Optimizing Satellite Communication With Adaptive and Phased Array Antennas

Mary Ann Ingram, Robert Romanofsky, Richard Q. Lee, Felix Miranda, Zoya Popovic, John Langley, William C. Barott, M. Usman Ahmed, Dan Mandl

Goddard Space Flight Center

GRC GLENN RESEARCH CENTER at Lewis Field

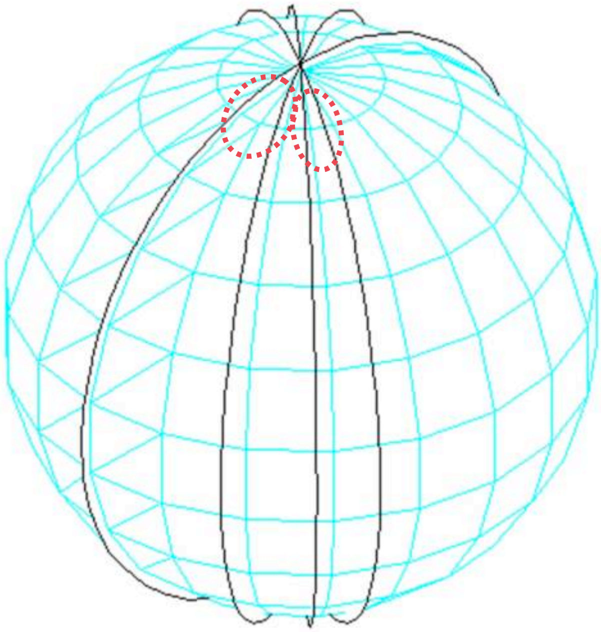
Georgia Institute of Technology

Smart Antenna Research Laboratory

John Langley
Half Moon Bay, CA
jlangley@saquishgrp.com
June 30, 04

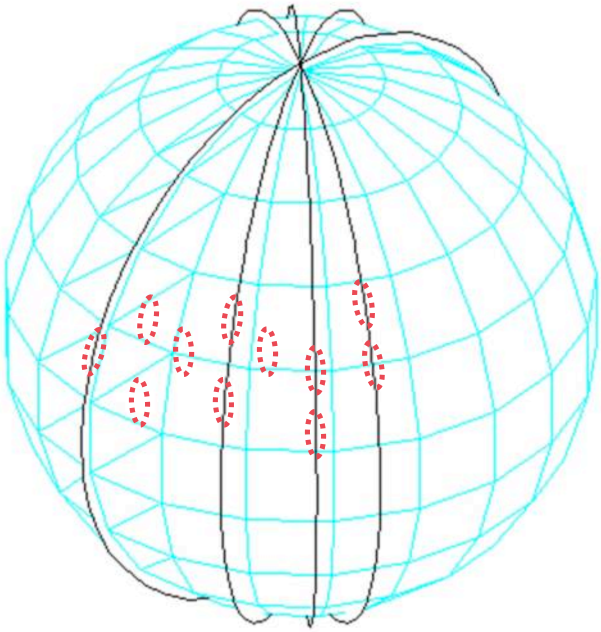
Background

- **Satellites with Earth Science missions are in low-altitude, polar orbits**
- **Cost of past ground node designs has allowed only a small number of ground nodes**
  - Ground nodes must be located at high latitudes to maximize satellite visibility
  - High latitude locations often have inhospitable climatic conditions



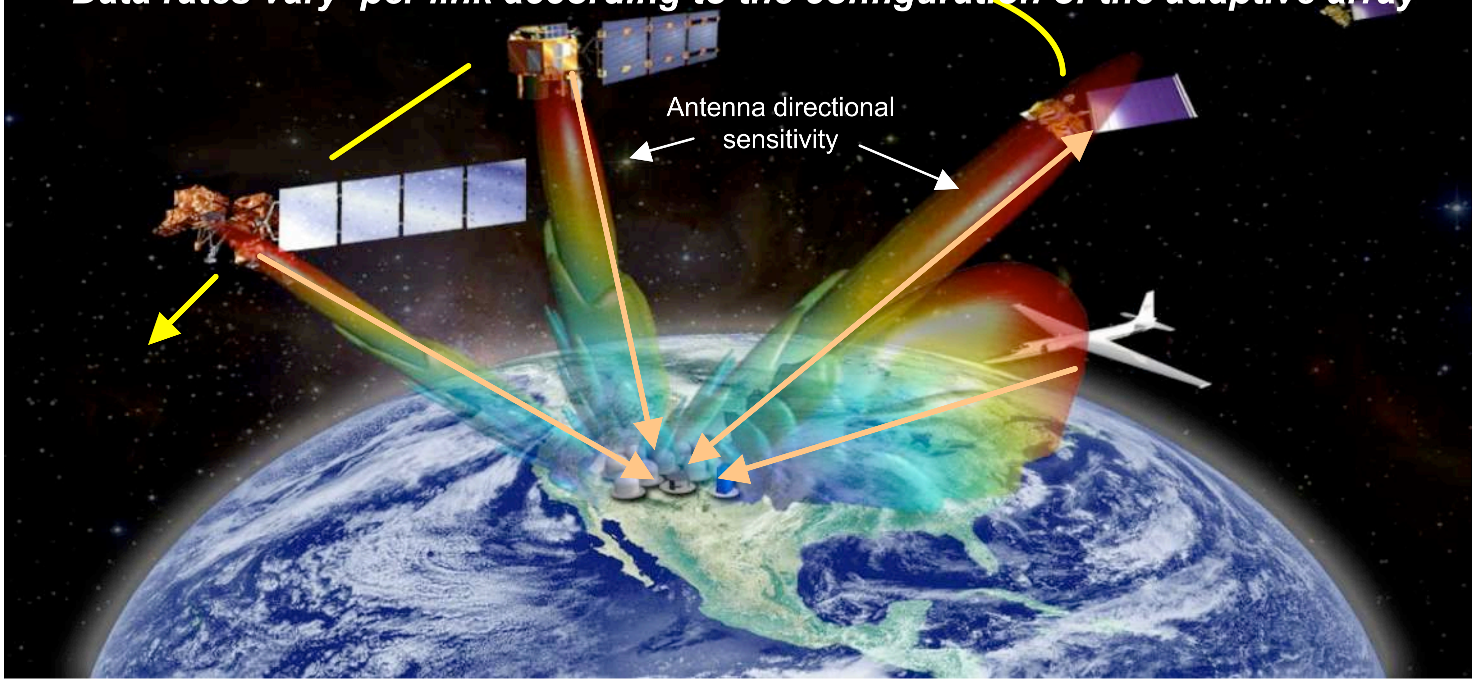
A New Approach to LEO Ground Nodes

- **Many Low-cost Ground Nodes**
  - Build from adaptive arrays of small antennas
  - Electronically scanned array elements would have no moving parts
- **Network Large Number of Low-cost Ground Nodes to Provide Near-continuous Coverage**



