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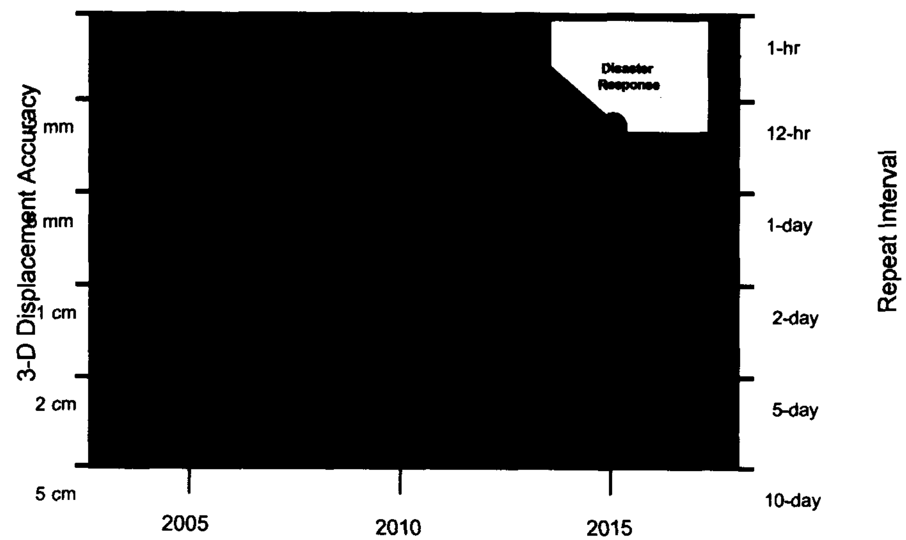
May 6, 2002

ACES Meeting, May 6, 2002
Science Summary

- **Goals of the Study**
- **Develop a 20-year linked science and technology plan leading to understanding of the physics of faults and fault systems and targeted, short-term earthquake forecasting**
  - **Provide data to develop and test models**
  - **Enable dynamic seismic hazard assessments**
  - **Support effective disaster response**
- **Align NASA with EarthScope (NSF/USGS) to enable revolutionary breakthroughs in earthquake science through partnership**



Activities

- **Develop science requirements**
- **Fund investigators to perform detailed requirements definition studies**
  - **InSAR system characteristics**
  - **Inputs needed for models**
  - **Non-InSAR measurements**
- **Investigator's Workshop (Snowbird, UT 10/9)**
- **Seismology from Space Mtg (Caltech, 11/29)**
- **Troposphere/Ionosphere corrections**

Status/ Plans

- **Collate and incorporate results of funded investigations into detailed science requirements document**
- **Organize special session at Spring AGU meeting for community feedback**
- **Develop science/technology roadmap**
- **Feed science requirements into research and technology strategies and ESTO/NMP capability needs**

Science Questions

1. How does the crust deform during the interseismic period between earthquakes and what are its temporal characteristics (if any) before major earthquakes?
2. Are there precursory phenomena (potential field, electromagnetic effects, or thermal field changes) preceding earthquakes that could be resolved from space?
3. How do earthquake ruptures evolve both kinematically and dynamically and what controls the earthquake size?
4. What controls the space-time characteristics of complex earthquakes and triggered earthquakes and aftershocks?
5. What are the sources and temporal characteristics of postseismic processes and how does this process relate to triggered seismicity?
6. How can we identify and map earthquake effects postseismically or identify regions with a high susceptibility to amplified ground shaking or liquefaction/ground failure?

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GESS Requirements Definition

