Section 5

Spacecraft Technologies

Enhanced Formation Flying (EFF)

Enhanced Formation Flying (EFF)

Technology Need:

Constellation Flying

Description:

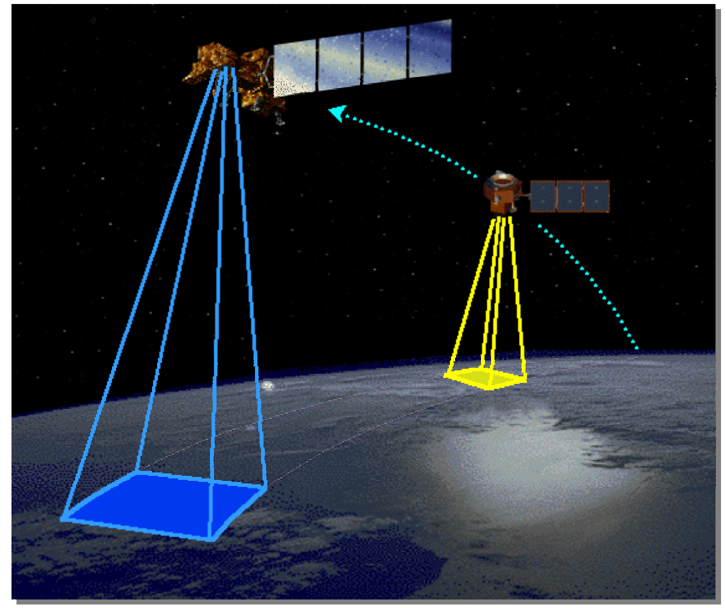
The enhanced formation flying (EFF) technology features flight software that is capable of autonomously planning, executing, and calibrating routine spacecraft maneuvers to maintain satellites in their respective constellations and formations.

Validation:

Validation of EFF has demonstrated on-board autonomous capability to fly over Landsat 7 ground track within a +/- 3km while maintaining a one minute separation while an image is collected.

Partners:

JPL, GSFC, Hammers



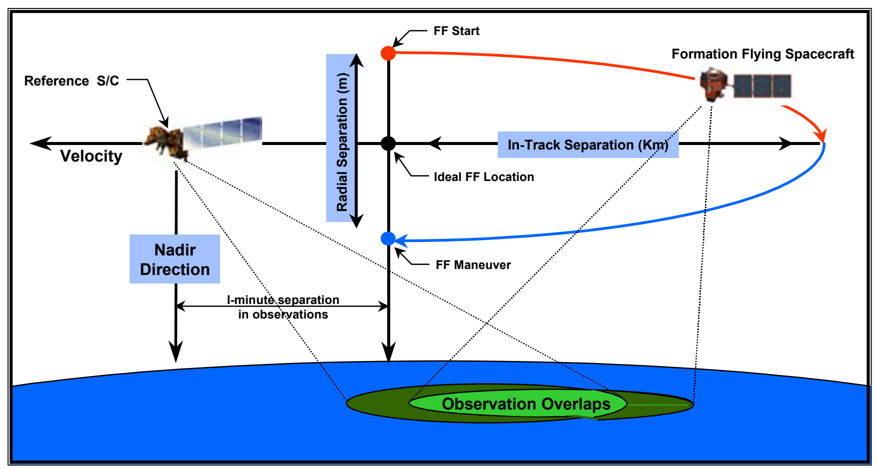
Benefits to Future Missions:

The EFF technology enables small, inexpensive spacecraft to fly in formation and gather concurrent science data in a "virtual platform."

This "virtual platform" concept lowers total mission risk, increases science data collection and adds considerable flexibility to future Earth and space science missions.

Performance Required

- ***Mission Orbit Requirements***
  - ***Paired scene comparison requires EO-1 to fly in formation with Landsat-7.***
  - ***Maintain EO-1 orbit with tolerances of:***
    - *One minute separation between spacecraft*
    - *Maintain separation so that EO-1 follows current Landsat-7 ground track to +/- 3 km*
- ***Derived Orbit Requirements***
  - ***Approximately six seconds along-track separation tolerance (maps to +/- 3km with respect to earth rotation)***
  - ***Plan maneuver in 12 hours***
- ***Derived Software Constraints***
  - ***Code Size approximately <655Kbytes***
  - ***CPU Utilization approximately <50% Average over 10 Hours during maneuver planning***
  - ***Less than 12 hours per maneuver plan***



EO-1 Formation Maneuver Frequency Is Ballistic Dependent

Earth Observing-1

June 4, 2002

Difference in EO-1 Onboard & Ground Maneuver Quantized ΔVs

Mode	***Onboard ΔV1 cm/s***	***Onboard ΔV2 cm/s***	***Ground ΔV1 Difference cm/s***	***Ground ΔV2 Difference cm/s***	***% Diff ΔV1 vs. Ground %***	***% Diff ΔV2 vs. Ground %***
Auto	4.9854078	0.0000000	0.0000001	0.0000000	0.00015645	0.00000000
Auto	2.4376271	3.7919202	0.0000003	0.0000002	0.00111324	0.00053176
Semi-Auto	1.0831335	1.6247106	0.0000063	-.0026969	0.05852198	-14.2361365
Semi-Auto	2.3841027	0.2649020	0.0000000	0.0000000	0.00011329	0.00073822
Semi-Auto	5.2980985	1.8543658	-0.0008450	-0.0002963	-1.56990117	-1.57294248
Manual	2.1915358	5.2049883	0.0000004	-0.0332099	0.00163366	-0.00022414
Manual	3.5555711	7.9318735	-0.0000003	-0.0272687	-0.00081327	3.57089537

Note: A final fully autonomous GPS derived maneuver was performed June 28, with preliminary validation results yielding a 0.005% difference in quantized ΔV and similar results in 3-axis

EFF Summary / Conclusions

- ***A demonstrated, validated fully non-linear autonomous system for formation flying***
- ***A precision algorithm for user defined control accuracy***
- ***A point-to-point formation flying algorithm using discretized maneuvers at user defined time intervals***
- ***A universal algorithm that incorporates***
  - ***Intrack velocity changes for semi-major axis control***
  - ***Radial changes for formation maintenance and eccentricity control***
  - ***Crosstrack changes for inclination control or node changes***
  - ***Any combination of the above for maintenance maneuvers***

Summary / Conclusions

- ***A system that incorporates fuzzy logic for multiple constraint checking for maneuver planning and control***
- ***Single or multiple maneuver computations***
- ***Multiple / generalized navigation inputs***
- ***Attitude (quaternion) required of the spacecraft to meet the ΔV components***
- ***Proven executive flight code***

Bottom Line:

Enabling Future Formation Flying / Multiple Spacecraft Missions

X-Band Phased Array Antenna (XPAA)

X-Band Phased Array Antenna (XPAA)

Technology Need:

High rate, reliable RF communication subsystems

Description:

The X-band phased array antenna is composed of a flat grid of many radiating elements whose transmitted signals combine spatially to produce desired antenna directivity (gain)

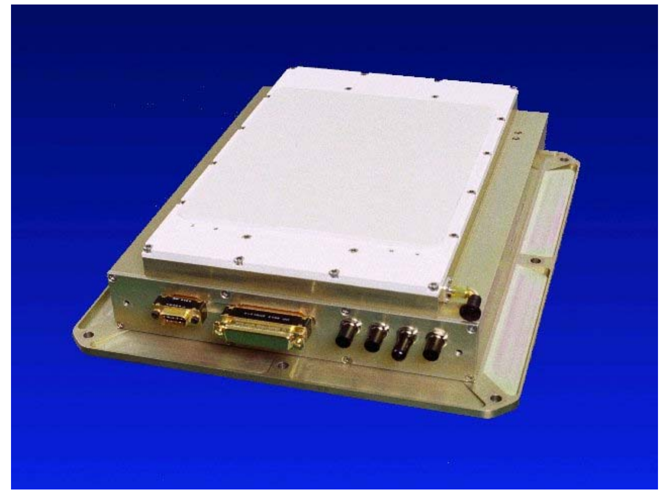
- *Avoids problems of deployable structures and moving parts*
- *Lightweight, compact, supports high downlink (100's Mbps) rates.*
- *Allows simultaneous instrument collection and data downlink.*

Validation:

The XPAA was validated through measurement of bit error rate performance and effective ground station EIRP during science data downlinks over the lifetime of the mission.