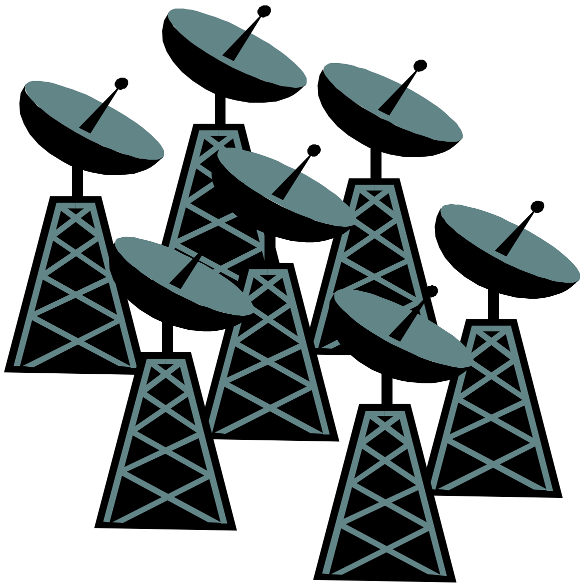
Adaptive Arrays as LEO Ground Nodes

- *Antenna patterns adjusted electronically thousands of times per second to follow users and avoid interference*
- *Array can be built out of phased array elements or conventional antenna elements*
- *Capability for multiple access on a single channel*
- *Data rates vary per link according to the configuration of the adaptive array*



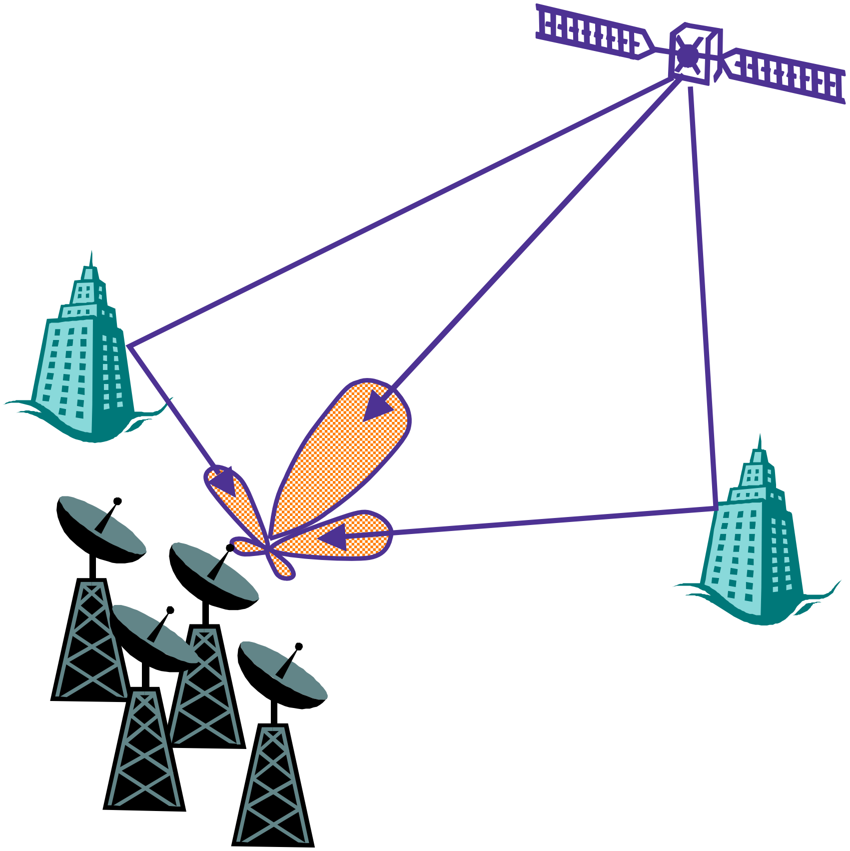
Adaptive Array Concepts

- The outputs of multiple apertures are combined coherently to provide the signal to be demodulated
- An adaptive combination algorithm changes in response to changes in the propagation environment



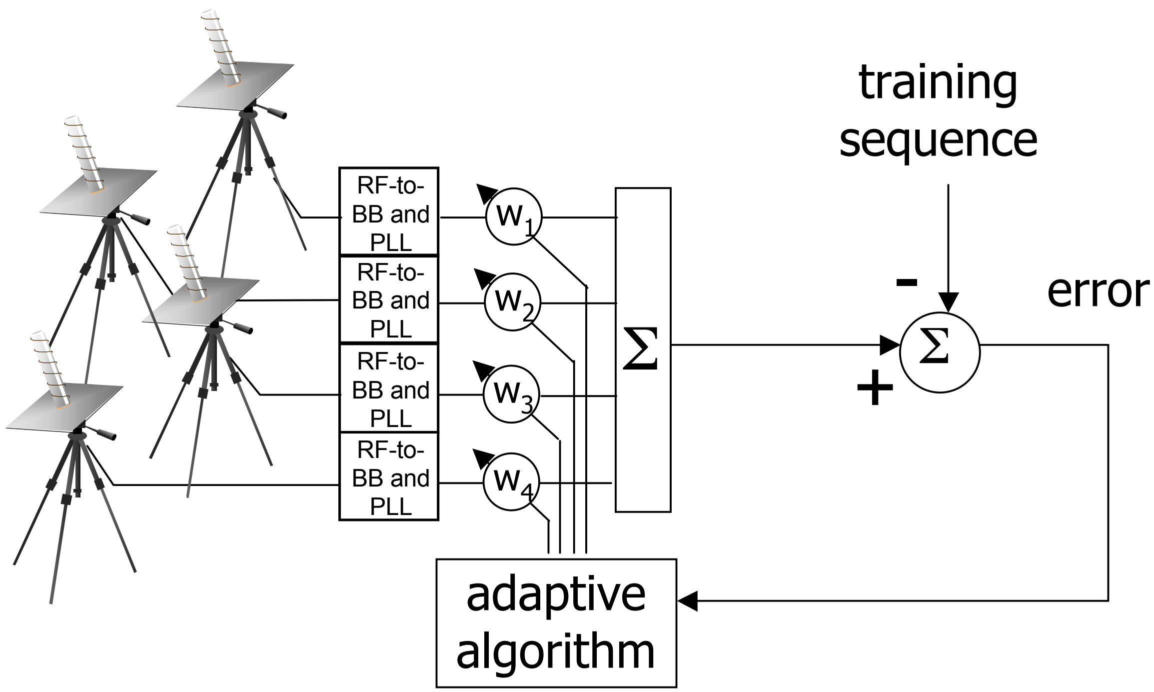
Propagation Environment

- LOS
- Multipath from terrestrial reflections
- High Doppler, but low Doppler spread
- Interference?
- Tracking errors among array elements

