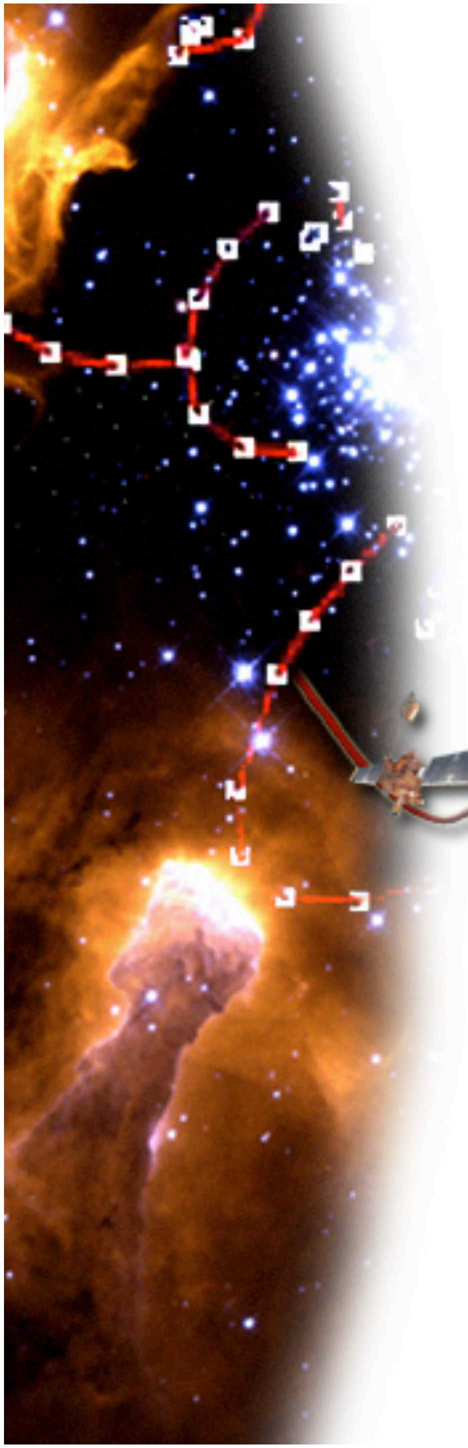


Evolutionary Antenna Design for Increased Science Return

Greg Hornby & K. KrishnaKumar

Adaptive Control & Evolvable Systems Group
Intelligent Systems Division
NASA Ames Research Center
Mountain View, CA USA
hornby@email.arc.nasa.gov

Introduction

Problem:

- Communications bandwidth limits the amount of scientific data returned from Science missions.

Solution:

- Better antennas will significantly increase scientific data.

Approach:

- Use evolutionary algorithms to automatically design better antennas.

Goal:

- Routinely produce 10-20% better antennas.

Objectives

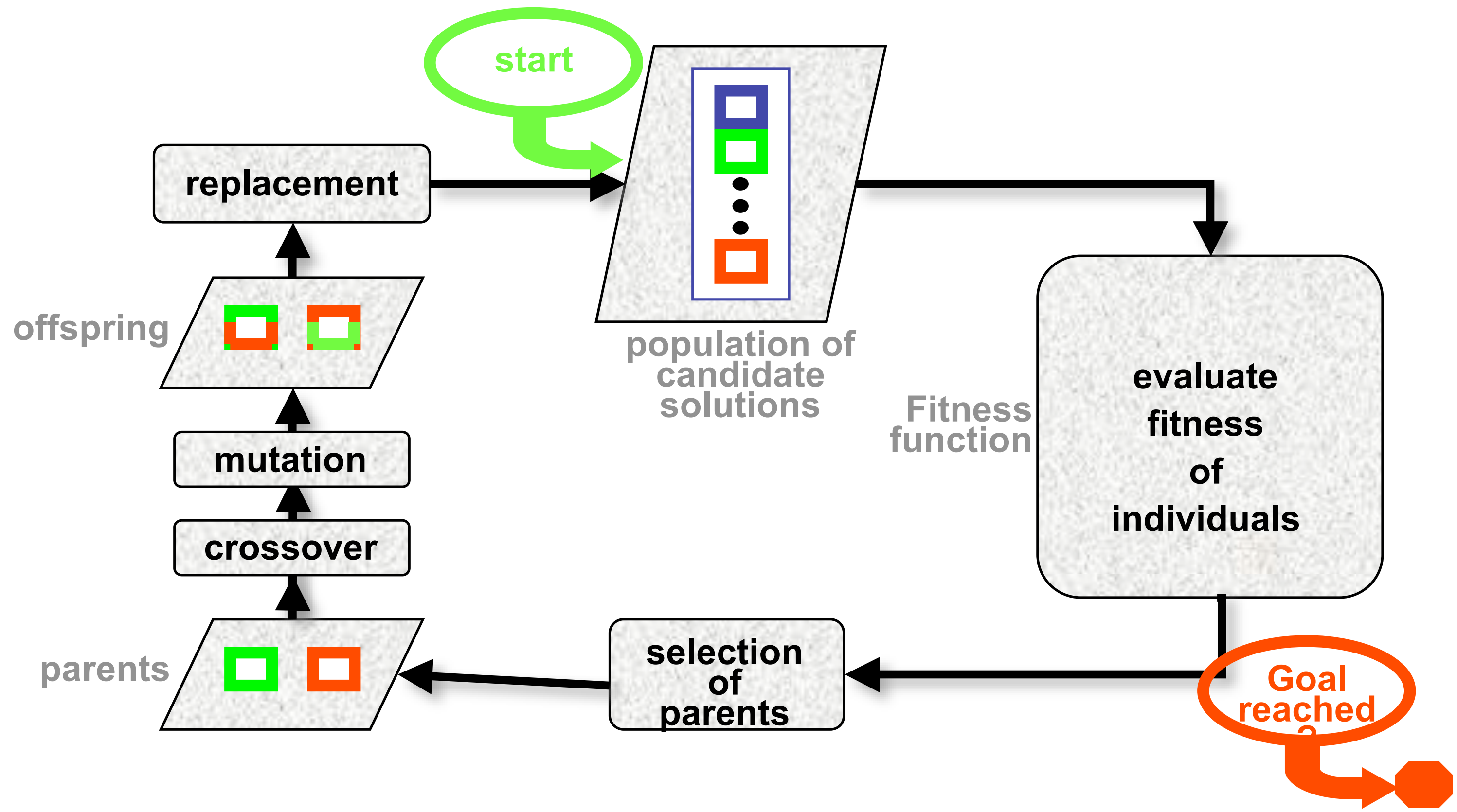
- Improve evolutionary design system to routinely produce 10-20% better antennas.
- On the ST5 mission we have demonstrated:
  - Higher efficiency (97% vs 38%).
  - More uniform coverage.
  - Shorter design time (3 months vs 5 months).
- Add ability to produce additional classes of antenna designs:
  - Phased array.
  - Reconfigurable.
  - Ultra wideband.
  - Reflect-array.
- In-situ design optimization.
- Infuse a NASA mission with an evolved antenna.

