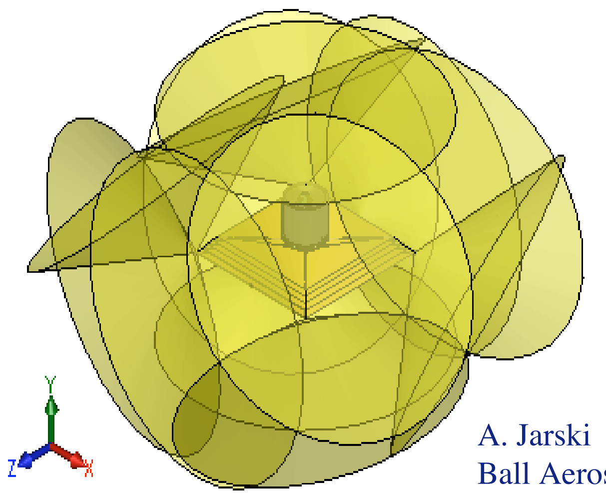
High-level functional block diagram



Results of the Trades Considered

• Sensing technology	RF
• Carrier frequency selection	S-band
• Antenna configuration	4 tx and 12 rx
• Signal Structure	Ultra-BOC*
• Time-division duplexing (TDD)	Yes





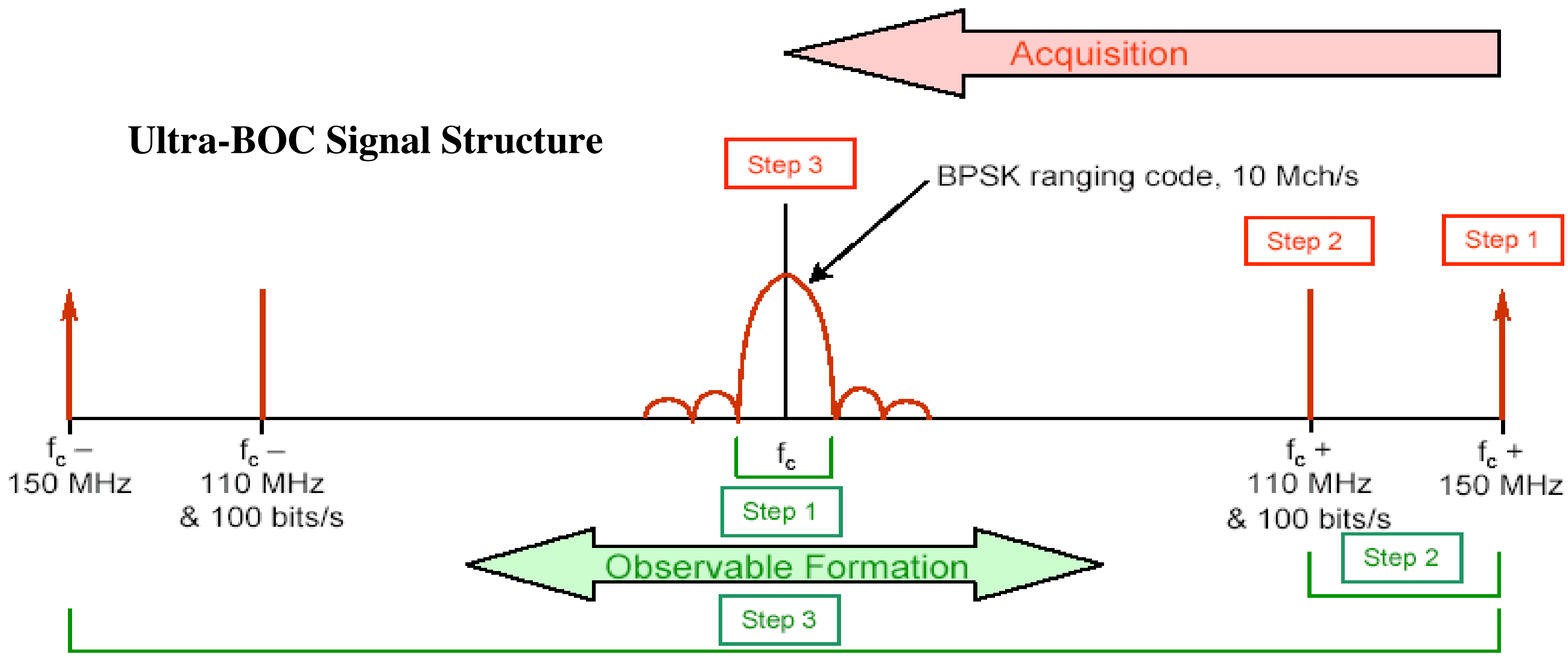
A. Jarski
Ball Aerospace

* Multi-component extension of Binary Offset Carrier (BOC) modulation developed specifically for TPF