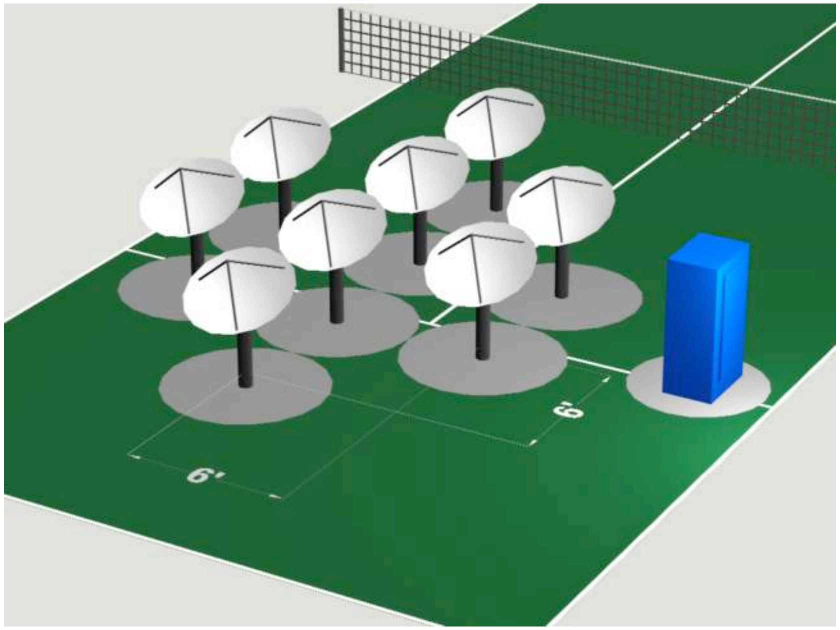


How an Adaptive Algorithm Works

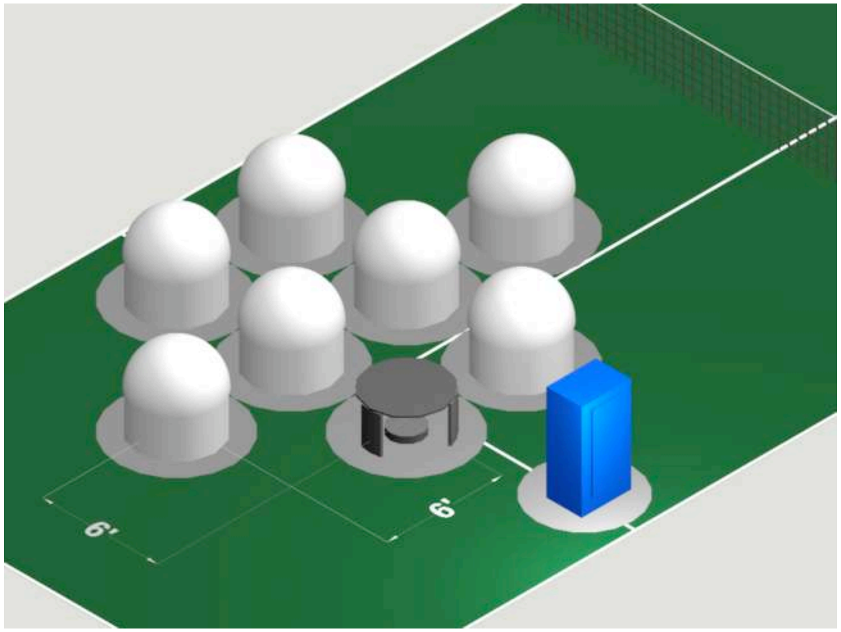
- A feedback control loop iterates on the adaptive weights 4000 times a second to try to drive the error to zero
- A training sequence is what the ideal combiner output should look like



Adaptive Array Ground Node Configurations



An Adaptive Array Composed of Eight Mechanically Scanned 1.0 Meter Parabolas

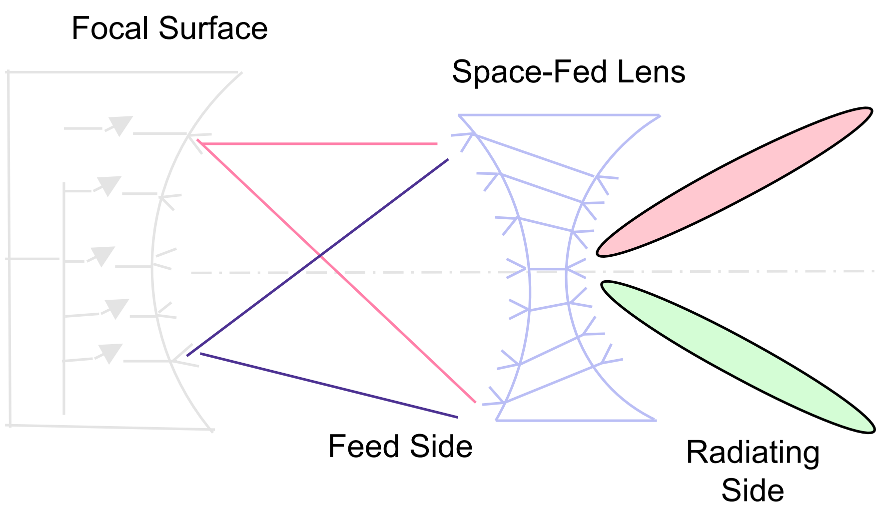


An Adaptive Array Composed of Eight Electronically Scanned 500 Element Space Fed Lens Antennas

