

# Evolutionary Optimization of a Quadrifilar Helical Antenna

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## 1 Introduction

Automated antenna synthesis via evolutionary design has recently garnered much attention in the research literature [9]. Evolutionary algorithms show promise because, among search algorithms, they are able to effectively search large, unknown design spaces.

NASA's Mars Odyssey spacecraft is due to reach final Martian orbit insertion in January, 2002. Onboard the spacecraft is a quadrifilar helical antenna that provides telecommunications in the UHF band with landed assets, such as robotic rovers. This antenna can be seen in Fig. 1. Each helix is driven by the same signal which is phase-delayed in 90° increments. A small ground plane is provided at the base. It is designed to operate in the frequency band of 400-438 MHz.

Based on encouraging previous results in automated antenna design using evolutionary search, we wanted to see whether such techniques could improve upon Mars Odyssey antenna design. Specifically, a coevolutionary genetic algorithm is applied to optimize the gain and size of the quadrifilar helical antenna.

The optimization was performed *in-situ* – in the presence of a neighboring spacecraft structure [5]. On the spacecraft, a large aluminum fuel tank is adjacent to the antenna. Since this fuel tank can dramatically affect the antenna's performance, we leave it to the evolutionary process to see if it can exploit the fuel tank's properties advantageously.

Optimizing in the presence of surrounding structures would be quite difficult for human antenna designers, and thus the actual antenna was designed for free space (with a small ground plane). In fact, when flying on the spacecraft, surrounding structures that are moveable (e.g., solar panels) may be moved during the mission in order to improve the antenna's performance.

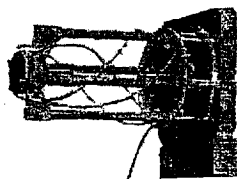


Figure 1: Photograph of the quadrifilar helical UHF antenna deployed on the Mars Odyssey spacecraft.

## 2 Antenna Representation and Operators

The representational scheme used for the Mars UHF antenna parameterized a generic quadrifilar helical antenna, and was specified as follows. An array of byte-encoded floating point numbers represented the number of wire segments, number of turns, wire thickness, bottom diameter, top diameter, and height.

## 3 Experimental Setup

Experiments were set up as follows. The NEC simulation program [2] was used to evaluate all antenna designs. We used a parallel master/slave generational genetic algorithm with a population size of 6000. One point crossover across byte boundaries was used at a rate of 80%. Mutation was uniform across bytes at a rate of 1%. Runs were executed on 32-node and 64-node Beowulf computing clusters [8].

The wire geometry encoded by each individual chromosome was first translated into a NEC input deck, which was subsequently sent to the NEC simulator. The segment size for all elements was fixed at  $0.1\lambda$ , where  $\lambda$  was the wavelength corresponding to 235 MHz.

For the quadrifilar helical runs, a coarse model of the neighboring fuel tank was used in the simulations. Its size and position was calculated based on engineering drawings of the spacecraft. To compare our results to the spacecraft antenna, we modeled that antenna with the best data we had at the time of this writing.

A coevolutionary genetic algorithm [6] was applied to the quadrifilar helical antenna optimization. Two populations are used: one consisting of antenna designs, and one consisting of target vectors. The fundamental idea is that the target vectors encapsulate level-of-difficulty. Then, under the control of the genetic algorithm, the target vectors evolve from easy to difficult based on the level of proficiency of the antenna population.

Each target vector consists of a set of objectives that must be met in order for a target vector to be "solved." A target vector consisting of two values: the average gain (in dB), VSWR, and antenna volume. A target vector was considered to be solved by a given antenna if the antenna exceeds the performance thresholds of all target.

Values for target gain ranged between -50 dB (easy) and 8 dB (difficult). Target VSWR values ranged between 100 (easy) and 20 (difficult). Target antenna volumes ranged from 100,000 cm<sup>3</sup> (easy) to 100 cm<sup>3</sup> (difficult). Target vectors are represented as a list of floating point values that are mutated individually by randomly adding or subtracting a small amount (5% of the largest legal value). Single point crossover was used, and crossover points were chosen between the values.

The general form of the fitness calculations are from [6]. In summary, antennas are rewarded for solving difficult target vectors. The most difficult target vector is defined to be the target vector that only one antenna can solve. Such a target vector garners the highest fitness score. Target vectors that are unsolvable, or are very easy to solve by the current antenna population, are given low fitness scores.

Fitness was expressed as a cost function to be minimized. The calculation was as follows:

$$F = -G_L + \sum (C * V_i) \quad C = \begin{cases} 0.1 & \text{if } V_i \leq 3 \\ 1 & \text{if } V_i > 3 \end{cases}$$

where:  $G_L$  = lowest gain of all frequencies measured at  $\theta = 0^\circ$  and  $\phi = 0^\circ$ ,  $V_i$  = VSWR at the  $i$ th frequency.

Lacking from this calculation was a term involving sidelobe/backlobe attenuation. We chose not include such a term because we reasoned that as the mainlobe gain increased, the sidelobes/backlobes would decrease in size.

