# Design of a Vehicular Antenna for GPS/IRIDIUM Using a Genetic Algorithm

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***Abstract*—In this paper, we describe a vehicular wire antenna, designed using a genetic algorithm that may be used for both the GPS and IRIDIUM systems. It has right-hand circular polarization, near hemispherical coverage, and operates over the frequency band from 1225 to 1625 MHz. This antenna was simulated using the Numerical Electromagnetics Code (NEC) and then fabricated and tested. The antenna consists of five copper tubing segments connected in series, has an unusually odd shape, and is very inexpensive. It fits in a volume approximately 10 cm × 10 cm × 15 cm. The input voltage standing wave ratio (VSWR) and circular polarization radiation patterns were computed and measured. The VSWR was under 2.2 at the design frequencies of 1225, 1575, and 1625 MHz. The gain varied by less than 12 dB for a 170° sector; it generally fell off near the horizon so the variation was less for 150° and 160° sectors. This new design process, which uses a genetic algorithm in conjunction with an electromagnetics code, produces configurations that are unique and seem to outperform more conventional designs.**

***Index Terms*—Genetic algorithms, land mobile antennas.**

## I. Introduction

NAVIGATION and earth-to-satellite mobile communication systems often require ground-based antennas that are circularly polarized, have near-hemispherical coverage and minimize the interference from multipath reflections. Circular polarization is necessary for systems operating at frequencies below about 3 GHz since the Faraday rotation produced by the ionosphere can cause a linearly polarized transmitted signal to rotate out of alignment with the receiving antenna; a circularly polarized signal averts this problem. Near hemispherical coverage is desirable since the ground antenna is often required to receive a signal from a satellite anywhere above the horizon except at very low elevation angles, where signals may have multipath components that can disrupt system performance. Currently, helical or patch antennas are often used for these applications; but these antennas are generally too narrow band to cover the entire frequency band with a single element. Also they often require a phasing network that increases their complexity and cost. A review of global positioning system (GPS) antenna designs showed that a bifilar conical spiral antenna outperformed the patch and helix [1].

The GPS broadcasts at frequencies of 1575.4 MHz (the L1 coarse acquisition) and 1227.6 MHz (the L2 precision code). The signals use right-hand circular polarization (RHCP). The receiving antenna needs near hemispherical coverage so that it can receive signals from satellites at elevation angles above about 5°. IRIDIUM is a new low earth orbit (LEO) global mobile satellite communication system. It operates over the frequency band from 1610 to 1626.5 MHz, uses RHCP, and has near hemispherical coverage. We expect that many vehicles will utilize both GPS and IRIDIUM.

In this paper, we describe an antenna with a single coaxial line input that will operate over the band from about 1225 to 1625 MHz and thus cover both GPS and IRIDIUM frequencies. This antenna radiates nominal RHCP at elevation angles above about 5° and was designed with a process that uses a genetic algorithm (GA) [2] in conjunction with an electromagnetic code. In this method, the beamwidth, VSWR, and frequency band are specified and the antenna configuration that most closely approaches these characteristics is synthesized. After a design is obtained, we conduct an in-depth computational analysis and then verify these results by fabricating and testing the antenna.

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## II. Approach

To begin, a cost function, which contains the parameters to be optimized, must first be defined. Then the GA randomly selects a sample population set of configurations, from the total population of possible configurations. The GA evaluates the performance of each member of this population and compares each individual performance with the desired or ideal performance specified in the cost function and returns a single number to the GA that is a measure of its fitness. As in the evolutionary process of "survival of the fittest," high-quality chromosomes (strings) mate and produce offspring, while poor quality strings are removed from the population. Offspring can be created through many different procedures, each of which is essentially a method of combining information from parent chromosomes to form a child with the potential of outperforming its parents. With succeeding "generations," the quality of the strings continually improves and an optimized solution is ultimately obtained. The GA method of antenna design is analogous to a method of breeding racehorses, where the "horses" are antenna designs and the "race track" is a simulation to determine antenna performance. "Champions" will have many offspring, while those who do not perform well, will perish without offspring. Even when the problem to be solved may have many interrelated unknowns and a large, complex, and spiky search space, the better the GA will perform over other methods of search. The GA is highly resistant to becoming trapped in local extrema, which allows it to work well for search spaces like those of the antenna design problems to be described.