Array Elements

- **Adaptive Arrays can be built of many types of elements**
  - The first S-band array is built of fixed elements
- **Two electronically scanned array elements are under development at Glenn Research Center for use at X-band**
  - Space Fed Lens
  - Ferroelectric Reflectarray

Space Fed Lens



Approach:

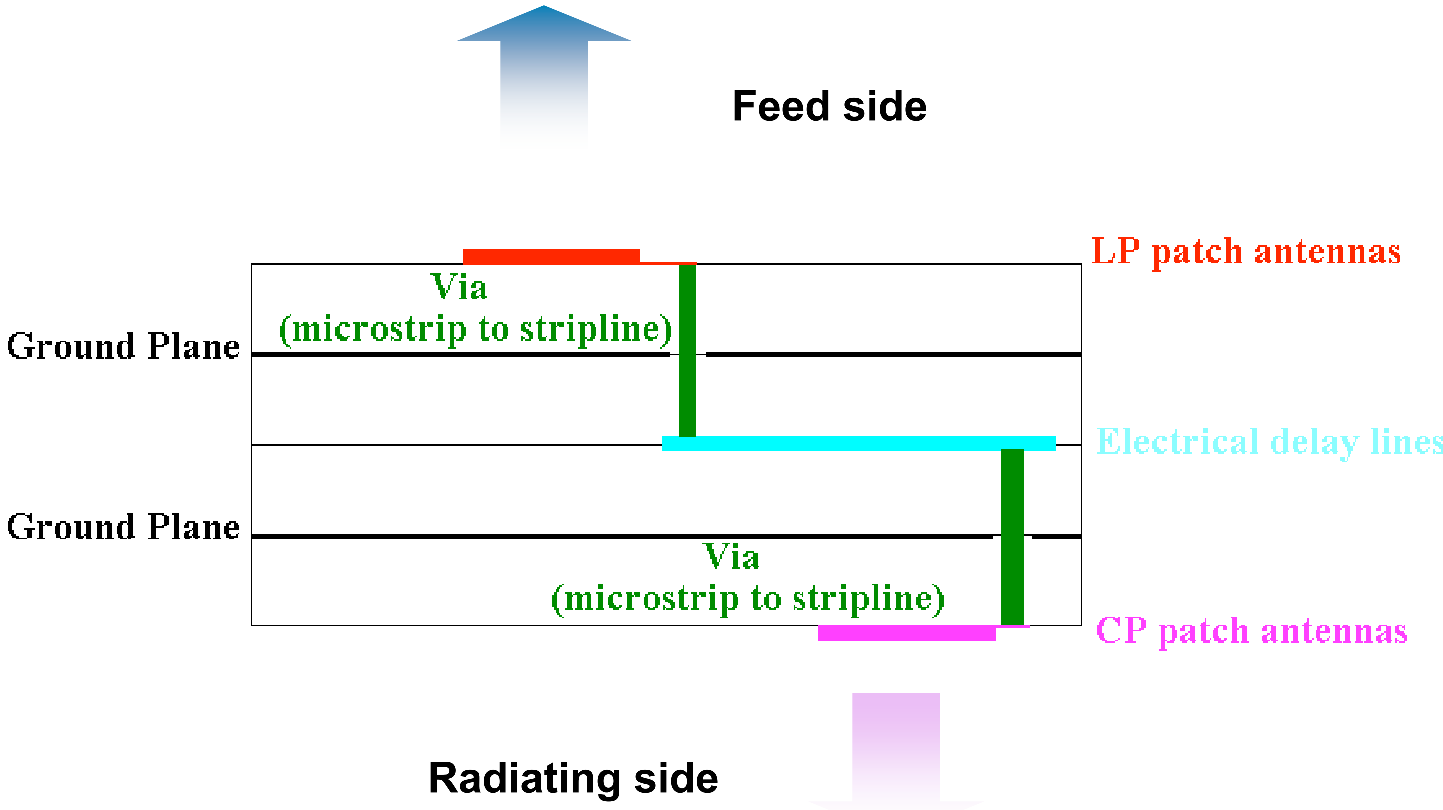
- Based on discrete lens array design.
- Switches used to achieve beam scan
- Polarization: LHCP
- Frequency: X-band
- Scan coverage: ± 55 ^{o}

What is it?

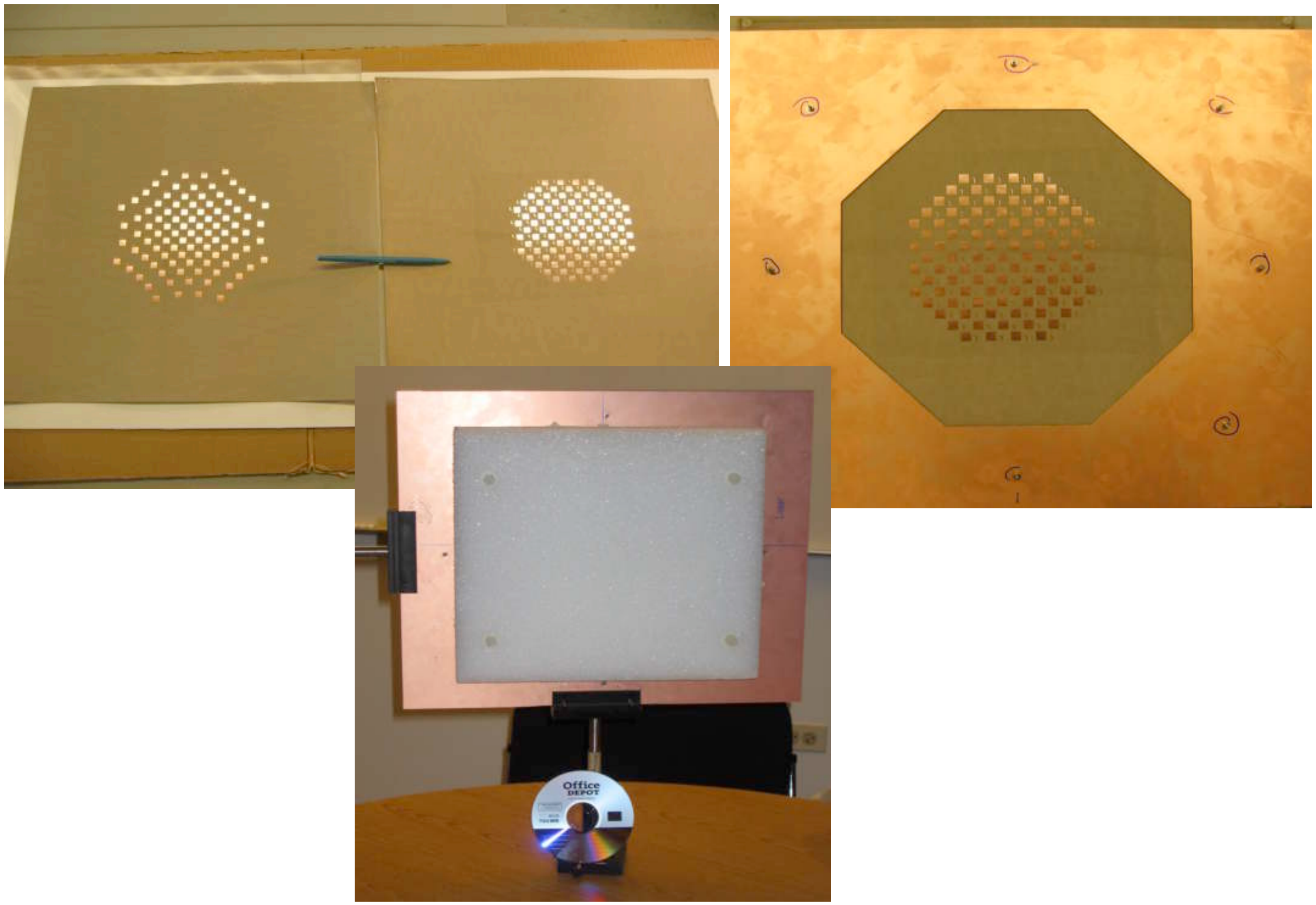
- A space-fed lens array is composed of a feed array and a radiating array with each corresponding element pair interconnected by transmission lines of different lengths to radiate a plane wave in the forward direction
- As in the case of reflector antennas, the feed array is space-fed with feeds located on a focal surface.