Outline

- Evolutionary Algorithms (EAs).
- Initial work:
  - Success with the ST5 Mission.
- MEMS work.
- Conclusion.

Evolutionary Algorithms

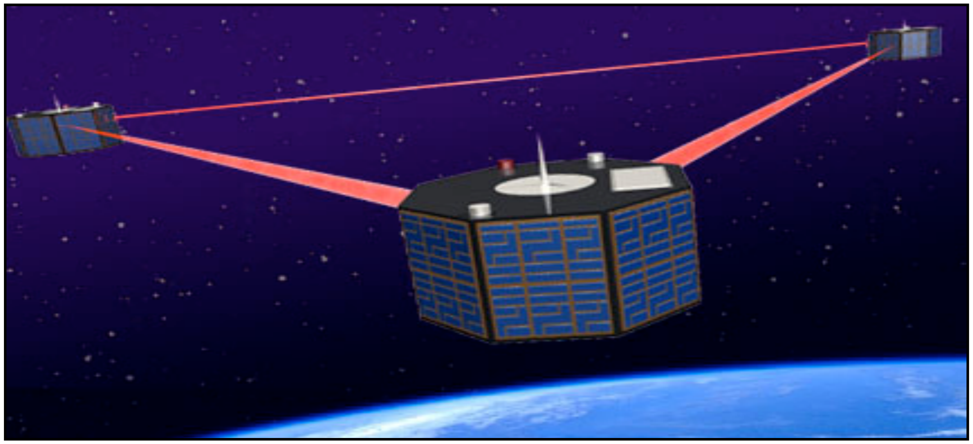
- Algorithms coarsely modeled after neo-Darwinism (natural selection + genetics)
- Breeding solutions to problems (animal husbandry)
- Generate-and-test search strategy
- Suited for very large, complex, search spaces