PI Name	PI Institution/Dept	Title of Investigation	Q1	Q2	Q3	Q4	Q5	Q6
M Shinozuka	USC/Civ. Eng	Change Detection studies for liquefaction ground failure						√
L. Kellogg	UC Davis	Requirements Def.for Modeling Systems Assoc. with NASA Global Earth Satellite. Sys.	√		√	√	√	
J.B. Rundle	Univ. of Colorado	Requirements Def.for Modeling Systems Assoc. with NASA Global Earth Satellite. Sys.	√		√	√	√	
D. Sandwell	Scripps Inst.	Requirements for Observing Slow Crustal Deformation	√					
M. Simons	Caltech	Constraining Co-seismic Fault Motion and Surface Disruption of Large Earthquakes using INSAR and Seismology			√			
B. Chao	NASA GSFC	Global Earthquake satellite Sys. Requirements Derived from a Suite of Scientific Observational Modeling Studies	√					√
H. Zebker	Standford Univ.	Characterizing Space-time Patterns of Slip at Depth along fault systems	√					
T. Melbourne	Central Wash. Univ.	Using Global Seismicity and the Surface Deformation power spectrum to optimize GESS architecture.						
K. Olsen	UC Santa Barbara	Which Rupture Dynamics Parameters can be Estimated from SAR and Strong Ground Motion Data?			√			
R. Burgmann	UC Berkeley	InSAR System Requirements for Resolution of Crustal Deformation Parameters Assoc. with the Earthquake Cycle	√		√	√	√	
E. Price	Univ. of Alaska	Requirements of a SAR Satellite for Monitoring Earthquakes and Crustal Deformation in Alaska	√					
R. Reilinger	MIT	Geodetic Improvements for Calculating, Analyzing and Modeling INSAR measurements in synergetic combination with GPS.	√			√	√	
P. Taylor	NASA GSFC	Search for seismic related events (pre-, co-, post-earthquake) in the magnetic field data from Magsat		√				
P. Lundgren	JPL	Constraints on earthquake cycle surface deformation observational and modeling requirements for a Global Earthquake Satellite System	√		√	√		
A. Donnellan	JPL	Detecting surface deformation from a suite of fault models						
E. Fielding	JPL	Deformation on complex fault zones, interseismic, co-seismic and post-seismic strain	√		√	√	√	
E. Ivins & C. Sammis	JPL/USC	Earthquake and creep event statistics and long-term surface deformation monitoring	√			√	√	
F. Webb	JPL	Neutral atmospheric delay in InSAR applications: statistical description and mitigation						
R. Crippen	JPL	Thermal Anomalies at EQ epicenters		√				

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Science Requirements

Surface Deformation Measurement Attribute	Minimum	Goal
Displacement accuracy	25 mm instantaneous	5 mm instantaneous
3–D displacement accuracy	50 mm (1 week)	10 mm (1 day)
Displacement rate	2 mm/yr (over 10 y)	<1 mm/yr (over 10 y)
Temporal Accessibility	8–days	1–day or less
Daily Coverage	$6 \cdot 10^6$ km^2	Global (land)
Map region	±60° latitude	Global
Spatial resolution	100 m	10 m or less
Geo-location accuracy	25 m	3 m
Swath	100 km	500 km
Data latency in case of event	1 day	2 hours after acq.

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Future Plans - Science

Develop long-term science roadmap

- Revise science requirements based on studies
- Add detailed requirements for disaster mitigation/response (separate roadmap?)
- Obtain feedback during AGU special session (investigator reports/GESS report)
- Define approach to evaluating/achieving useful earthquake prediction

Complete ground data system architecture

- Integrate and align with SCEC IT
- Respond to science and disaster needs
- Define interfaces and unique role for NASA, if any

Evaluate system architecture concepts' ability to address science requirements

- InSAR: Orbits, constellation configuration, tropospheric/ionospheric correction
- Role of Lidar, magnetic, thermal and optical measurements