Unit Element and Interconnects

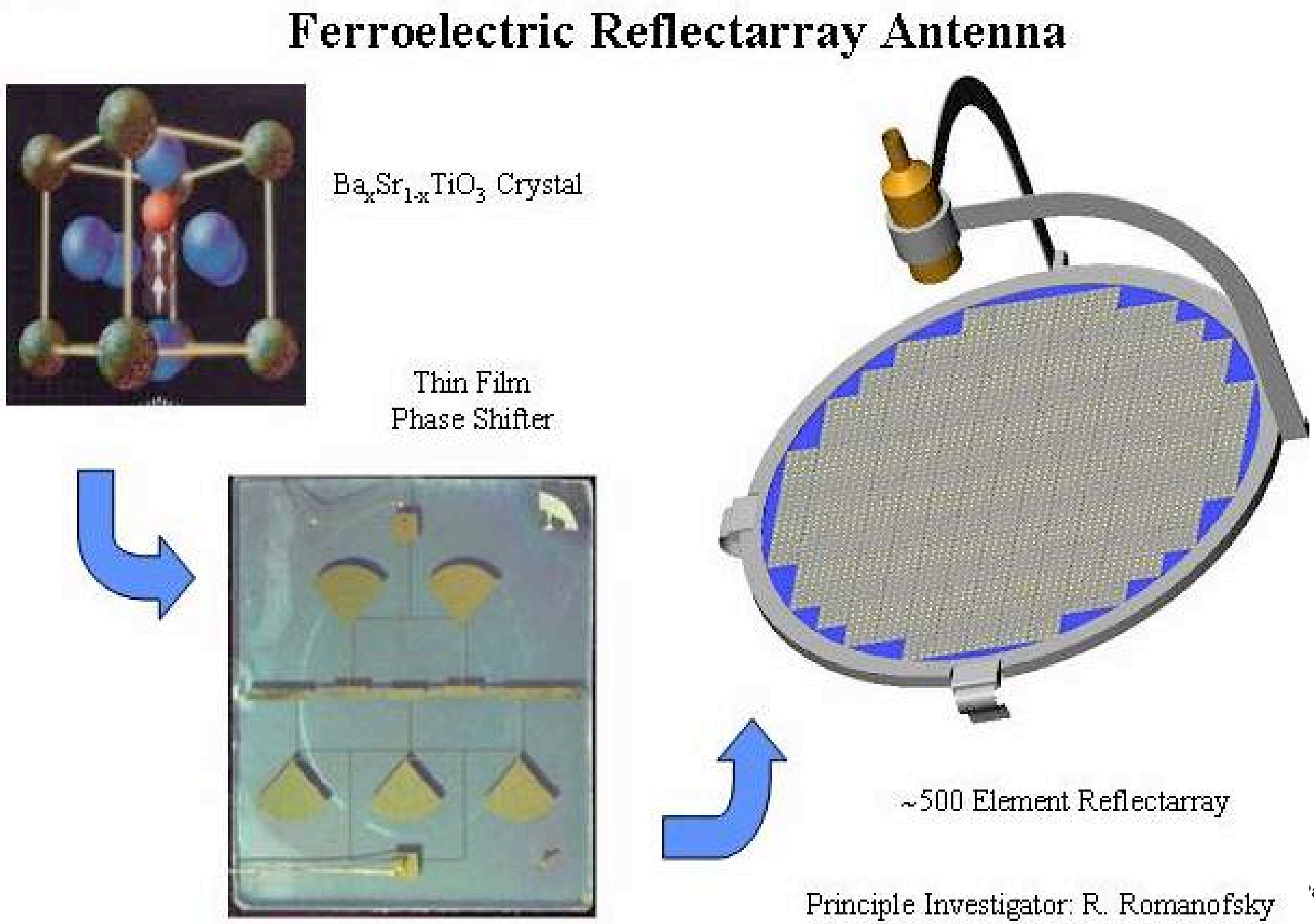
- 4 substrate layers, 2 ground planes
- Coplanar strip delay lines
- Metallized via interconnects