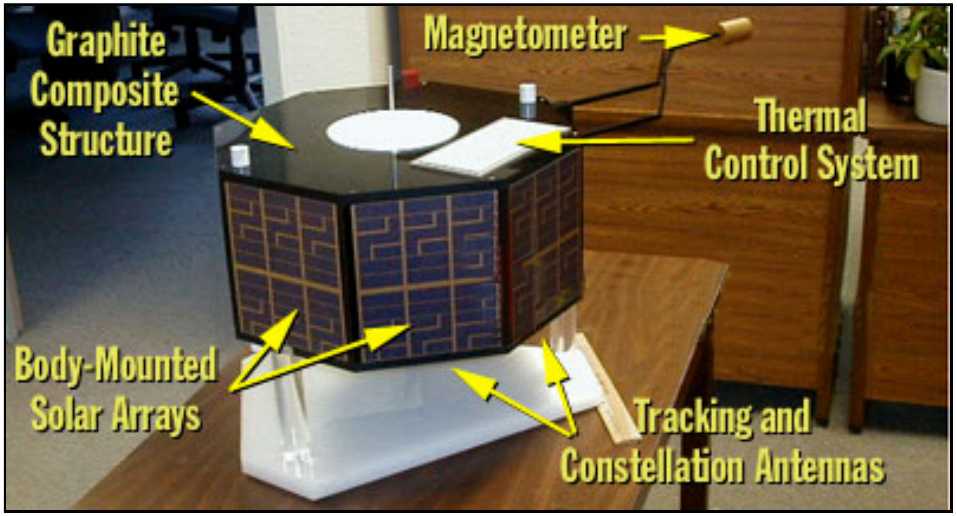


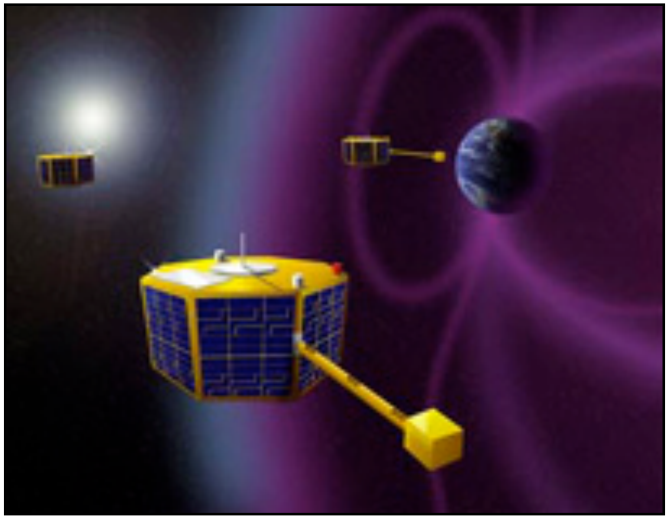
Initial Work:
NASA's Space Technology 5

ST5 Mission

- Three nanosats (20in diameter).
- Measure effect of solar activity on the Earth's magnetosphere.



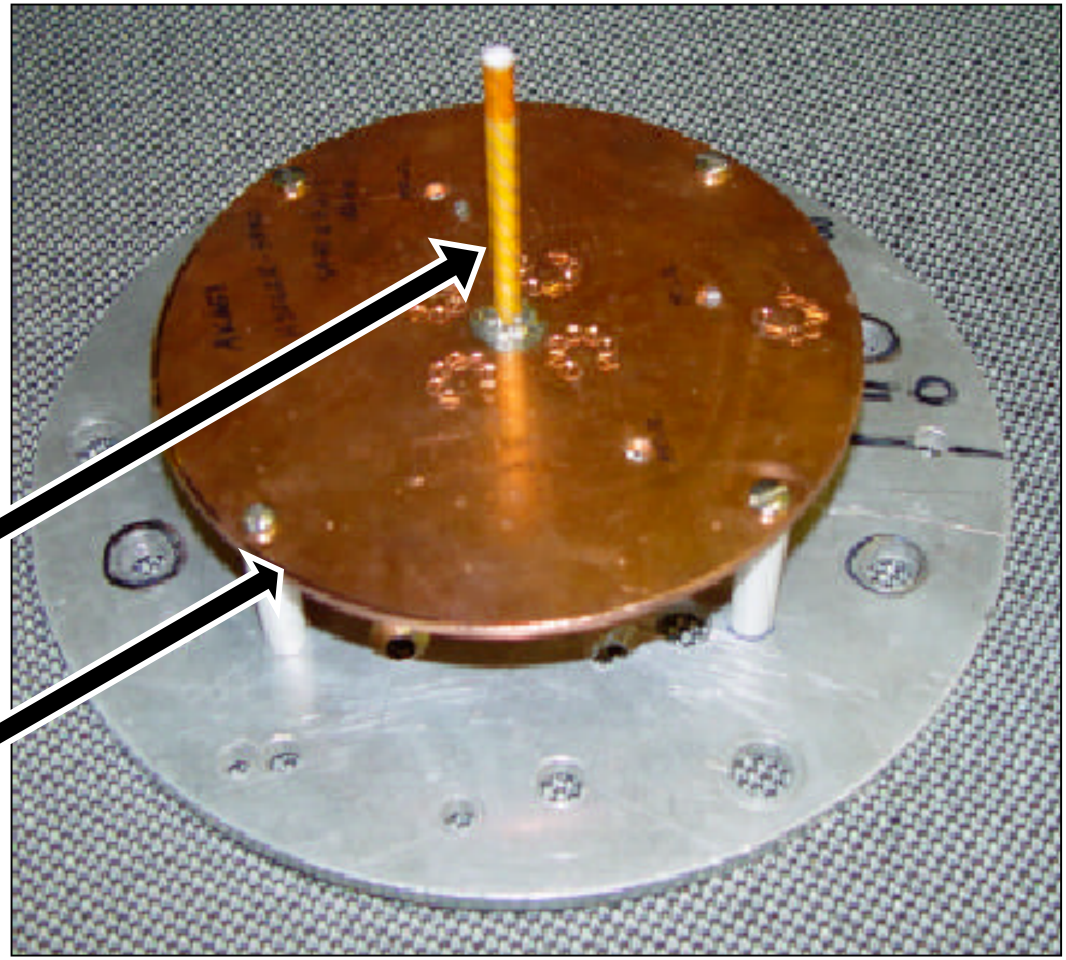




ST5 Quadrifilar Helical Antenna

Prior to our work, a contract had been awarded for an antenna design.

Result: quadrifilar helical antenna (QHA).