#### 4 Experimental Results

For the quadrifilar helical antenna, a set a five runs were executed using the algorithm described above. Only one of the runs found an antenna design that exceed that benchmark antenna. Fig. 2 shows the gain plots for both the evolved and actual Mars UHF antennas. Fig. 3 show the antennas, structures, and radiation patterns of actual Mars Odyssey UHF and evolved antenna. The evolved antenna measures  $6\text{cm} \times 6\text{cm} \times 16\text{cm}$  which approximately four times as small volumewise as the benchmark (roughly  $10\text{cm} \times 10\text{cm} \times 25\text{cm}$ ). At 400 MHz, the average gain of the evolved antenna was 3.77 dB and 1.95 for the benchmark antenna. At 438 MHz, the average gain of the evolved antenna was 2.82 dB and 1.90 for the benchmark antenna. This represent a 93% improvement at 400 MHz and a 48% improvement at 438 MHz in the average gain.

Given that our model of the actual spacecraft antenna was reasonable, though imprecise, it had relatively poor VSWR values: 76.76 to 103.51. The VSWR of the evolved antenna ranged from 4.92 to 20.00 which is an improvement, though VSWR values less than or equal to 2.0 are specified as design constraints.

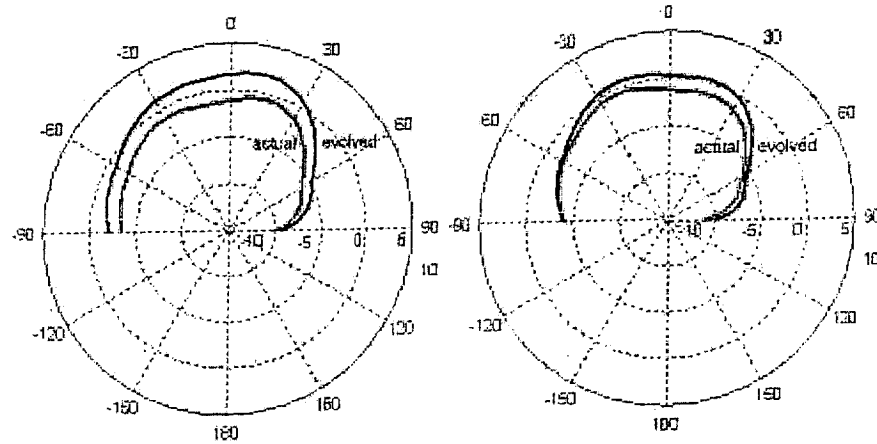


Figure 2: Gain plots for 400 MHz (left) and 438 MHz (right). In each case, the evolved antenna maintains a higher gain than the actual Mars Odyssey antenna. Plots take into account circular polarization.

#### 5 Discussion

An improved version of the quadrifilar antenna currently flying on Mars Odyssey was presented. The evolutionary algorithm allowed the antenna to be designed in the presence of the surrounding structure, whereas the human-designed antenna was designed for free-space. Results showed a 93% improvement at 400 MHz and a 48% improvement at 438 MHz in the average gain. The evolved antenna was also one-fourth the size of the actual antenna on the spacecraft, which is important because of the scarcity of area on spacecraft.

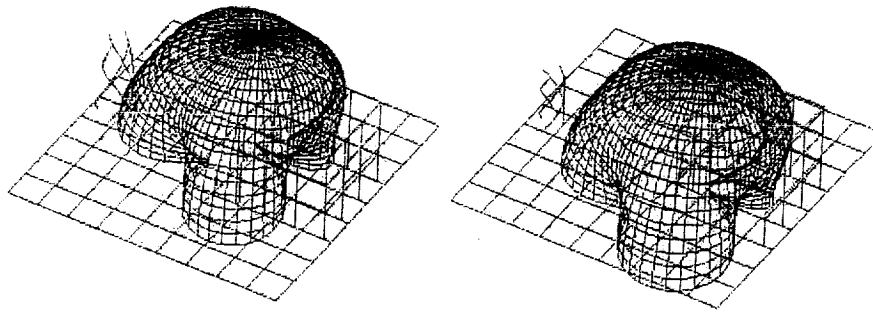


Figure 3: Antennas, structures, and radiation patterns of actual Mars Odyssey UHF (left) and evolved antenna (right). The antennas can be seen in the upper left and the fuel tanks in the lower right of each diagram.

Previous work has explicitly included a sidelobe/backlobe term in the fitness function in order to minimize radiation outside of the desired direction [3]. We did not include an explicit sidelobe/backlobe term but rather relied on the fact that the radiation pattern of an antenna is a zero sum quantity - increasing the intensity in one direction will implicitly reduce the amount of radiation in other directions.

For human antenna designers, designing an antenna to be synergistic with its surrounding structures is typically a daunting task. The results from the quadrifilar helical antenna provide encouraging evidence that evolution can exploit those structures to give increased antenna performance.

## 6 Acknowledgments

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