Different Layers of the Lens Array

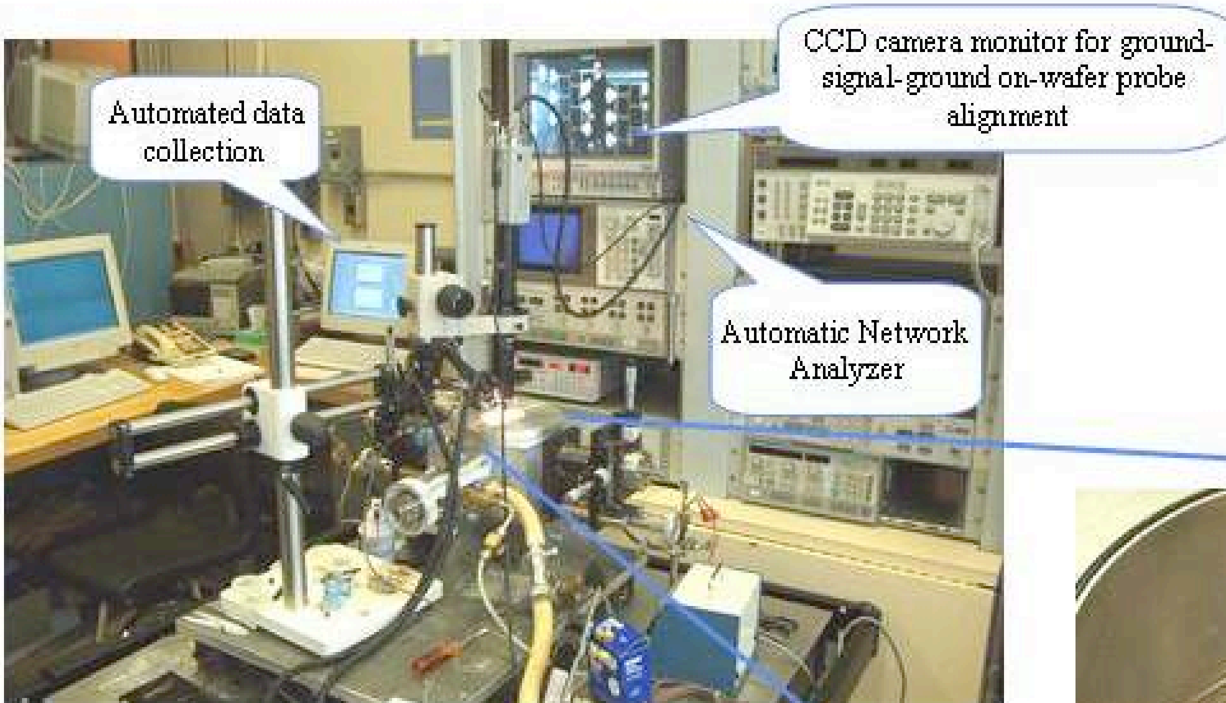


Reflectarray Front End



Reflectarray Front End Testing

Customized On-Wafer Phase Shifter Characterization Station



NASA GRC's semi-automated on-wafer probing system allows accurate characterization of ferroelectric phase shifters (S- through Ka-band.)

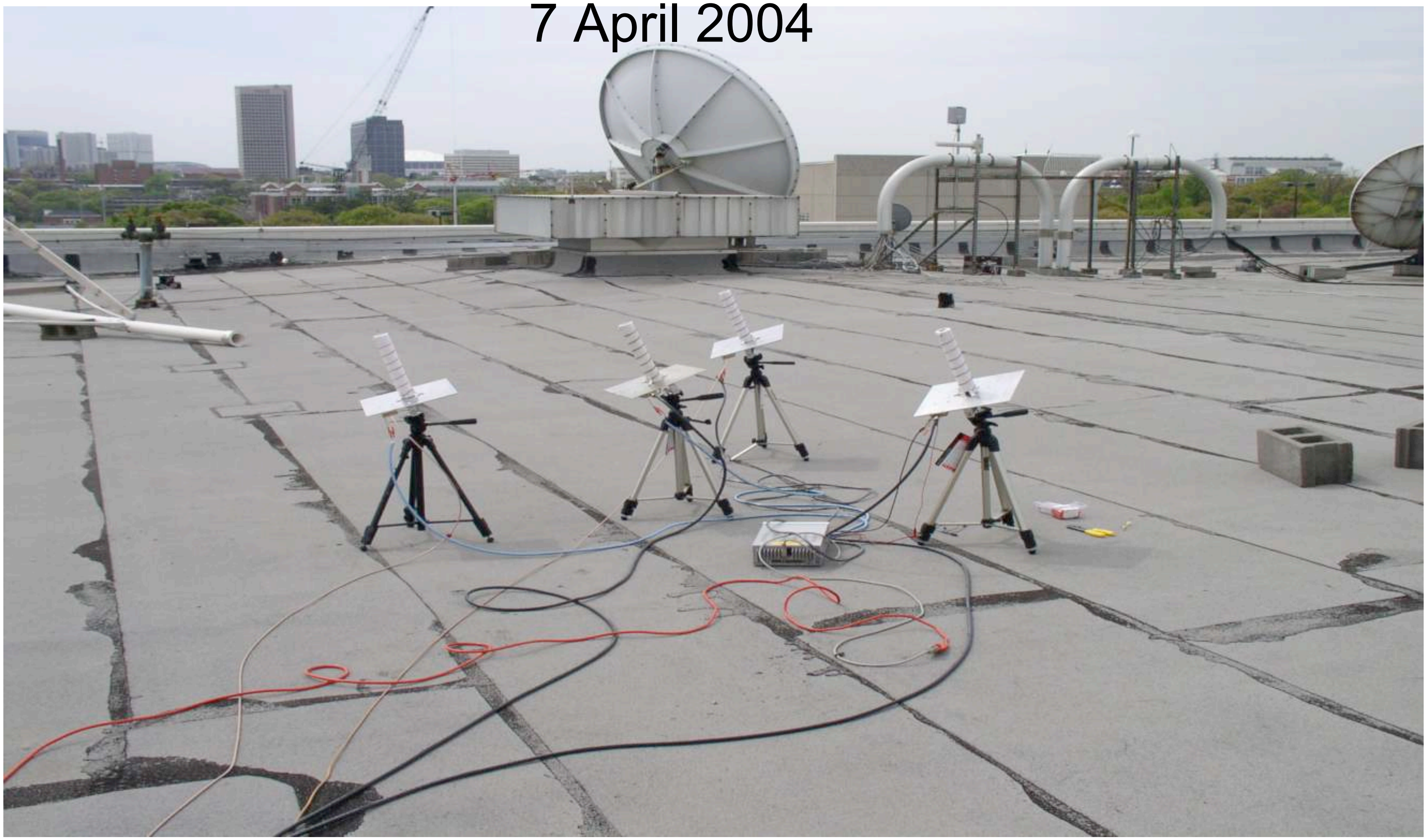
Probe Station Assembly

Adaptive Array Demonstration

- The EO-1 was scheduled to transmit 4 kbps (coded) on 7 April 2004 as it passed over Atlanta, GA
- During the pass, we recorded the signal through four channels
- Later, we performed adaptive combining of the four channels using digital signal processing