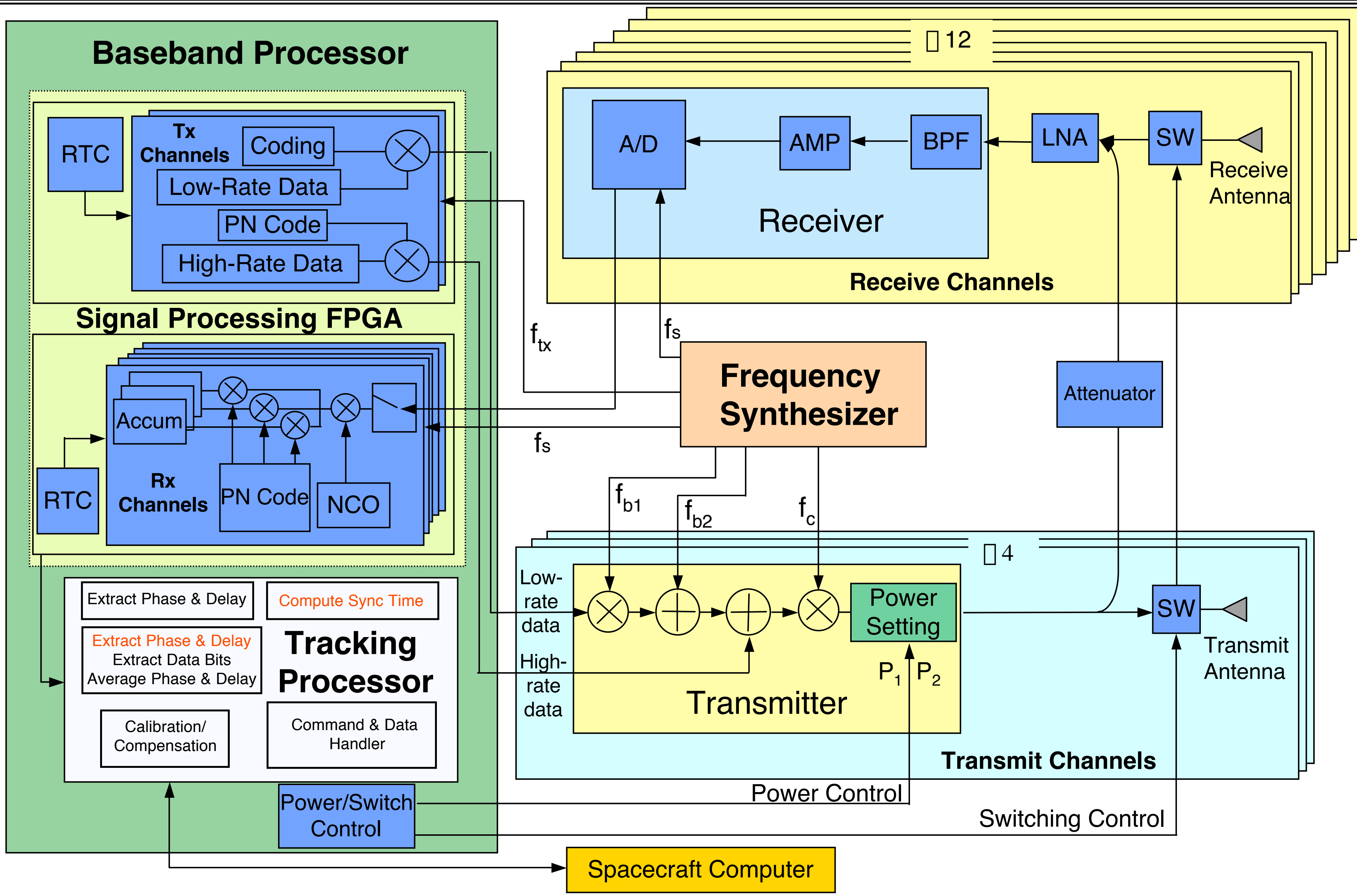
Signal Structure

New signal structure and associated algorithms will be developed to enable:

- Simultaneous operation on many spacecraft.
- Fast signal acquisition of less than 1 minute for multiple spacecraft operation.
- An order of magnitude reduction of range error.
- Fine bearing angle measurement without the need for spacecraft rotation calibration maneuver.