Commercial Partner:

Boeing Phantom Works



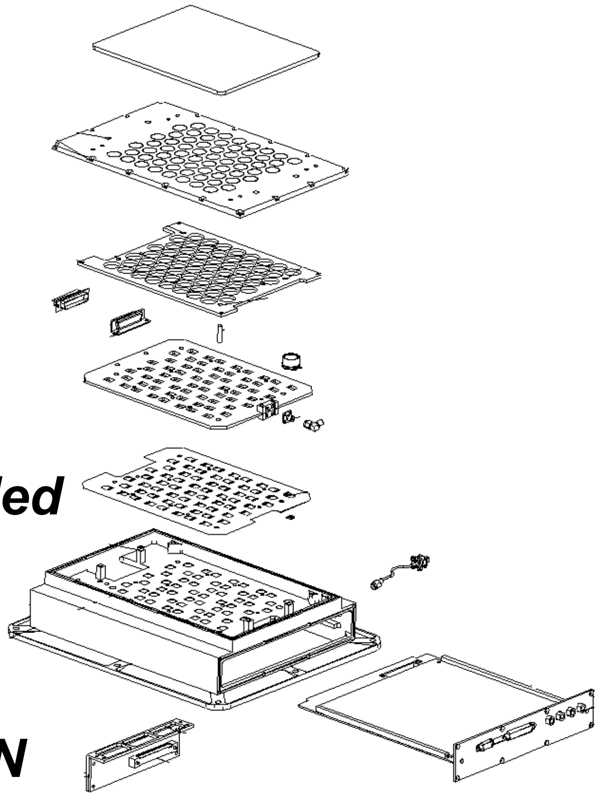
Benefits to Future Missions:

Future Earth Science missions will produce tera-bit daily data streams. The Phase Array antenna technology will enable:

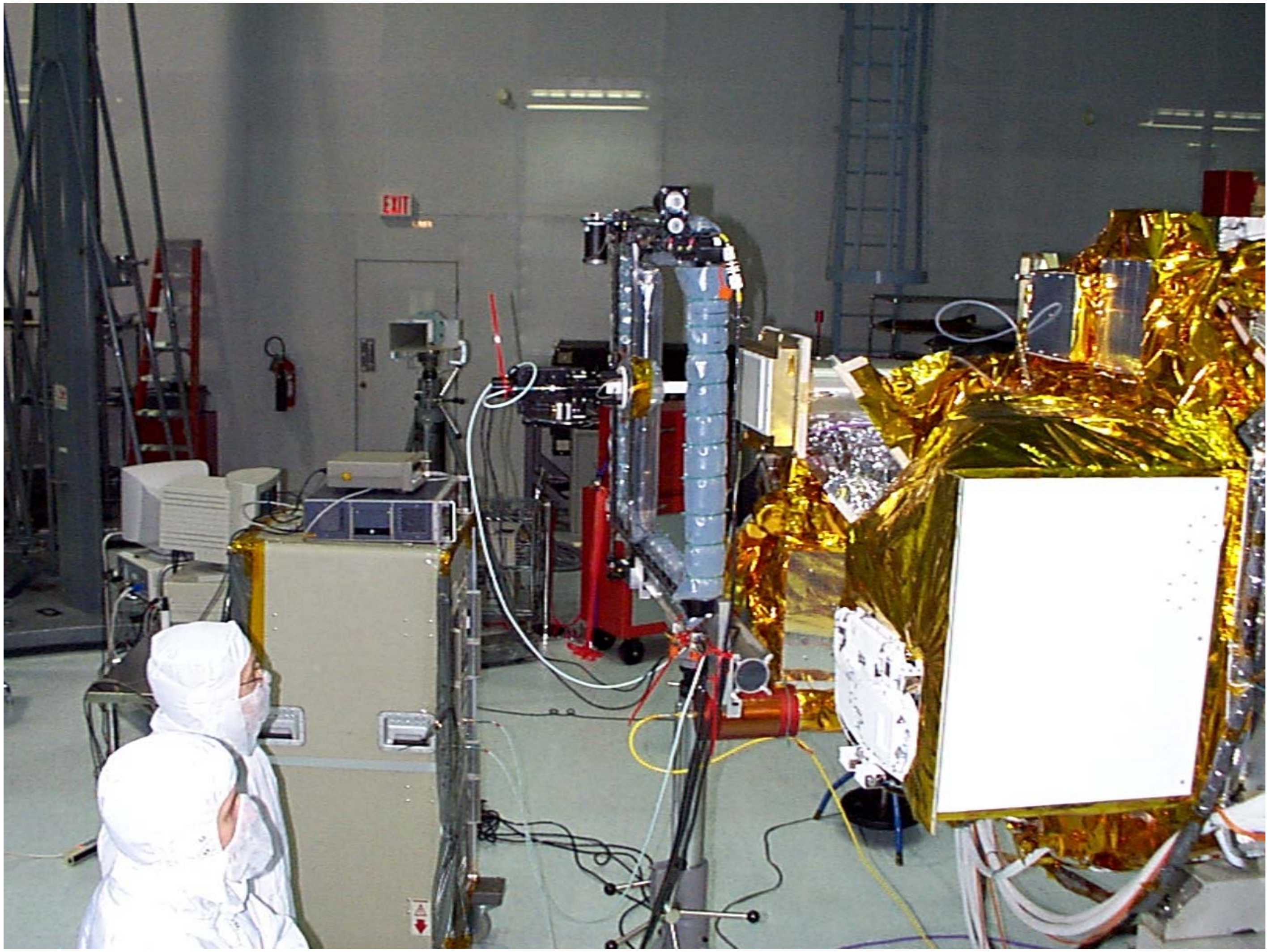
- *Lower cost, weight and higher performance science downlinks*
- *Lower cost and size ground stations*
- *More flexible operations*

XPAA Performance Summary

- ***Frequency - 8225 MHz***
- ***Bandwidth - 400 MHz***
- ***Scan Coverage - 60 deg half-angle cone***
- ***Radiating Elements - 64***
- ***RF Input - 14 dBm***
- ***EIRP - greater than 22 dBW at all commanded angles***
- ***Polarization - LHCP***
- ***Command Interface / Controller - 1773 / RSN***
- ***Input DC Power - <58 watts over 0 to 40 C***
- ***Mass - 5.5 kg***



NF Scanner in Position in Front of the XPAA During Near Field Test #3



XPAA Pattern Comparison

Comparison of NF3 Cut and Boeing Anechoic Chamber Cut for XPAA Pointed to Theta=00, Phi=000