Four-Channel Recording of EO-1

7 April 2004

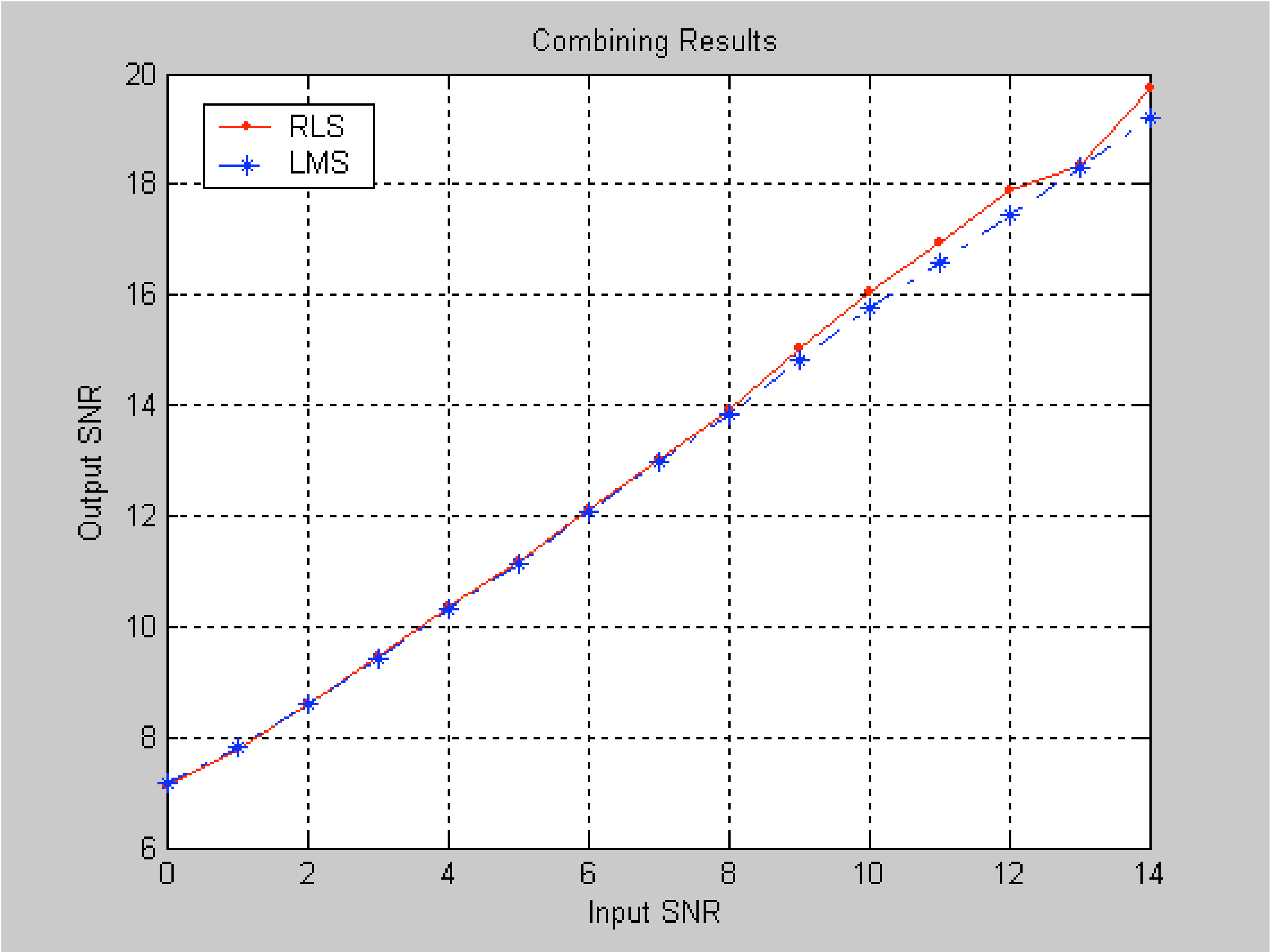


Four-Channel Reception of EO-1

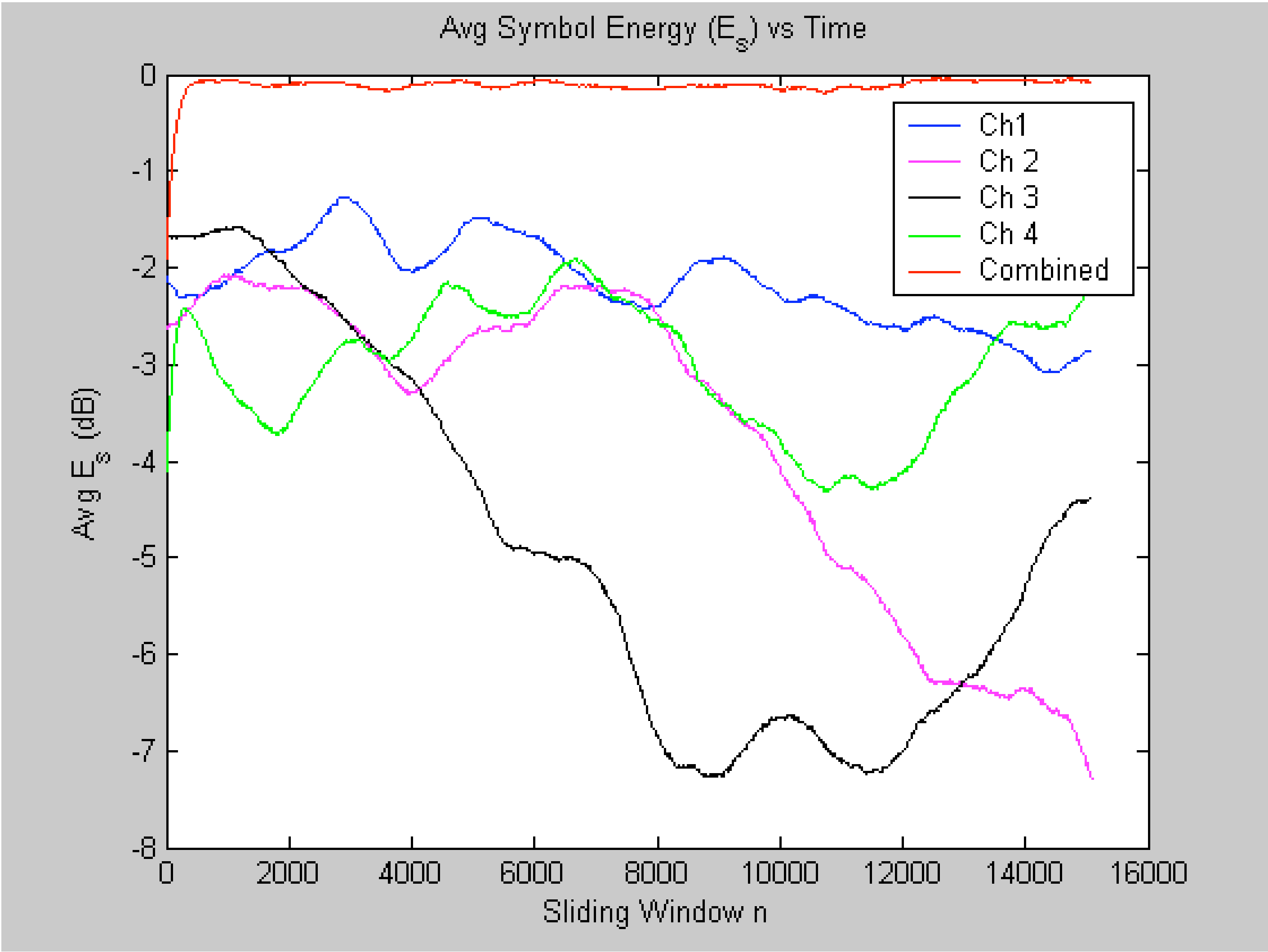
7 April 2004

Four radio receivers convert the signal from a continuous waveform, centered at 2.27GHz, down to complex baseband digitized samples

Some Initial Results



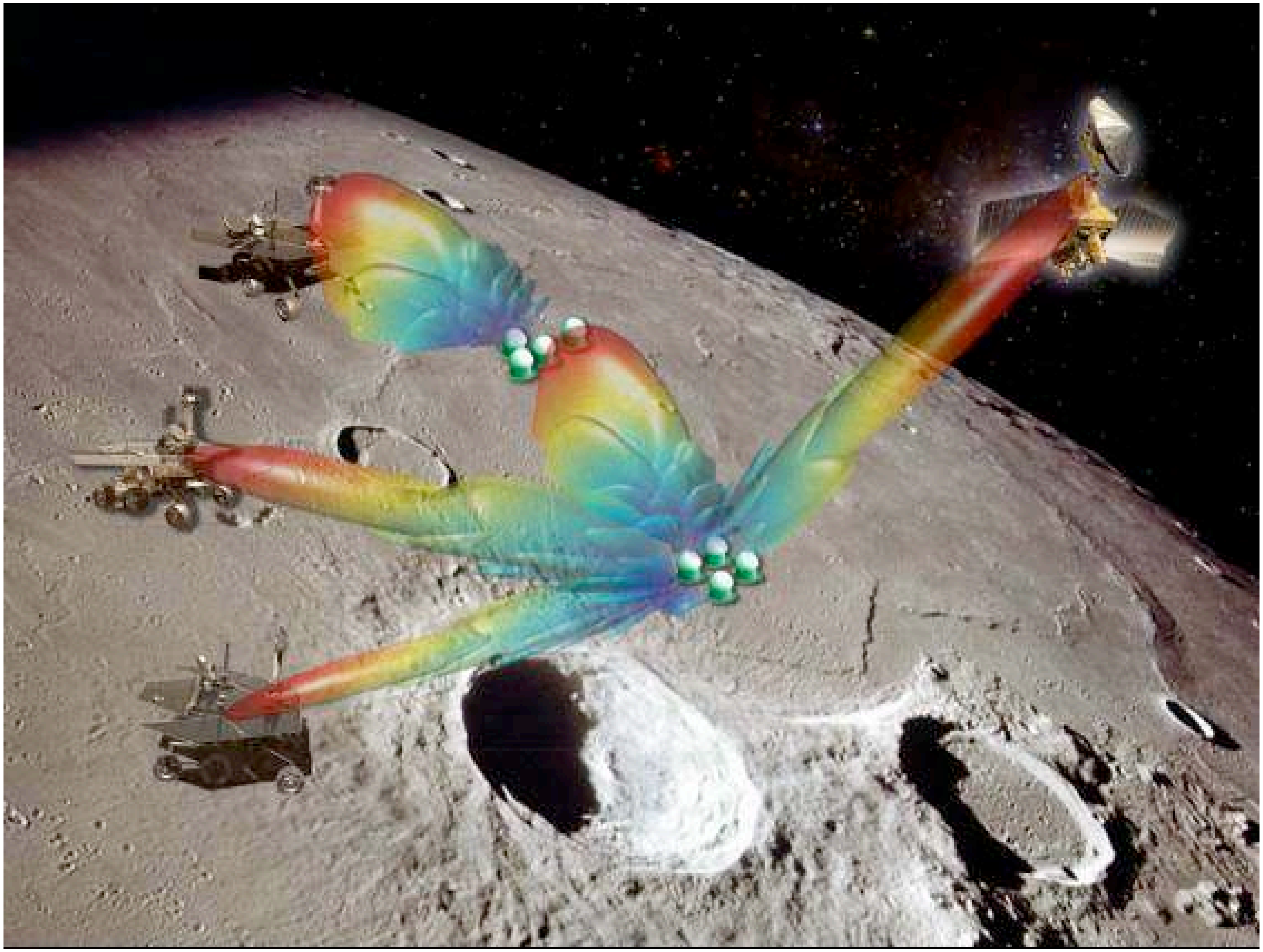
Some Initial Results



Summary & Next Steps

- Adaptive Arrays of small antennas offer a low-cost way to construct ground nodes for LEO Earth Science data reception
- Exploiting multi-path propagation permits lower elevation acquisition and longer tracking times
- Good agreement with theory has been demonstrated for strong multipath channels
- Several electronically and mechanically steered array elements are possible
- Next year a prototype X-band Adaptive Array will be demonstrated

Ultimately, We Needn't Stop on Earth...



This work is being funded through ESTO AIST NRA research on Ground Hybrid Phased Array Antennas,

PI: Dan Mandl, NASA/GSFC, Code 584