Chapter 1

AN EVOLVED ANTENNA FOR DEPLOYMENT ON NASA'S SPACE TECHNOLOGY 5 MISSION

Jason D. Lohn
NASA Ames Research Center
Computational Sciences Division
jlohn@email.arc.nasa.gov

Gregory S. Hornby
NASA Ames Research Center, QSS Group, Inc.
Computational Sciences Division
hornby@email.arc.nasa.gov

Derek S. Linden
Linden Innovation Research, LLC.
dlinden@lindenir.com

Abstract We present an evolved X-band antenna design and flight prototype currently on schedule to be deployed on NASA's Space Technology 5 (ST5) spacecraft. Current methods of designing and optimizing antennas by hand are time and labor intensive, limit complexity, and require significant expertise and experience. Evolutionary design techniques can overcome these limitations by searching the design space and automatically finding effective solutions that would ordinarily not be found. The ST5 antenna was evolved to meet a challenging set of mission requirements, most notably the combination of wide beamwidth for a circularly-polarized wave and wide bandwidth. Two evolutionary algorithms were used: one used a genetic algorithm style representation that did not allow branching in the antenna arms; the second used a genetic programming style tree-structured representation that allowed branching in the antenna arms. The highest performance antennas from both algorithms were fabricated and tested, and both yielded very similar performance. Both antennas were comparable in performance to a hand-designed antenna produced by the antenna contractor for the mission, and so we consider them examples of human-competitive performance by evolutionary algorithms. As of this writing, one of our evolved antenna prototypes is undergoing flight qualification testing. If successful, the resulting antenna would represent the first evolved hardware in space, and the first deployed evolved antenna.

Keywords: Design, computational design, antenna, wire antenna, spacecraft, genetic programming, evolutionary computation.

Introduction

Researchers have been investigating evolutionary antenna design and optimization since the early 1990s (e.g., [Michielssen et al., 1993, Haupt, 1995, Altshuler and Linden, 1997a, Rahmat-Samii and Michielssen, 1999]), and the field has grown in recent years as computer speed has increased and electromagnetics simulators have improved. Many antenna types have been investigated, including wire antennas [Linden and Altshuler, 1996], antenna arrays [Haupt, 1996], and quadrifilar helical antennas [Lohn et al., 2002]. In addition, the ability to evolve antennas *in-situ* [Linden, 2000], that is, taking into account the effects of surrounding structures, opens new design possibilities. Such an approach is very difficult for antenna designers due to the complexity of electromagnetic interactions, yet easy to integrate into evolutionary techniques.

Below we describe two evolutionary algorithm (EA) approaches to a challenging antenna design problem on NASA's Space Technology 5 (ST5) mission [ST5]. ST5's objective is to demonstrate and flight qualify innovative technologies and concepts for application to future space missions. Images showing the ST5 spacecraft are seen in Figure 1.1. The mission duration is planned for three months.

1. ST5 Mission Antenna Requirements

The three ST5 spacecraft will orbit at close separations in a highly elliptical geosynchronous transfer orbit approximately 35,000 km above Earth and will communicate with a 34 meter ground-based dish antenna. The combination of wide beamwidth for a circularly-polarized wave and wide bandwidth make for a challenging design problem. In terms of simulation challenges, because the diameter of the spacecraft is 54.2 cm, the spacecraft is 13-15 wavelengths across which makes antenna simulation computationally intensive. For that reason, an infinite ground plane approximation or smaller finite ground plane is typically used in modeling and design.

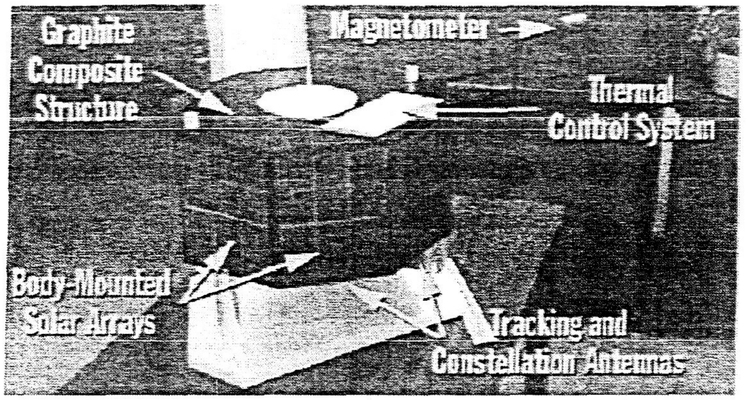

Figure 1.1. ST5 satellite mock-up. The satellite will have two antennas, centered on the top and bottom of each spacecraft.

The antenna requirements are as follows. The gain pattern must be greater than or equal to 0 dBic (decibels as referenced to an isotropic radiator that is circularly polarized) at $40° \leq \theta \leq 80°$ and $0° \leq \phi \leq 360°$ for right-hand circular polarization. The antenna must have a voltage standing wave ratio (VSWR) of under 1.2 at the transmit frequency (8470 MHz) and under 1.5 at the receive frequency (7209.125 MHz) - VSWR is a way to quantify reflected-wave interference, and thus the amount of impedance mismatch at the junction. At both frequencies the input impedance should be 50 Ω. The antenna is restricted in shape to a mass of under 165 g, and must fit in a cylinder of height and diameter of 15.24 cm.

In addition to these requirements, an additional "desired" specification was issued for the field pattern. Because of the spacecraft's relative orientation to the Earth, high gain in the field pattern was desired at low elevation angles. Specifically, across $0° \leq \phi \leq 360°$, gain was desired to meet: 2 dBic for $\theta = 80°$, and 4 dBic for $\theta = 90°$.

ST5 mission managers were willing to accept antenna performance that aligned closer to the "desired" field pattern specifications noted above, and the contractor, using conventional design practices, produced a quadrifilar helical (QFH) (see Figure 1.2) antenna to meet these specifications.

2. Evolved Antenna Design

From past experience in designing wire antennas [Linden, 1997], we decided to constrain our evolutionary design to a monopole wire antenna with four identical arms, each arm rotated 90° from its neighbors. The