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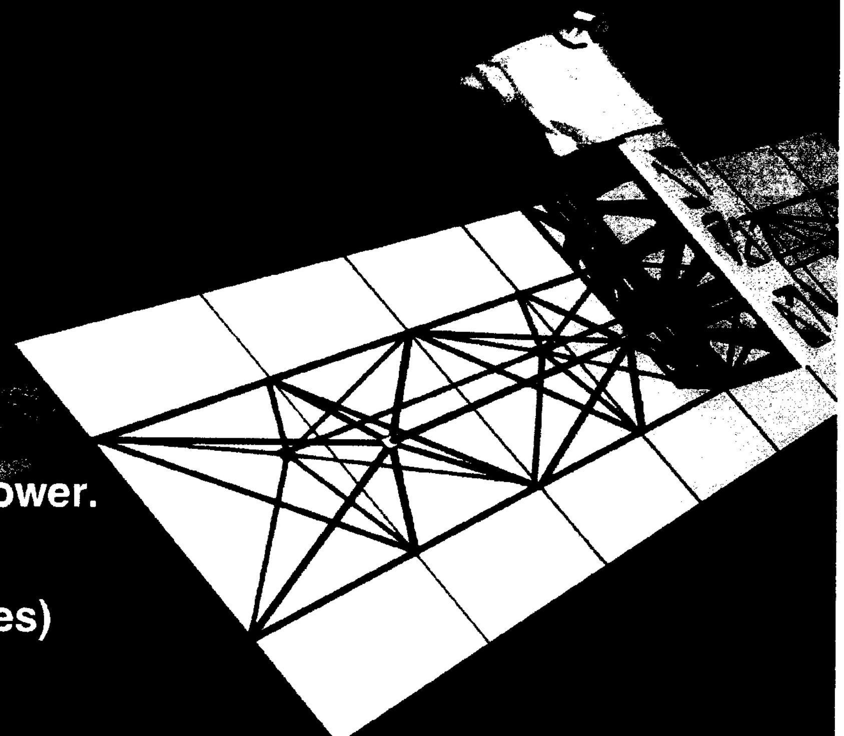
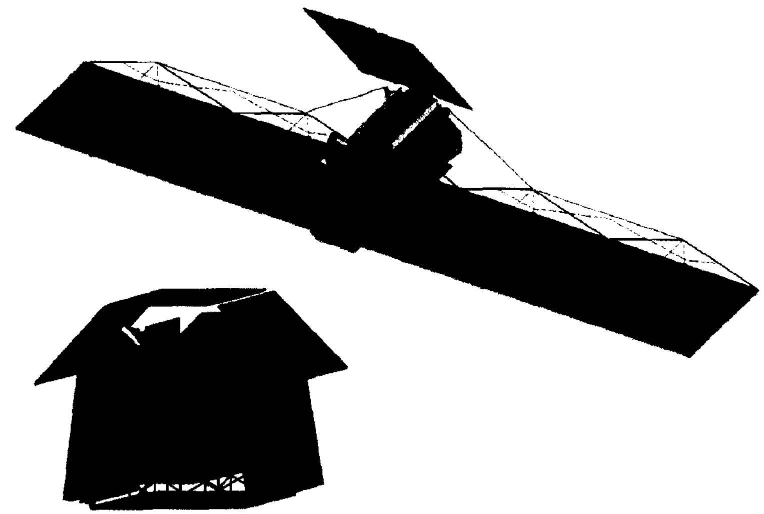
Concept Alternatives

- Low Earth Orbit (LEO)
  780 km elevation
  ECHO/LightSAR class satellite
  Cheapest option, 8-day repeat
- Enhanced Low Earth Orbit (LEO+)
  1325 km elevation,
  6-day repeat
  50–80% larger targeted range, stable orbits
  Technology as LEO but larger antenna and power.
- Constellation of LEO+ satellites (2/4/8 satellites)
- Geosynchronous SAR (GeoSyncSAR)
  35789 km elevation,
  1-day repeat, 1 satellite covers ±60° in longitude
  5500 km "targetable" swath on either side of ground track
  Very large antenna (30 m @ L-band), moderately large power (65 kW DC)



LEO+ Mission Design

- **Objective** –Verify initial design and cost based upon overall mission requirements
- **Goals** –Maximize science data return at a minimum cost and with minimize risk (mission, cost, schedule, etc..).
- **Approach** –Utilize commercially available HW/SW with minimum modifications. Risk management based upon redundancy, maximizing design margins and use of standard management and review processes.