Functional Block Diagram

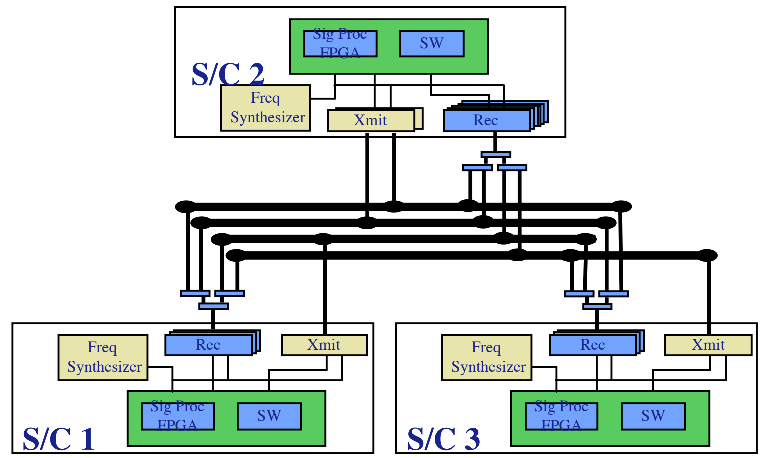


Development Approach

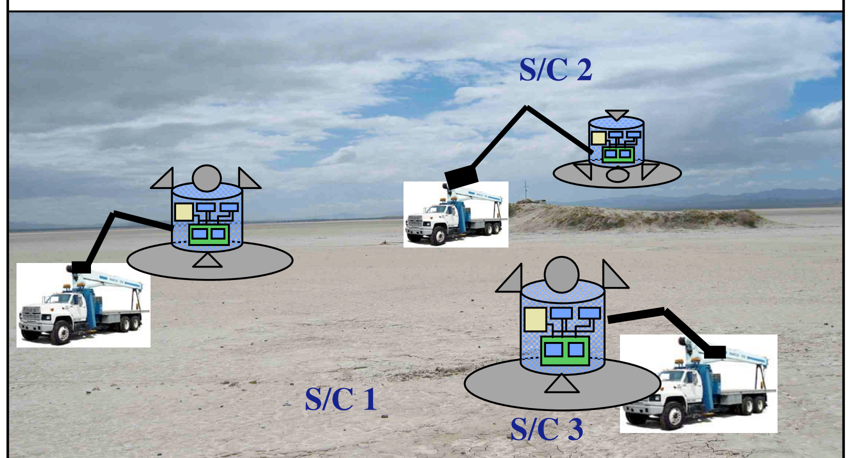
FST Acquisition Sensor Analysis

- Error Budget
  - Multipath
  - System noise
  - Link budget
  - Covariance analysis
- Signal acquisition analysis
- Frequency system analysis
- Antenna radiation & phase pattern modeling including the effect of s/c structure

FST Acquisition Sensor Testbeds



Indoor Functionality Testbed



Outdoor Articulated Testbed

Technical Challenges & Mitigation Approach

Challenges	Mitigation			
	Analysis	Indoor Testbed	Outdoor Testbed	Other
• Achieve 4π coverage for both range and bearing measurements	√		√	√
• Calibrate the coarse sensor without spacecraft maneuvers	√	√	√	
• Perform adequate instrumental delay and phase calibration	√	√	√	
• Maintain the array with the coarse sensor disabled on one spacecraft (Radar mode)	√		√	
• Mitigate effect of multipath	√		√	√
• Acquire and track a combination of close and distant spacecraft	√	√	√	
• Meet requirement for heat dissipation on the cold side of the s/c	√			√
• Switch receiving and transmitting antennas dynamically	√		√	
• Frequency subsystem design	√	√	√	