Radiator

Under ground plane: matching and phasing network

Original ST5 Antenna Requirements

- Transmit Frequency: 8470 MHz
- Receive Frequency: 7209.125 MHz
- Antenna RF Input: 1.5W = 1.76 dBW = 31.76 dBm
- VSWR: < 1.2 : 1 at the antenna input port at Transmit Freq, < 1.5 : 1 at the antenna input port at Receive Freq
- Antenna Gain Pattern: Shall be 0 dBic or greater for angles 40 <= theta <=80; 0 <= phi <= 360
- Antenna pattern gain (this shall be obtained with the antenna mounted on the ST5 mock-up) shall be 0.0 dBic (relative to anisotropic circularly polarized reference) for angles 40 <= theta <=80; 0 <= phi <= 360, where theta and phi are the standard spherical coordinate angles as defined in the IEEE Standard Test Procedures for Antennas, with theta=0 to direction perpendicular to the spacecraft top deck. The antenna gain shall be measured in reference to a right hand circular polarized sense (TBR).
- Desired: 0 dBic for theta = 40, 2 dBic for theta = 80, 4 dBic for theta = 90, for 0 <= phi <= 360
- Antenna Input Impedance: 50 ohms at the antenna input port
- Magnetic dipole moment: < 60 mA-cm^2
- Grounding: Cable shields of all coaxial inputs and outputs shall be returned to RF ground at the transponder system chasis. The cases of all comm units will be electrically isolated from the mounting surface to prohibit current flow to the spacecraft baseplate.
- Antenna Size: diameter: < 15.24 cm (6 inches), height: < 15.24 cm (6 inches)
- Antenna Mass: < 165 g.

- Transmit: 8470 MHz
- Receive: 7209.125 MHz
- Gain:
  - **>= 0dBic, 40 to 80 degrees**
  - >= 2dBic, 80 degrees
  - >= 4dBic, 90 degrees
- 50 Ohm impedance
- Voltage Standing Wave Ratio (VSWR):
  - < 1.2 at Transmit Freq
  - < 1.5 at Receive Freq
- Fit inside a 6” cylinder

Evolutionary Design System

- Transmit Frequency: 8470 MHz
- Receive Frequency: 7209.125 MHz
- Antenna RF Input: 1.5W = 1.76 dBW = 31.76 dBm
- VSWR: < 1.2 : 1 at the antenna input port at Transmit Freq, < 1.5 : 1 at the antenna input port at Receive Freq
- Antenna Gain Pattern: Shall be 0 dBic or greater for angles 40 <= theta <=80; 0 <= phi <= 360
- Antenna pattern gain (this shall be obtained with the antenna mounted on the ST5 mock-up) shall be 0.0 dBic (relative to

Requirements

circular polarized sense (TBR).
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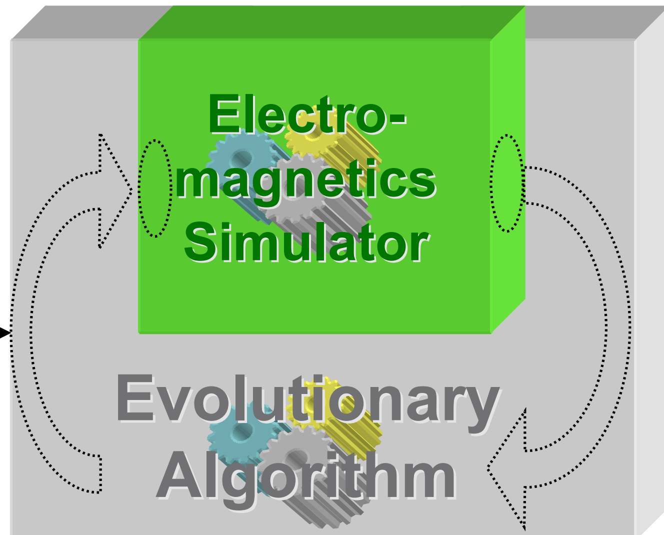
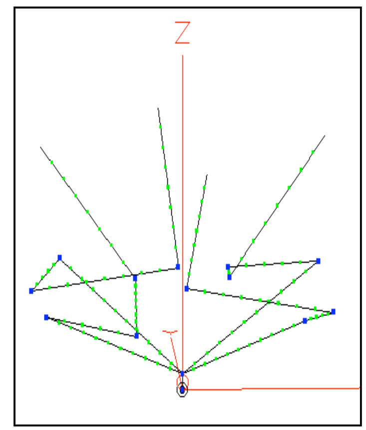
Small Amount of E/M Expertise