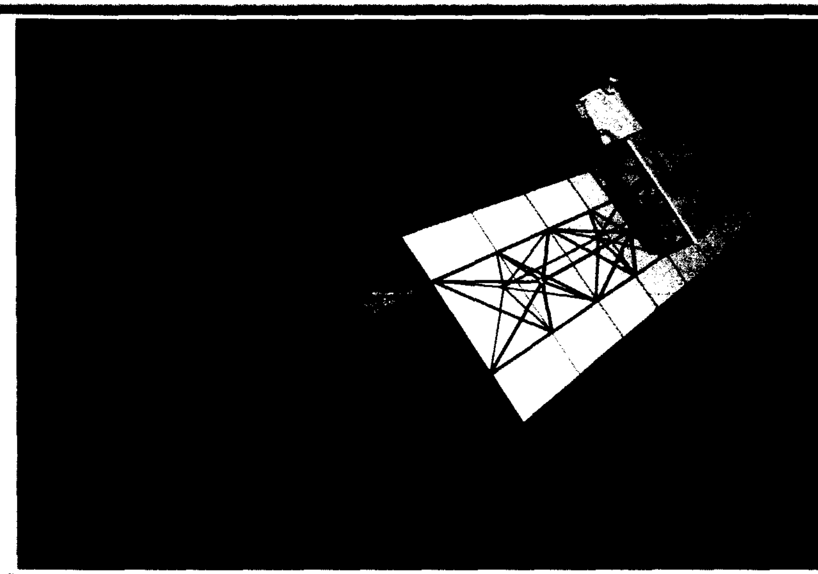
Spacecraft & Launch Vehicle Summary

- Use catalog bus for basic design and estimate design mods. Used Ball BCP-2000 as baseline BUS design.
  - Major mods: Structural changes for payload, Additional 128Gbit data recorder, Blackjack GPS, Larger propellant tank, Power(larger Battery,Solar Array)
  - Followed standard design principles with >=30% margins
- Launch Vehicle: Delta II 2420-10

To be continued...

LEO+ Mission Design

- Continued...



Ground System & Mission Operations Summary

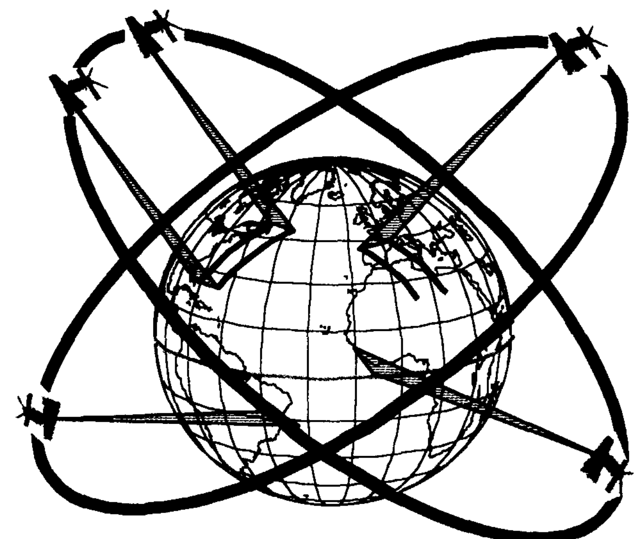
- Centralized design with lower-level distributed capability. Emphasis on use of commercial HW/SW, risk mitigation (redundancy, backups, security)
- Scalable system capable of processing, distributing, and archiving long-term, multi-platform data.
- Mission ops: Low-Cost design utilizing commercial services and extensive automation.

Cost Summary

- Team X costing focused in S/C, Launch Vehicle, Mission Operations. Grass roots estimates used for Instrument & Gnd Sys
- Team X estimate is about $364M (FY2002) with 30% reserves. S/C modification costs were $15M above the baseline bus cost provided by RSDO.

Remaining Issues on LEO+

- Remaining issues
- Characterization of tropospheric and ionospheric perturbations
- Characterization of the performance of ionospheric mitigation strategies
- Development of tropospheric mitigation strategies
- Coverage and 3-D displacement accuracies attained by one satellite respectively a constellation of 2/4/8 satellites.



Technology

- Characterization of tropo- and ionosphere relies on results reported by various research groups in particular from GPS observations
- Ionospheric mitigation relies on frequency diversity (split-spectrum) techniques
- Tropospheric mitigation techniques are not well developed presently (water vapor radiometry, GPS, and possibly data redundancy)

Status/Plans

- Working memos on tropos- and ionospheric perturbations written
- Draft memo on ionospheric mitigation techniques and performance written
- Tropospheric mitigation options need to be assessed and documented
- Constellation and 3-D performance is in progress using STK/Soap combined with 334-developed software