Black = Boeing Data, Red = NF3 Data

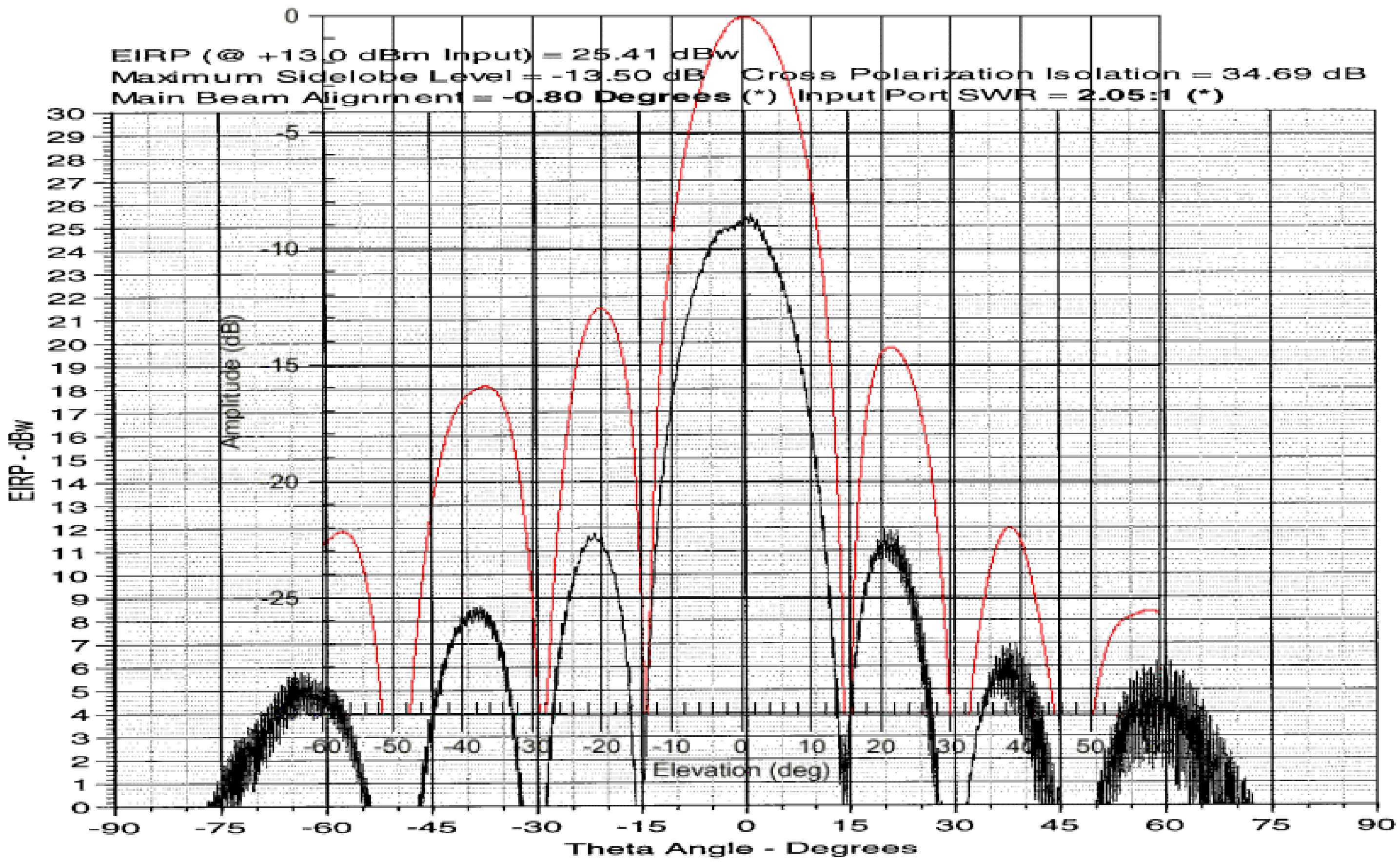
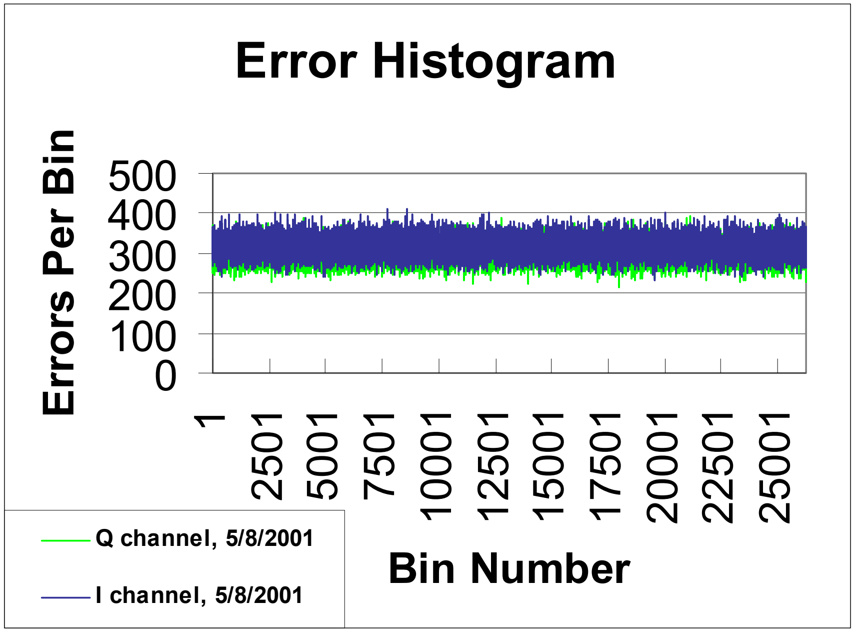
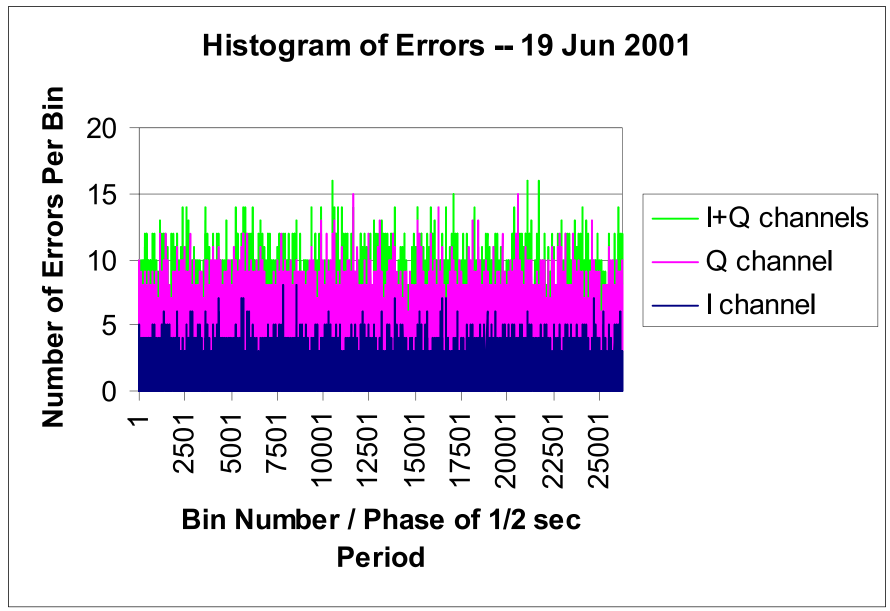


Figure 3 XPAA EIRP Radiation Pattern Performance - Frequency = 8.225 GHz, Scan Angle (theta, phi) = (0, 0), Phi = 0 - 180 Degree Plane Pattern Cut
(*) - Fails Specification Limit

XPAA Burst Error Evaluation



- ***XPAA downlinks are generally error-free. Error evaluations are made by deliberately degrading the downlink signal-to-noise ratio.***



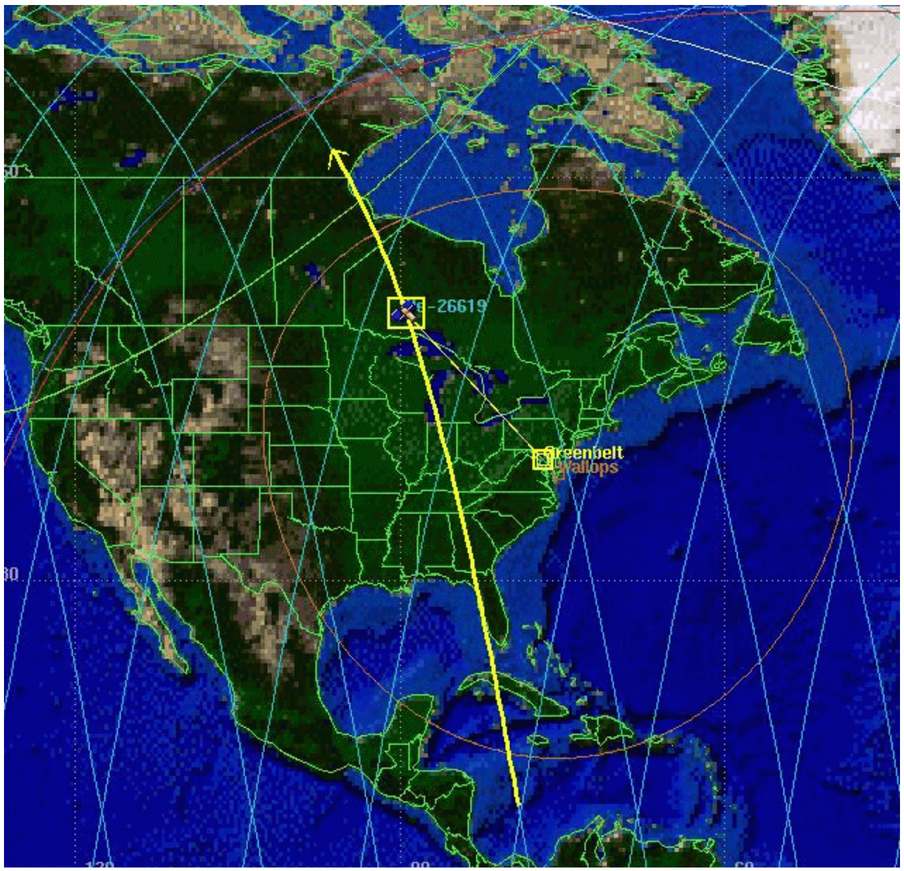
- ***No correlation found between electronic scanning of the antenna and downlink error performance.***