Small Amount of EA Expertise

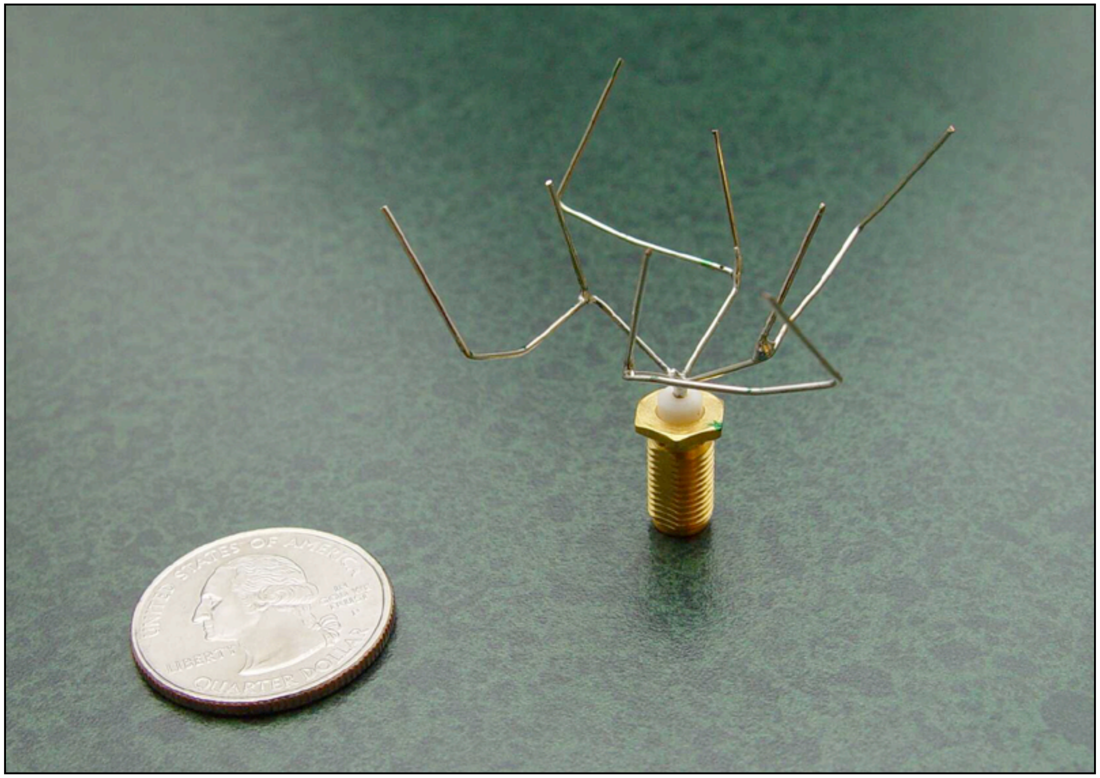




Antenna Design(s)

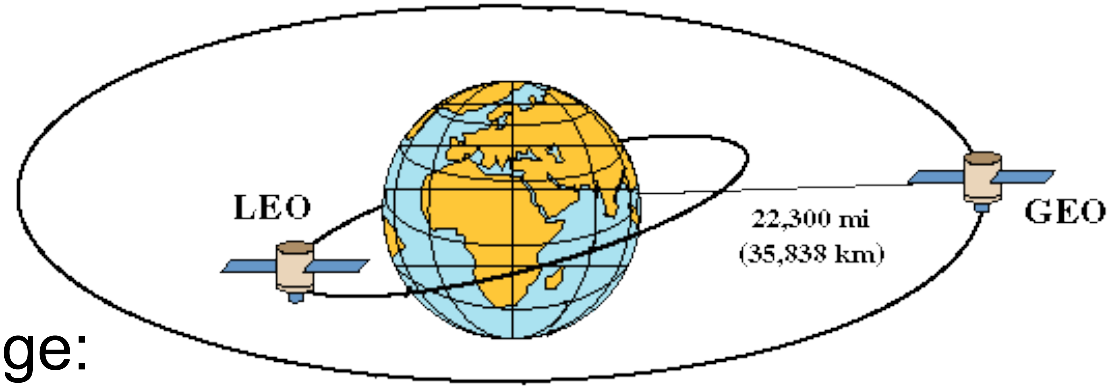
- Evolutionary Design Engine:
  - Parallel, any Unix.
  - Uses NEC4 or WIPL-D.
- Beowulf cluster of over 80 processors.

Initial Evolved Antenna



ST5-3-10

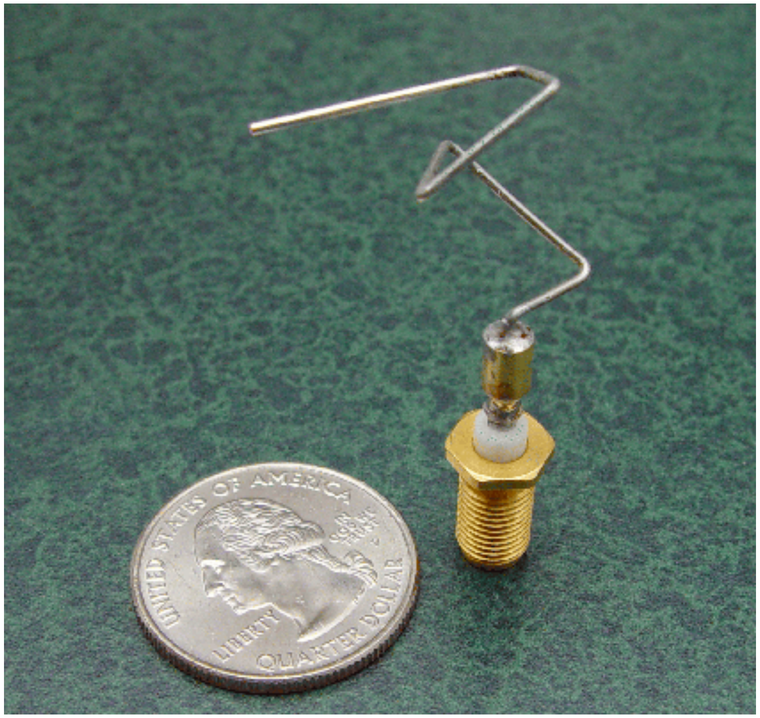
New ST5 Mission Requirements



- Launch vehicle change:
  - spacecraft will go into LEO
- New requirements:
  - Deep null at zenith not acceptable; No way to salvage original evolved design
  - Desire to have wider range of angles covered with signal:
    - Gain >= -5dBic, 0 to 40 degrees
    - Gain >= 0dBic, 40 to 80 degrees
- Quadrifilar helical antenna still ok, though not very good