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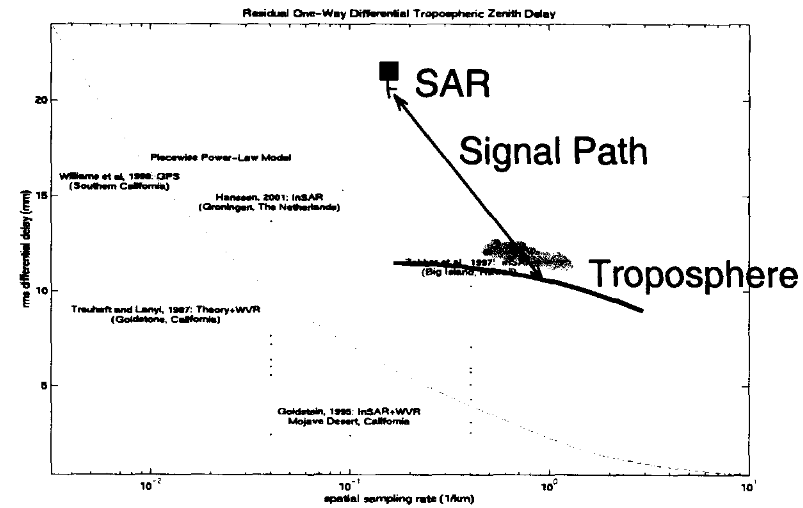
Tropospheric Mitigation

- Tropospheric Delay Correction
- InSAR phase affected by atmosphere's index of refraction along signal propagation path
- Variations in tropospheric water vapor introduce phase artifacts masking true surface deformation signature
- Tropospheric phase artifacts equivalent to centimeter-scale surface displacements



Technology

- Precision correction of tropospheric phase artifacts may require a combination of external calibration, multiple/redundant observations
- External calibration sources include simultaneous water-vapor radiometer measurements, GPS networks, and high resolution weather models
- Multiple/redundant observations including advanced data processing and system concepts

Status/Plans

- Performance impact of troposphere has been estimated and simulated based on existing InSAR data sets
- Possibility of calibration via onboard water vapor radiometer is being evaluated
- Data-processing algorithms for separating tropospheric artifacts from true ground signals are being considered

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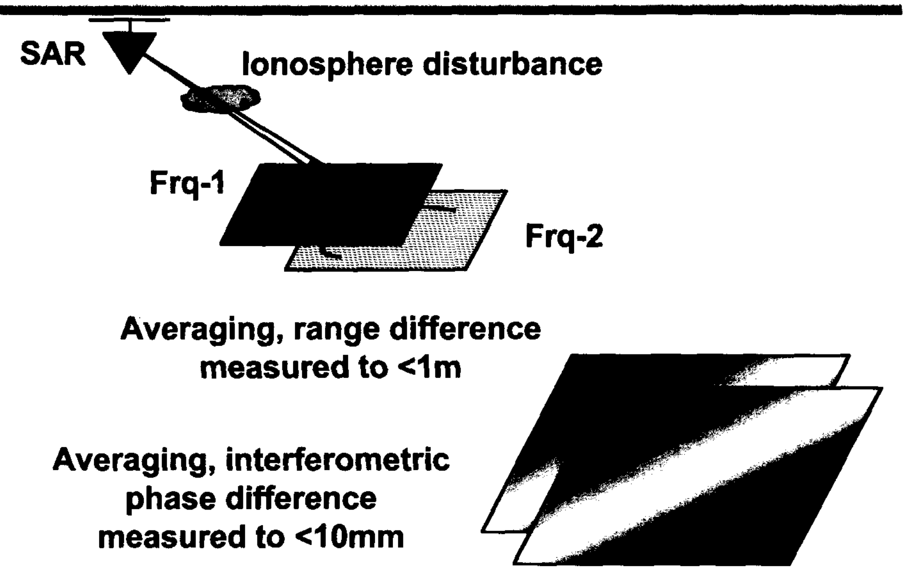
Ionospheric Mitigation

- Ionospheric Delay Correction
- InSAR phase and delay affected by ionosphere along signal propagation path
- Ionosphere can introduce a frequency dependent signal delay of many meters, which need to be removed almost entirely to resolve cm-level ground deformation with few local reference points
- Ionosphere exhibits a range of temporal and spatial variation scales, including turbulent behavior



Technology:

- Split-spectrum single image range offsets to resolve ionospheric delay to sub-meter level
- Split-spectrum interferograms to resolve differential delays to better than 1–2 cm level
- External ionospheric data from global models, GPS, etc. to remove long-wavelength perturbations
- LEO+ orbits chosen to minimize exposure to turbulent ionosphere (e.g. terminator-centered orbits)