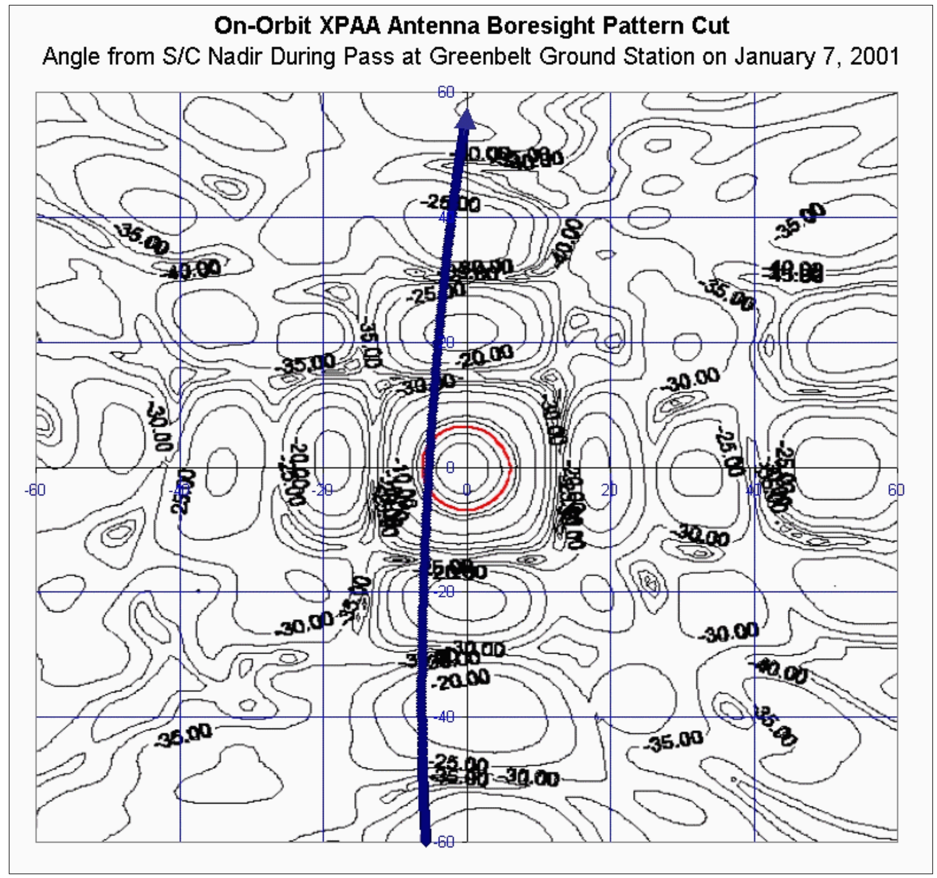
Earth Observing-1

XPAA Downlink Antenna Pattern

June 4, 2002

The EO-1 XPAA antenna pattern was evaluated by fixing the beam in a nadir-pointing mode and allowing the satellite to be program tracked from GGS.





XPAA Summary / Conclusions

- ***This technology was shown to be fully space qualifiable, and compatible with GSFC integration and test practices.***

- ***By all measures made , the XPAA has performed flawlessly. All tests show a consistent performance throughout the life cycle of the antenna.***

- ***EO-1 has verified that phased arrays are reliable and compatible with the NASA ground network.***

- ***The XPAA was designed to meet a requirement of delivering 40 Gigabits per day to the ground.***
  - ***The EO-1 project is currently receiving 160+ Gigabits of data per day via the X-band system.***
  - ***XPAA cycled 2x original requirement 7-8 passes avg vs 3-4 baseline operational scenario.***

Wideband Advanced Recorder / Processor (WARP)

Wideband Advanced Recorder Processor (WARP)

Technology Enabler

Description:

High Rate (up to 840Mbps capability), high density (48Gbit storage), low weight (less than 25.0 Kg) Solid State Recorder/Processor with X-band modulation capability.

Utilizes advanced integrated integrated circuit packaging (3D stacked memory devices) and “chip on board” bonding techniques to obtain extremely high density memory storage per board (24Gbits/memory card)

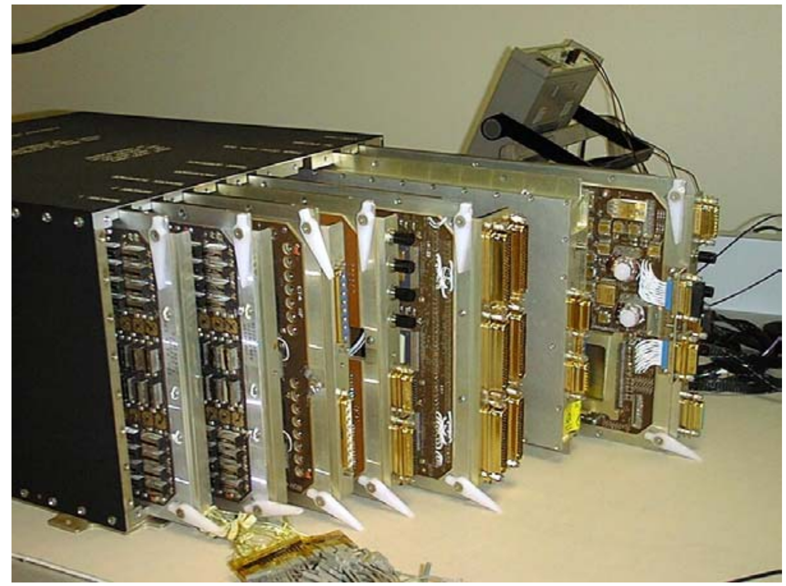
Includes high capacity Mongoose 5 processor which can perform on-orbit data collection, compression and processing of land image scenes.

Validation:

The WARP is required to store and transmit back science image files for the AC, ALI and Hyperion.

Partner:

Northrup Grumman



Benefits to Future Missions:

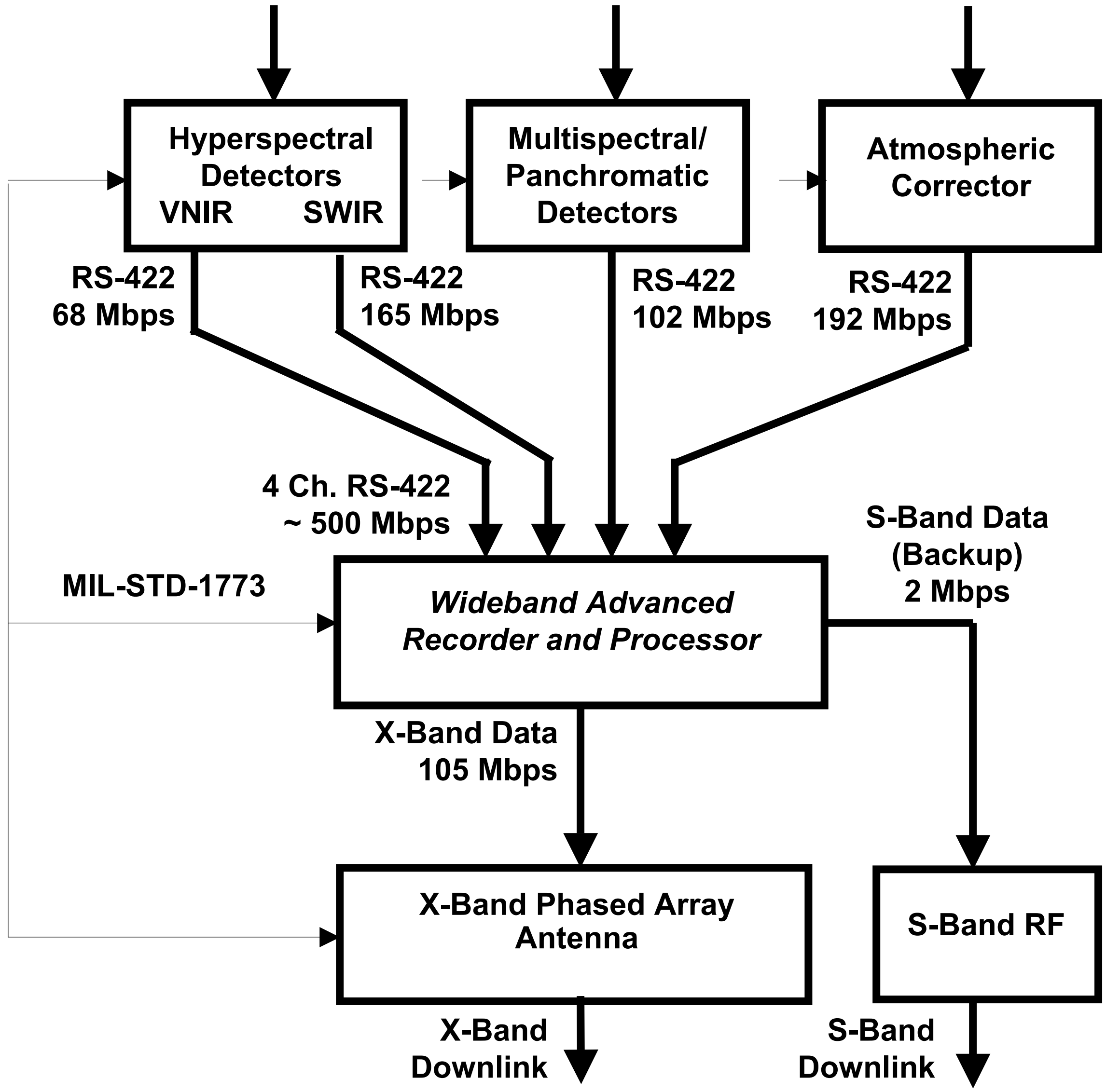
The WARP flight-validated a number of high density electronic board advanced packaging techniques and will provide the highest rate solid state recorder NASA has ever flown.

Its basic architecture and underlying technologies will be required for future earth imaging missions which need to collect, store and process high rate land imaging data.

Top-Level Specifications

- ***Data Storage:*** ***48 Gbits***
- ***Data Record Rate:*** ***> 1 Gbps Burst***
  900 Mbps Continuous (6 times faster than L7 SSR)
- ***Data Playback Rate:*** ***105 Mbps X-Band (with built-in RF modulator)***
  2 Mbps S-Band
- ***Data Processing:*** ***Post-Record Data Processing Capability***
- ***Size:*** ***25 x 39 x 37 cm***
- ***Mass:*** ***22 kg***
- ***Power:*** ***38 W Orbital Average., 87 W Peak***
- ***Thermal:*** ***15 - 40 °C Minimum Operating Range***
- ***Mission Life:*** ***1 Year Minimum, 1999 Launch***
- ***Radiation:*** ***15 krad Minimum Total Dose, LET 35 MeV***

EO-1 Flight Data System Architecture



Critical Technologies
(EDAC/HS Encoder/Decoder)

- ***Technology Description***
  - *Error Detection & Correction Chip*
  - *Reed-Solomon Encoder/Decoder*
  - *500 Mbytes per second*
  - *Total Dose 1 x 10E6 Rads*
- ***Technology Validation***
  - *First Flight*
  - *Flawless Operation*
- ***Technology Usage***
  - *Bulk DRAM Error Handling*
- ***Technology Transfer***
  - *Honeywell CMOS Gate Array HX2160*
  - *University of New Mexico: 505-272-7040*

Critical Technologies
(Chip On Board Packaging)

- **Technology Description**
  - Original Goal was Flip-Chip technology
  - Back-Up was wire-bond technology
  - Die adhered directly to board
- **Technology Validation**
  - Flawless Operation on–orbit
  - Severe handling constraints and risk
  - Time Consuming Manufacturing
  - Quality Assurance Concerns
- **Technology Usage**
  - Memory Board Logic
  - Significant Increase in Packaging Density
- **Technology Transfer**
  - Wire-Bonding to boards not recommended

Industry Solid State Recorder Technology

SEAKR QuickBird, JPL/Ball QuickScat

Data Storage:	***618 Gbits***
Data Record Rate:	***6 channels @ 800 Mbps each***
Size:	***2 boxes, each 25x51x28 cm***
Mass:	***2 boxes, each 41 kg***
Power:	***240 W***
Thermal:	***0-40 °C***
Redundancy:	***LVPC and Control Cards***
Radiation :	***40 krad total dose, LET 80 MeV***

WARPSummary / Conclusions

1) ***High Performance Data Compression (nearly lossless) is essential if the science community demands full spatial coverage, wide spectral coverage, high pixel resolution raw data. Otherwise, the size, mass, and power will be prohibitive.***

2) ***New technologies must be developed prior to flight projects (IR&D mode) to avoid schedule delays.***

3) ***The flight data systems that are required to handle extremely high data rates require significant development time. Therefore, their development should begin early, when the instrument development begins.***

Pulse Plasma Thruster (PPT)

Pulse Plasma Thruster (PPT)

Technology Need:

Increased payload mass fraction and precision attitude control

Description:

The Pulse Plasma Thruster is a small, self contained electromagnetic propulsion system which uses solid Teflon propellant to deliver high specific impulses (900-1200sec), very low impulse bits (10-1000uN-s) at low power.

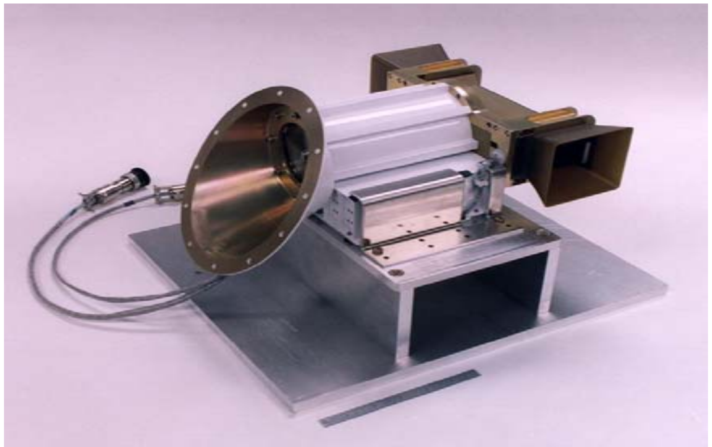
Advantages of this approach include:

- *Ideal candidate for a low mass precision attitude control device.*
- *Replacement of reaction control wheels and other momentum unloading devices. Increase in science payload mass fraction.*
- *Avoids safety and sloshing concerns for conventional liquid propellants*

Validation:

The PPT was substituted (in place of a reaction wheel) during the later phase of the mission. Validation included:

- *Demonstration of the PPT to provide precision pointing accuracy, response and stability.*
- *Confirmation of benign plume and EMI effects*



Benefits to Future Missions:

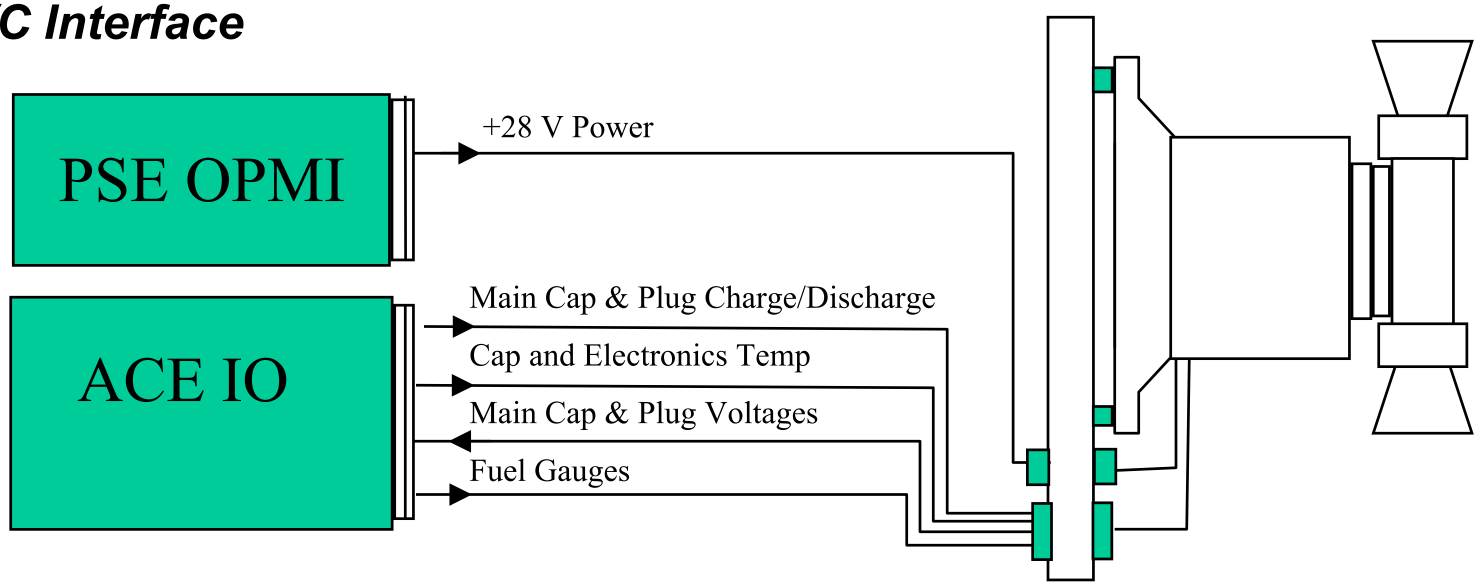
The PPT offers new lower mass and cost options for fine precision attitude control for new space or earth science missions

Partners

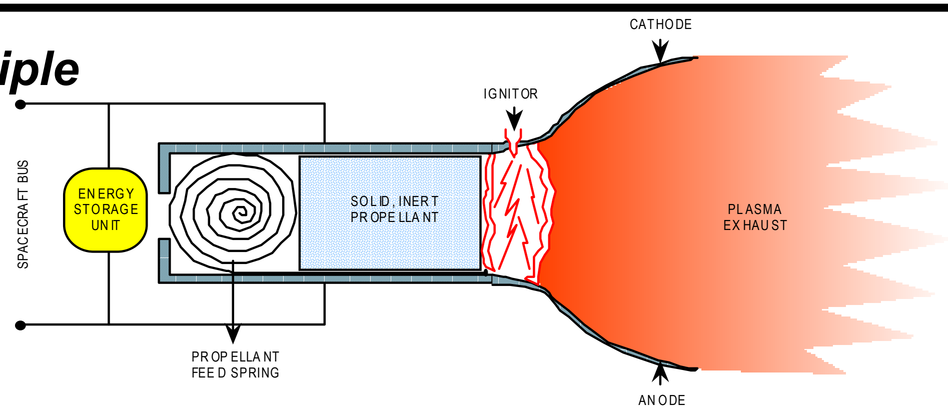
LeRC, Primex, GSFC

PPT Design

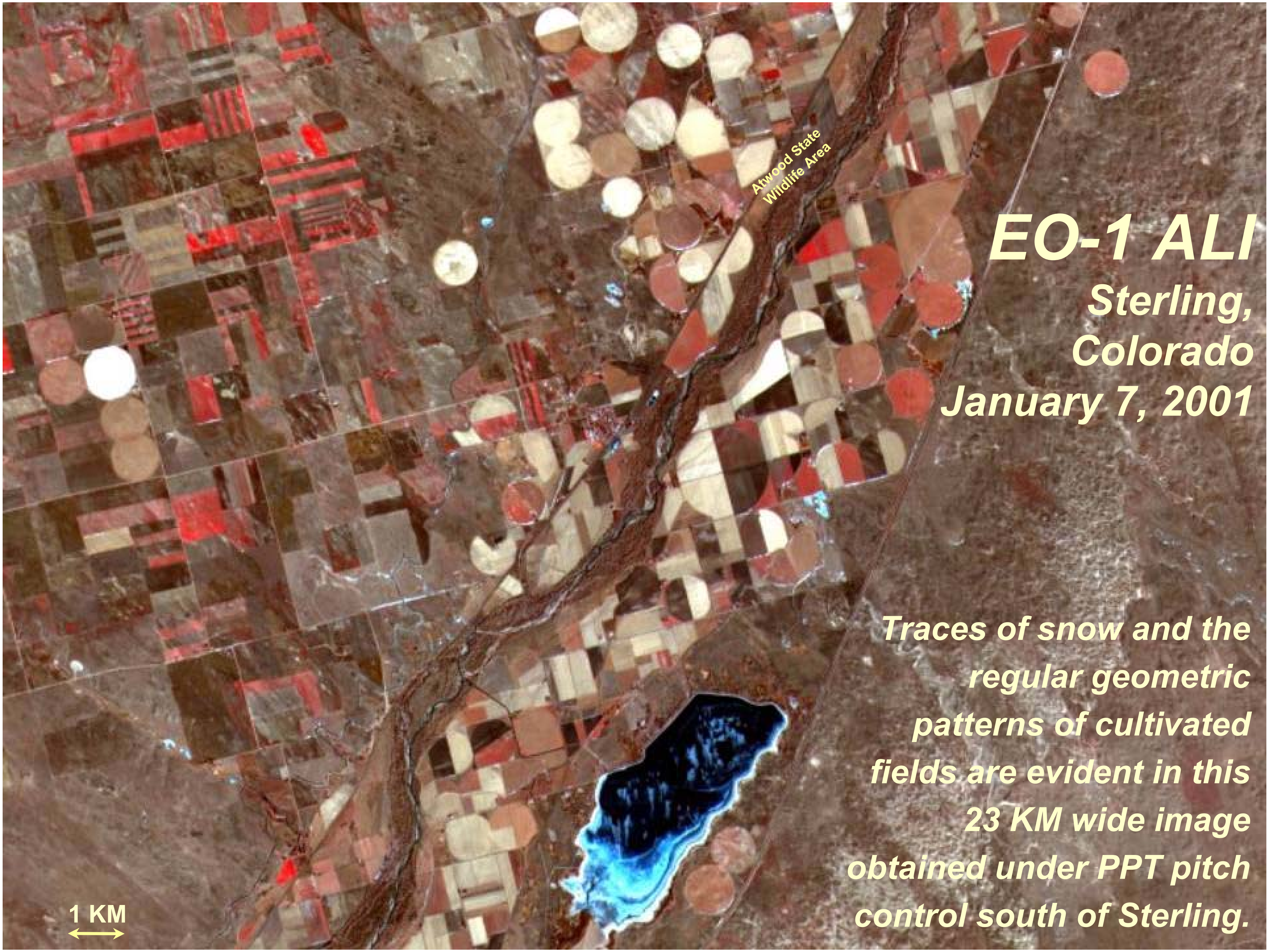
S/C Interface



Technology Principle



ABLATION → IONIZATION → ACCELERATION


Atwood State
Wildlife Area
EO-1 ALI
Sterling,
Colorado
January 7, 2001
Traces of snow and the
regular geometric
patterns of cultivated
fields are evident in this
23 KM wide image
obtained under PPT pitch
control south of Sterling.
1 KM

Carbon-Carbon Radiator (CCR)

Carbon-Carbon Radiator

Technology Need:

Increase instrument payload mass fraction.

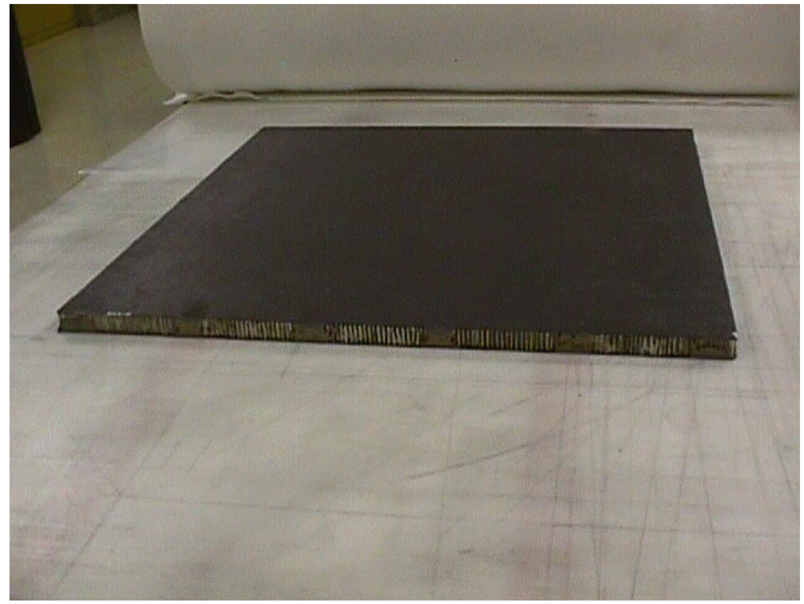
Description:

Carbon-Carbon is a special composite material that uses pure carbon for both the fiber and matrix. The NMP Earth Orbiter – 1 mission will be the first use of this material in a primary structure, serving as both an advanced thermal radiator and a load bearing structure Advantages of Carbon-Carbon include:

– *High thermal conductivity including through thickness*
– *Good strength and weight characteristics*

Validation:

EO-1 validated the Carbon-Carbon Radiator by replacing one of six aluminum 22" x27" panels with one constructed using the C-C composite materials. Mechanical and thermal properties of the panels will be measured and trended during environmental testing and on-orbit.