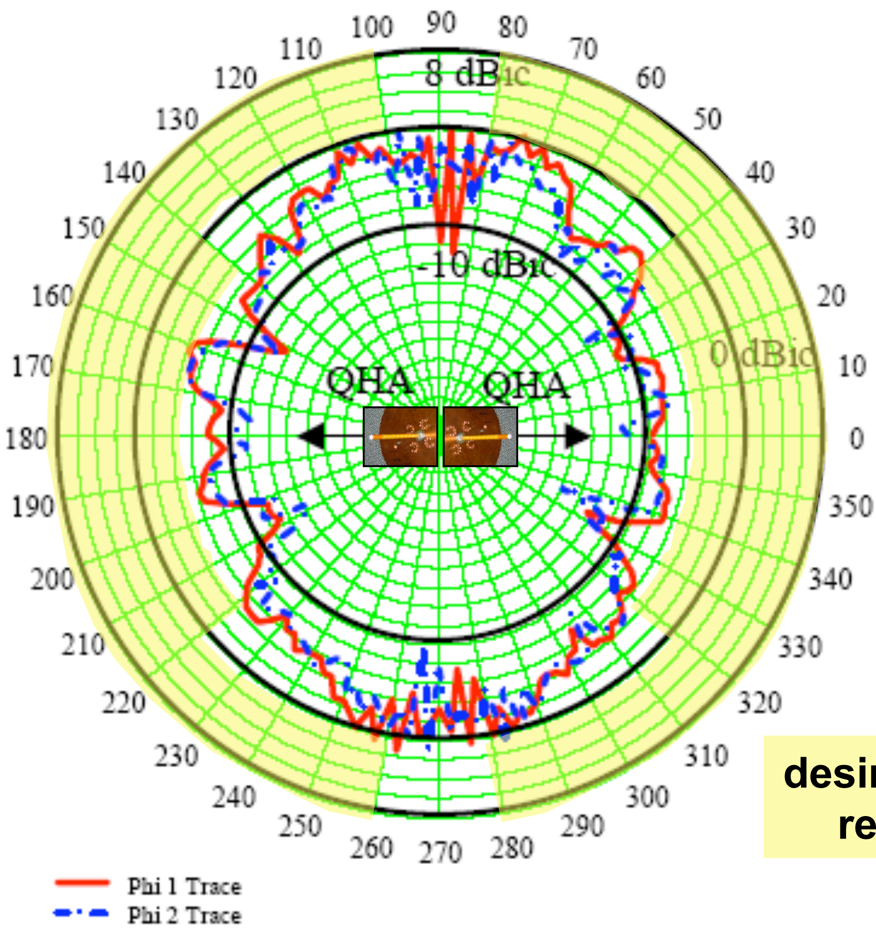
Newly Evolved Antenna

- Within 4 weeks we re-evolved new antennas.
- Because of the dual antenna configuration these antennas yield better overall performance due to less interference.