Status/Plan

- Working memos on ionospheric perturbations and possible mitigation techniques and performance written
- The performance of mitigation algorithms need to be further quantified analytically, by simulation, and using existing satellite data
- Dynamic considerations need to go into the analysis of geosynchronous SAR

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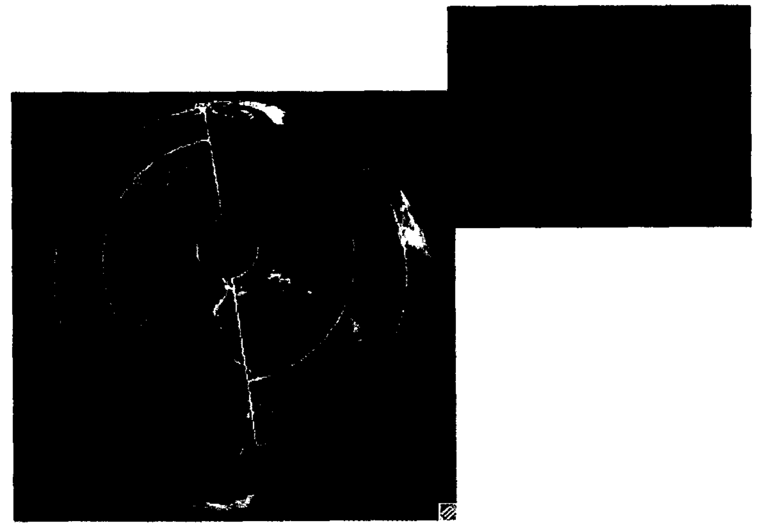
GeoSynchronous SAR

- Challenges
- Very large electronically scanned antennas (ESAs) are required, e.g. 30x30m
- Performance analysis methods and software need to be developed
- Processing algorithms needs to be developed
- Method to mitigate a dynamically varying atmosphere over the very long aperture times (up to 30 minutes) needs to be solved



Technology

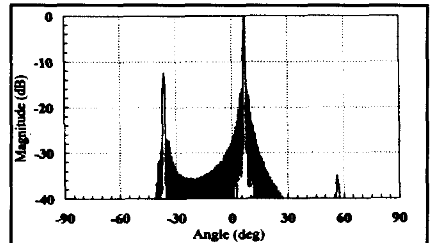
- Very large membrane apertures on deployable structures (see next slide)
- Generalization of the System Performance Analysis Tool (SPAT) presently used is required
- Multistage processing algorithms need to be develop (e.g. medium-resolution batch processing followed by higher resolution corrections and high-resolution image formation)

Status/Plans

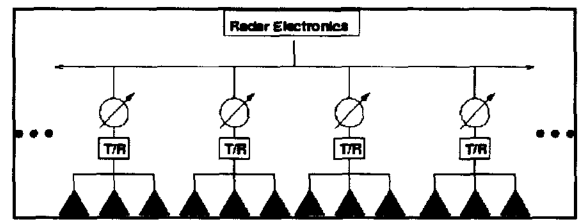
- Manual calculator system design performed
- Feasibility study including the antenna array design, packaging and deployment is in progress
- Assessment of required SPAT upgrades
- Simple point target simulation tool is in progress (no atmosphere)
- Outline of processing concept
- Further atmospheric studies

Geosynchronous SAR Antenna

- Challenges
- Very large aperture (30-m x 30-m) 2-D electronically scanning antennas are required for geosynchronous SAR
- Conventional rigid-manifold antennas will not meet the performance and cost goals
- Require deployable antenna structures



15m aperture, 2-element subarray, element spacing=0.7λ_o, beam scan angle=7°



Technology

- L-band membrane antenna aperture
- Large inflatable/deployable structures
- Membrane compatible T/R modules
- Ultra-high efficiency Class-E/F amplifiers
- Local thermal management
- Optical RF/DC signal distribution
- Thin-film solar arrays

Status/ Plans

- Identified three candidate array architectures (phased-array, reflect-array, lens)
- Studied subarray approaches (steering)
- Identified a 2-layer approach to the flexible hexagonal antenna signal distribution
- Initiated the structural design/deploy concept
- Complete structure packaging/deploy study and prepare Quick-Time movie of sequence
- Complete system architecture study
- Generate a technology roadmap