Benefits to Future Missions:

This technology offers significant weight reductions over conventional aluminum structures allowing increased science payload mass fractions for Earth Science Missions. Higher thermal conductivity of C-C allows for more space efficient radiator designs.

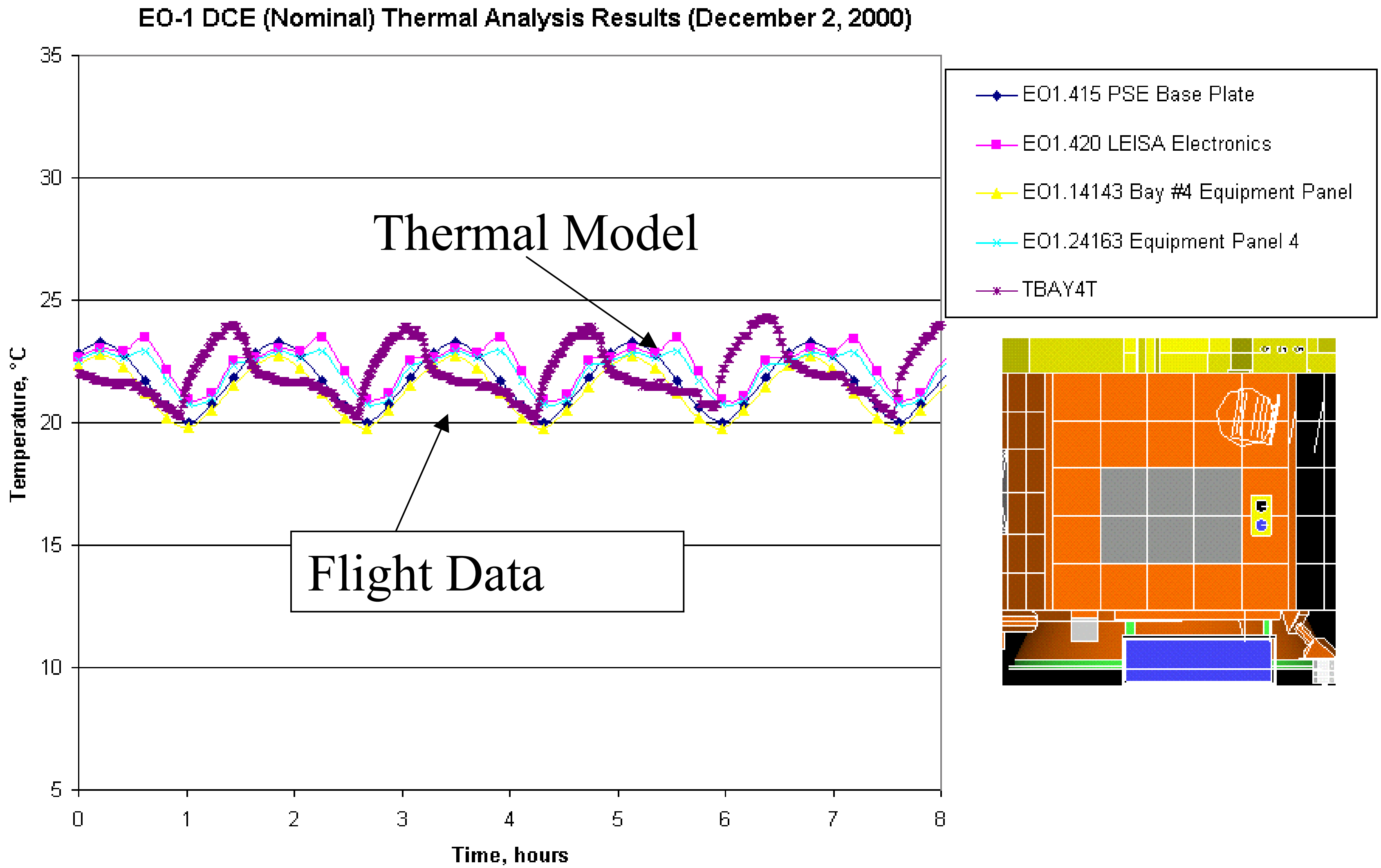
Partners

CSRP (consortium)

Performance Required

- ***Mass - Less than 2.5 kg***
- ***Stiffness - First mode frequency greater than 100 Hz when hard-mounted to the S/C***
- ***Strength - Inertial loading***
  - ***Simultaneous quasi-static limit and S/C interface loads***
    - *15 g acceleration in any direction*
    - *Shear load of 16,100 N/m*
    - *Edge normal load of 19,500 N/m*
    - *Panel normal load of 1,850 N/m*
  - ***Maximum fastener forces at the S/C attachment points***
    - *Maximum tension force of 25 N*
    - *Maximum shear force normal to panel edge of 135 N*
    - *Maximum shear force parallel to panel edge of 115 N*
- ***Strength - Thermal loading***
  - ***On-orbit temperature variations ranging from -20°C to +60°C***

EO-1 DCE Thermal Analysis Results



CCR Technology Transfer / Lessons Learned

- ***C-C Radiator technology was successfully validated***
  - *C-C radiator panels can be used to reduce S/C weight*
  - *They can also be used as part of the S/C structure*
- ***C-C has a niche, especially for high temperatures***
  - *Application on the Solar probe*
- ***C-C still needs further development (my opinion)***
  - *Reduction in fabrication time and cost - high conductivity "traditional" composites are competitive*
  - *CTE Interface issues with heat pipes*
- ***Redundancy a good idea - we flew the spare panel***
- ***Possible follow-on missions: C-C foam for low CTE mirrors/optical benches***

CCR Summary

- ***CSRP was a success - informal inter-agency partnership***
  - ***Thanks to all who contributed - this was a fun job***
- ***CSRP no longer in business, but manufacturers of Carbon-Carbon are still operating, i.e. B.F. Goodrich, Amoco***
- ***Thanks to EO-1 project and Swales for this opportunity***

Lightweight Flexible Solar Array (LFSA)

Lightweight Flexible Solar Array (LFSA)

Technology Need:

Increase payload mass fraction.

Description:

The LFSA is a lightweight photovoltaic(PV) solar array which uses thin film CuInSe2 solar cells and shaped memory hinges for deployment. Chief advantages of this technology are:

– *Greater than 100Watt/kg specific energies compared to conventional Si/GaAs array which average 20-40 Watts/kg.*

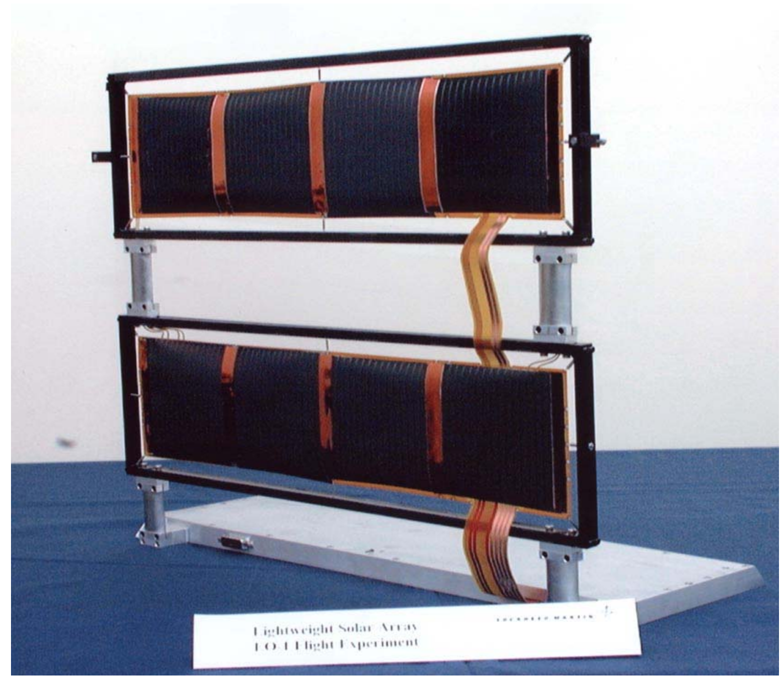
– *Simple shockless deployment mechanism eliminates the need for more complex mechanical solar array deployment systems. Avoids harsh shock to delicate instruments.*

Validation:

The LFSA deployment mechanism and power output was measured on-orbit to determine its ability to withstand long term exposure to radiation, thermal environment and degradation due to exposure to Atomic Oxygen.