Preliminary Test Result

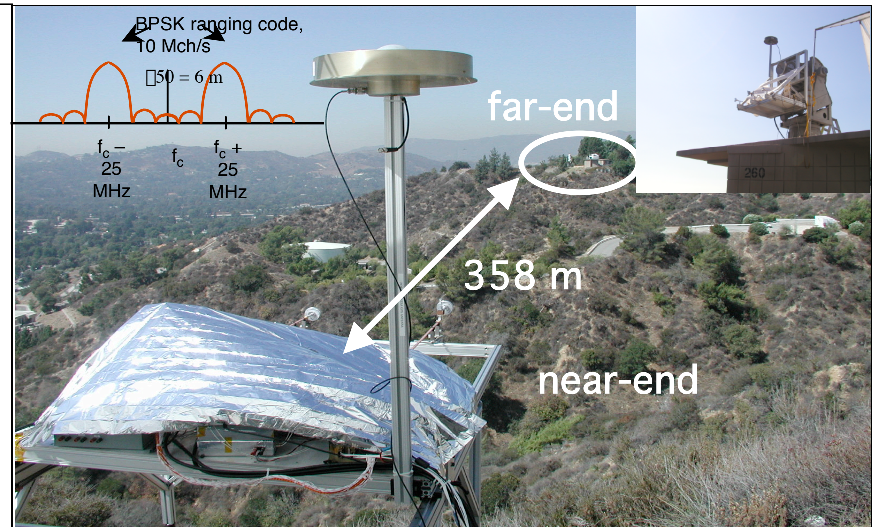
(JPL Mesa 1200 ft range)

Objective:

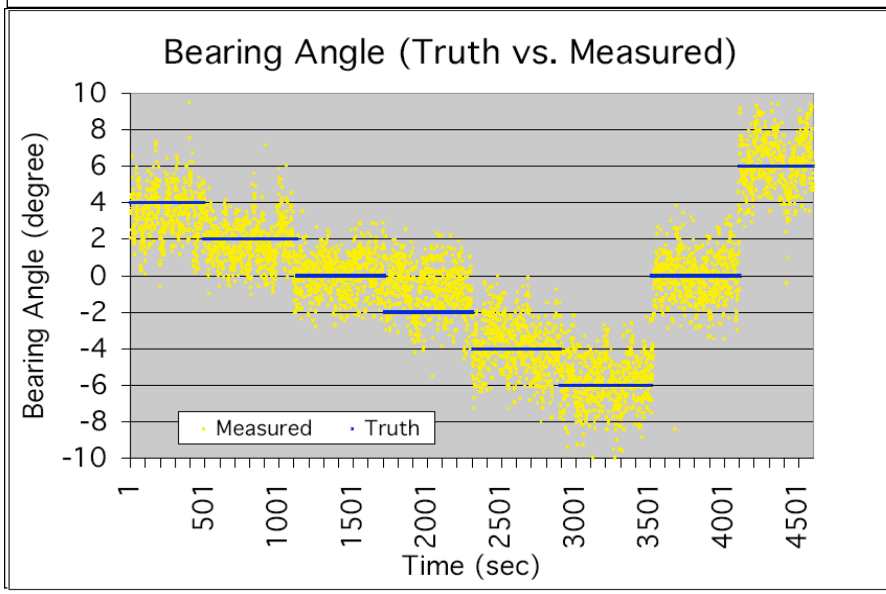
To use Binary Offset Carrier (BOC) signal structure to resolve differential synthesized cycle ambiguity to obtain bearing angle measurement without the need for spacecraft rotation calibration maneuver.

Requirement:

- Accuracy: < 5 degree bearing angle



JPL Mesa Antenna Test Range



Summary Results:

- Bearing accuracy: < 2 degrees
- Bearing precision: ~1 degree (1 σ)

Benefit for TPF:

- Significant reduction in flight system design and operational complexity.

Plans

Sept, 2004 - Demonstrate sensor functionality, range and bearing performance stability, and signal acquisition time for 2 s/c operation in the indoor testbed.

Sept, 2005 - Demonstrate sensor functionality, range and bearing performance stability (including jamming effect from the third s/c), and signal acquisition time for 3 s/c operation in the indoor testbed.

June, 2006 - Demonstrate end-to-end system performance and signal acquisition time for 3 s/c operation in the outdoor articulated testbed.