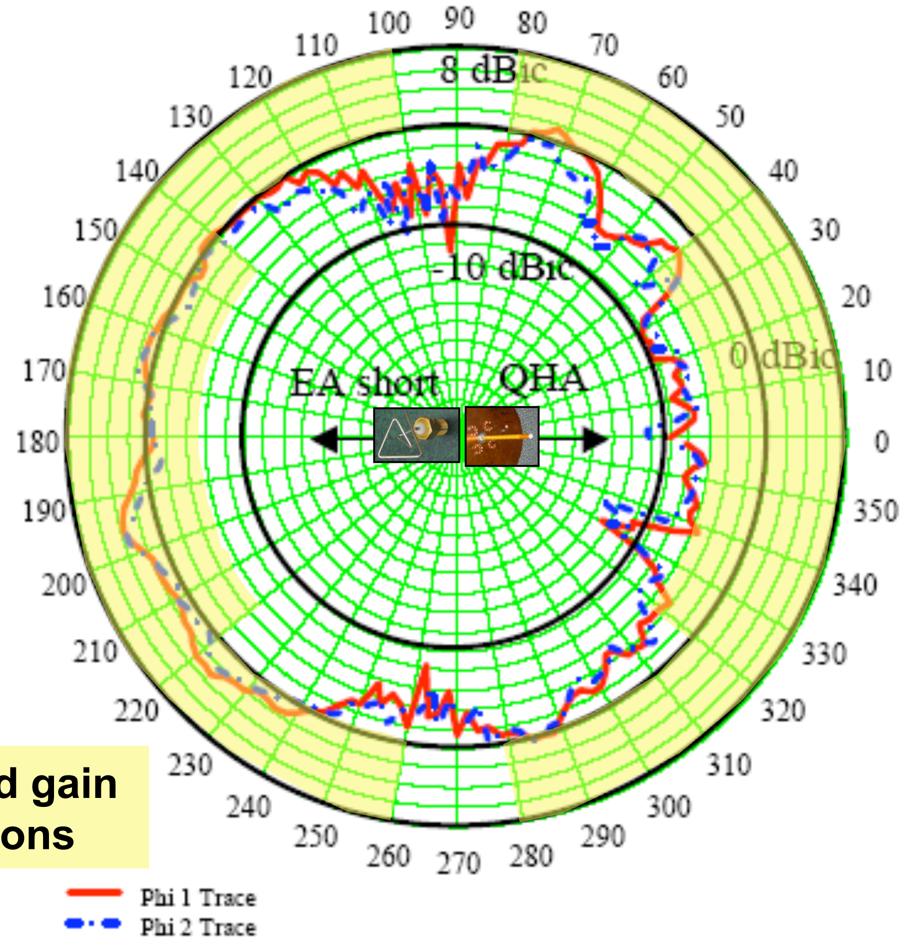


ST5-33-142-7

Measured Data



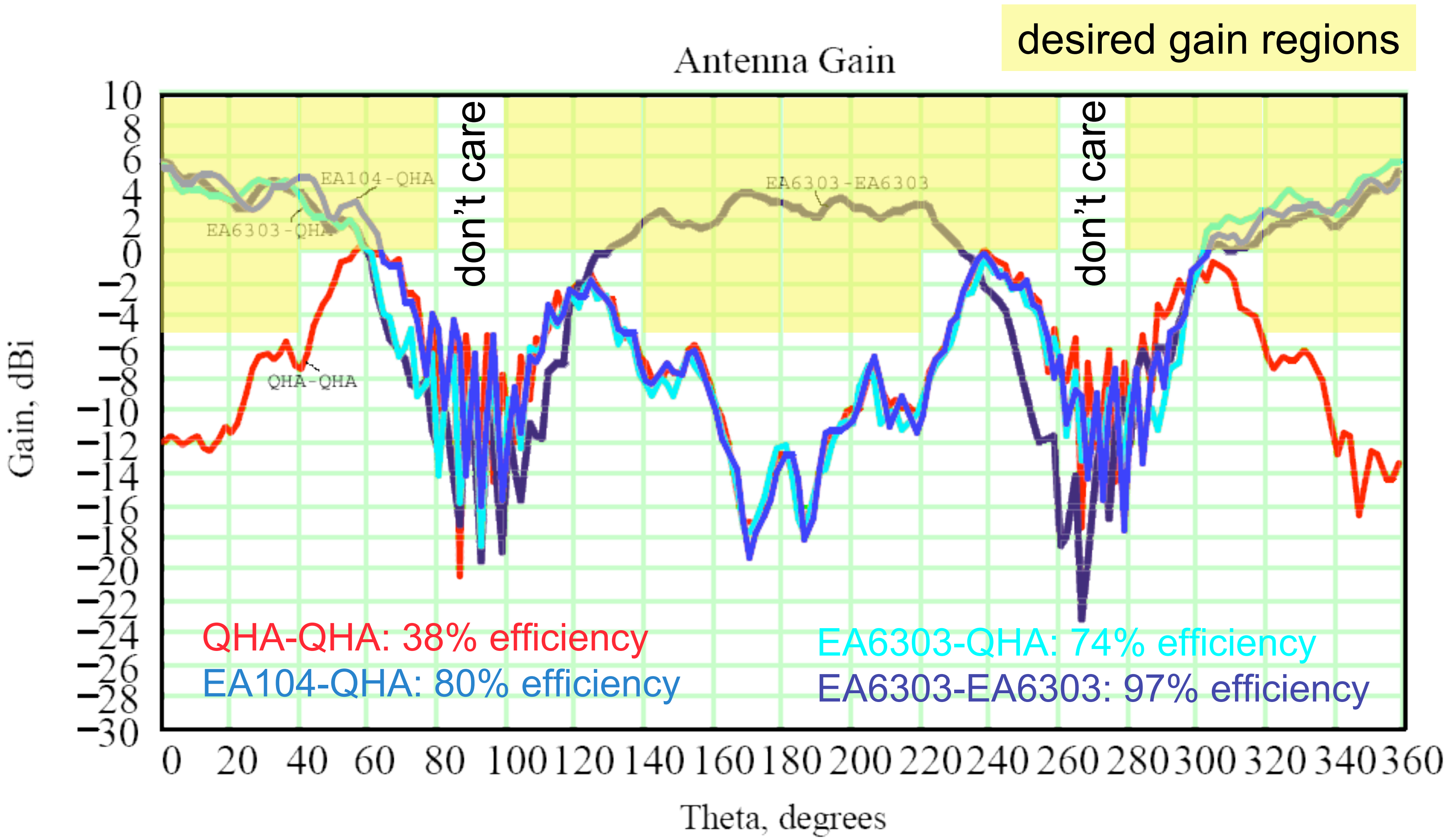
desired gain regions



QHA + QHA (phi 1 = 0 deg, phi 2 = 90 deg): 28% total efficiency, 8470 MHz

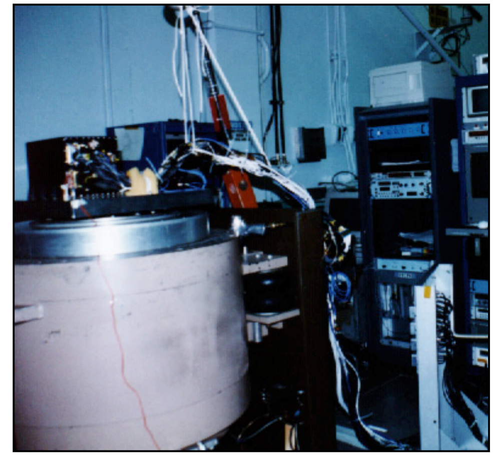
EA short + QHA (phi 1 = 0 deg, phi 2 = 90 deg): 63% total efficiency, 8470 MHz