Partners

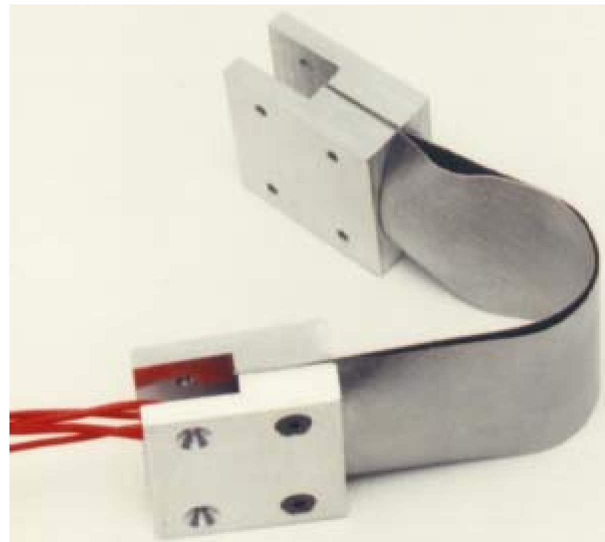
Phillips Lab, Lockheed Martin Corp



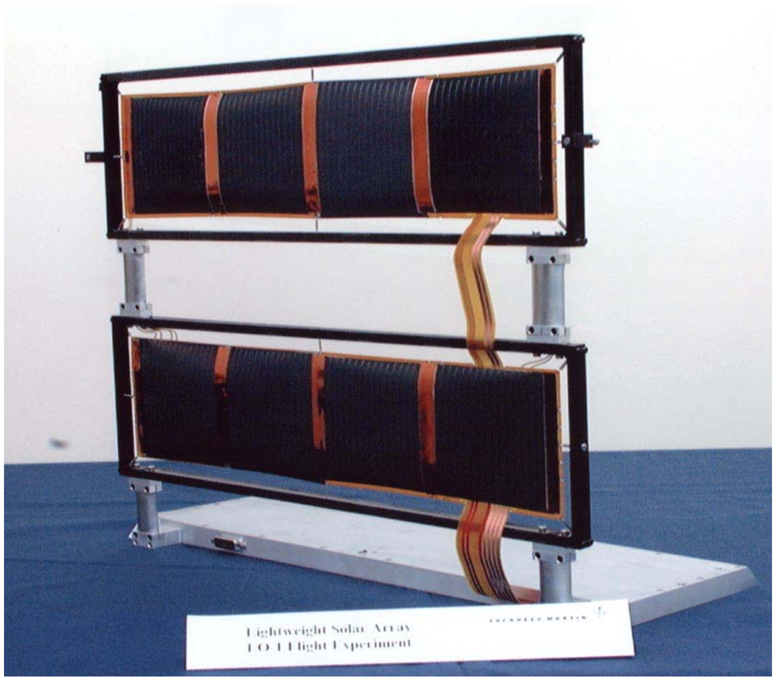
Benefits to Future Missions:

This technology provides much higher power to weight ratios (specific energy) which will enable future missions to increase science payload mass fraction.

Description *(continued)*



SMA - STOWED

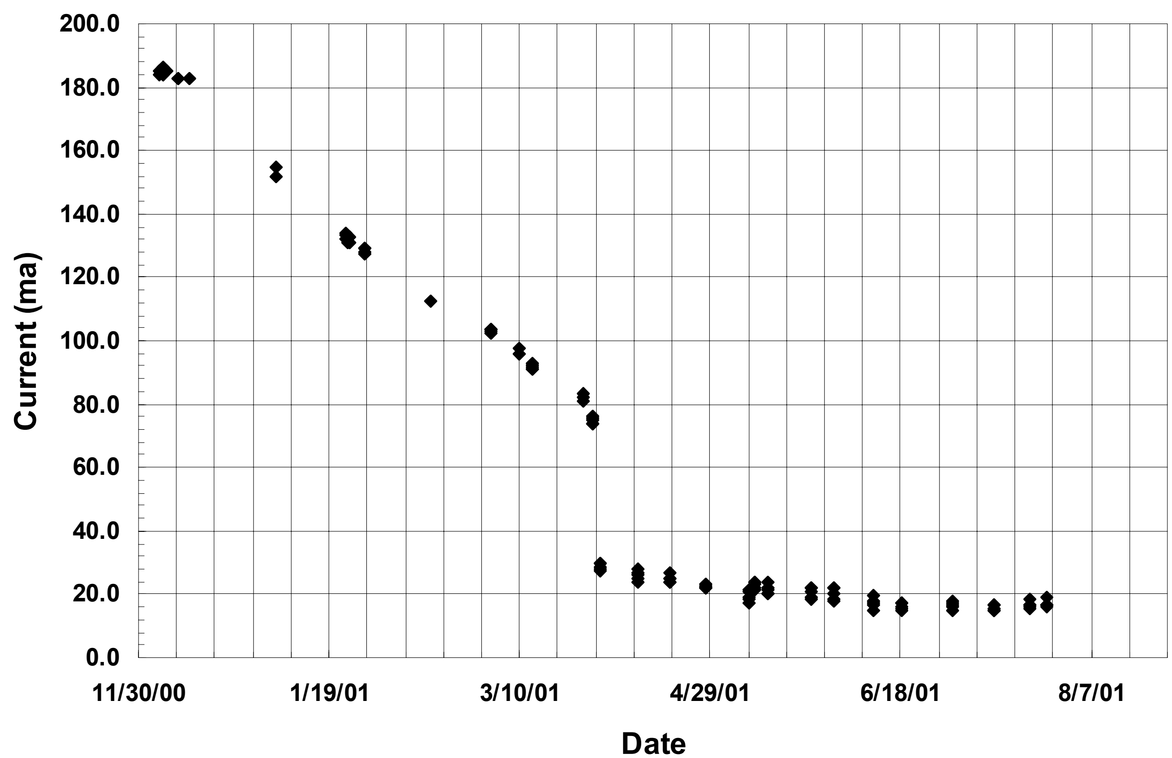


LFSA FLIGHT UNIT

SMA - DEPLOYED

LFSA On-Orbit Performance

- ***Initial current output consistent with ground module measurements***
- ***Anomalous degradation in current output was observed***
- ***Step decrease in output in late March 2001***



LFSA On-Orbit Performance

- ***Rapid thermal cycling was initiated at Lockheed Martin to attempt to duplicate on-orbit performance***
- ***Tests in progress. Early results indicate degradation in solder joints between CIS and flex harness used to carry current from the cells to LFSA measurement electronics.***

LFSA On-Orbit Performance Conclusions

- ***Work needed in developing a good solder joint between CIS and harness.***
- ***Further development is needed on CIS solar cells to increase efficiency of large-area modules (small cells at approximately 7% AM0 efficiency).***
- ***In meantime, amorphous silicon (approximately 9% AM0 efficiency) is the most mature thin-film solar cell technology. Can be used with LFSA concept.***

LFSA Summary

- ***The EO-1 LFSA experiment demonstrated critical technologies associated with future light weight solar array development***
- ***Flight qualification data and methodology provides the basis for future array builds***
- ***Leveraging LSA and DUST programs to fabricate primary power sources for Sport and Encounter spacecraft***