Gain vs Theta for Phi=90 degrees



Current Status

Flight Unit



Vibration Chamber

- Passed all environmental testing
- Vibration
- Thermal vac
- Scheduled launch: March 14

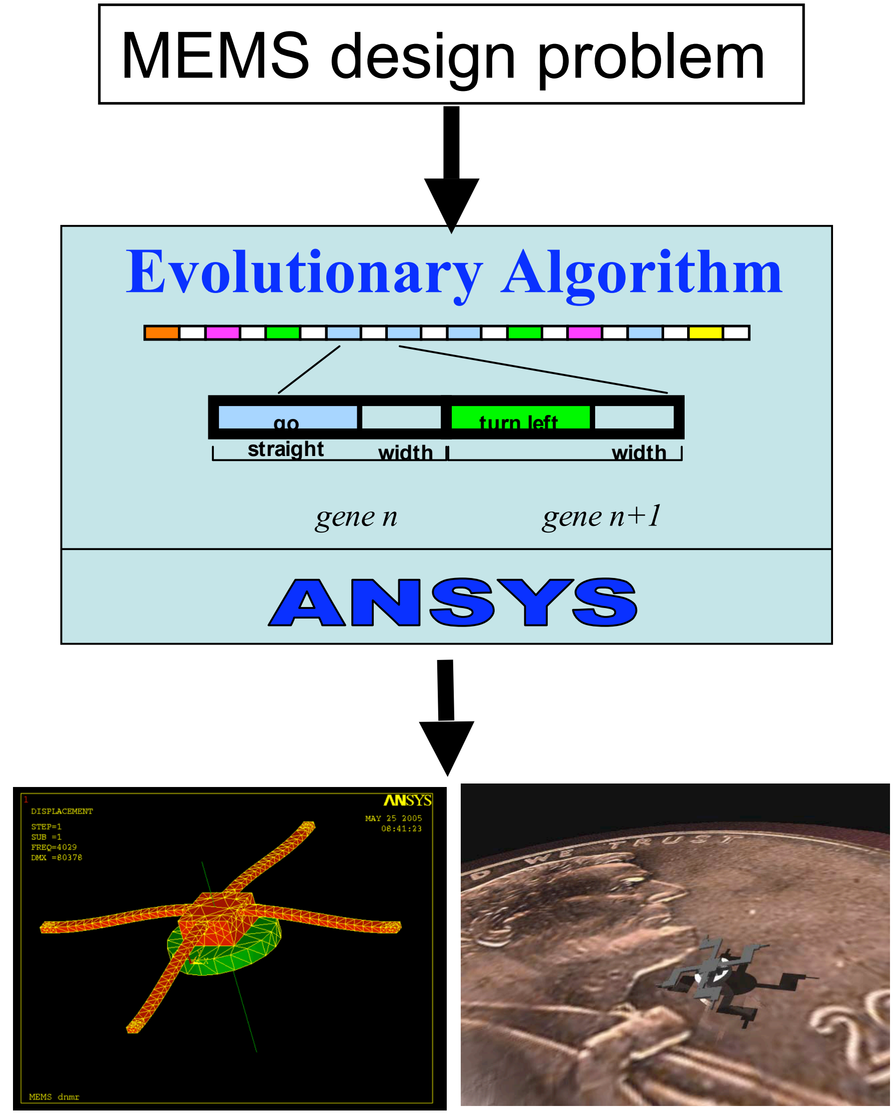
"The antenna performed above requirements during one survival cycle (-80c to +80c) and through each of eight qualification cycles (-70c to +50c)."

Thermal Vac

Improvements in Other Domains

Evolutionary Algorithms have produced better designs in other domains:

- MEMS (closer match to desired resonating frequency).
- Optical systems (fewer elements).
- …



Conclusion

Based on initial work we expect to be able to achieve 10-20% better antennas:

- **Potential Lower Power**: evolved antenna achieves high gain (2-4dB) across a wider range of elevation angles:
  - broader range of angles over which maximum data throughput can be achieved.
  - may require less power from the solar array and batteries.
- **More Uniform Coverage**: Very uniform pattern with small ripples in the elevations of greatest interest (40 – 80 degrees):
  - allows for reliable performance as elevation angle relative to the ground changes.
- **Inexpensive Design Cycle**: 3 person-months to run algorithms and fabricate the first prototype as compared to 5 person-months for contractor team.
- **Rapid Re-Design**: common in NASA missions.
- **On Schedule to be First Evolved Hardware in Space when mission launches in 2006.**
- Evolutionary design has produced better solutions in other domains: optical systems & MEMS.