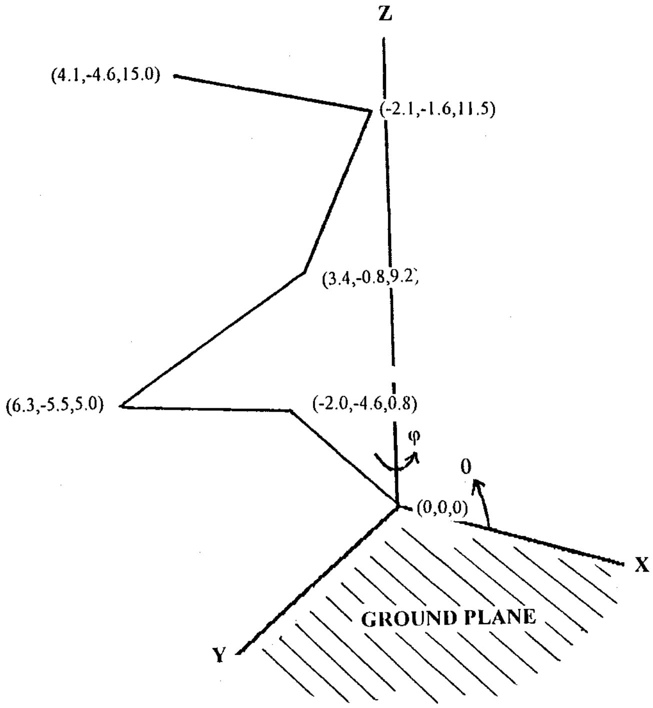


Fig. 1. Sketch of "crooked wire genetic antenna."

For this investigation, the GA starts with a randomly selected population of 175 potential antenna configurations, which satisfy the constraints of the problem. All configuration information (e.g., start and endpoints and wire sizes) is encoded into a set of numbers called a real chromosome [3]. The GA evaluates the performance of each member of this population based on a cost function that compares the individual performance of each configuration with the desired or ideal performance. Evaluating the cost function involves simulating each member of the population with an electromagnetics code and comparing the results with those desired; the NEC Version 2 (NEC2), was used for this design [4].

The antenna design program we created employs a steady-state GA (i.e., a portion of the current population carries over to the next generation). The top 30% of the population is saved from each generation after all chromosomes have been evaluated. These chromosomes are then used to generate the offspring that will fill the rest of the population. A virtual "weighted roulette wheel" is filled according to each chromosome's fitness; the more fit a chromosome, the larger its share of the wheel. For each new position, the wheel is "spun" and the first parent is chosen. The wheel is "spun" again and the second parent is chosen. Real chromosomes were mated using the quadratic and heuristic crossover method [3].

For this antenna optimization we allow the GA to search for a configuration that will produce the desired properties, subject to only very basic constraints; antenna size, excitation source, number of wires, and a ground plane. We previously investigated a set of crooked wire antennas having from three to eight wires connected in series [5]. We found that for this bandwidth a five-wire antenna seemed optimal. Our goal was to obtain RHCP, 5° above the horizon over the hemisphere, and a VSWR less than about 2.0, for frequencies of 1225, 1575, and 1625 MHz. The GA program computes the hemispherical radiation pattern at increments of 5° in elevation, from $\theta = -85°$ to $+85°$, and in azimuth, from $\phi = 0°$ to $\phi = 175°$ at frequencies of 1225, 1575, and 1625 MHz. It then reads the output of NEC2, calculates the average gain over the hemisphere and the

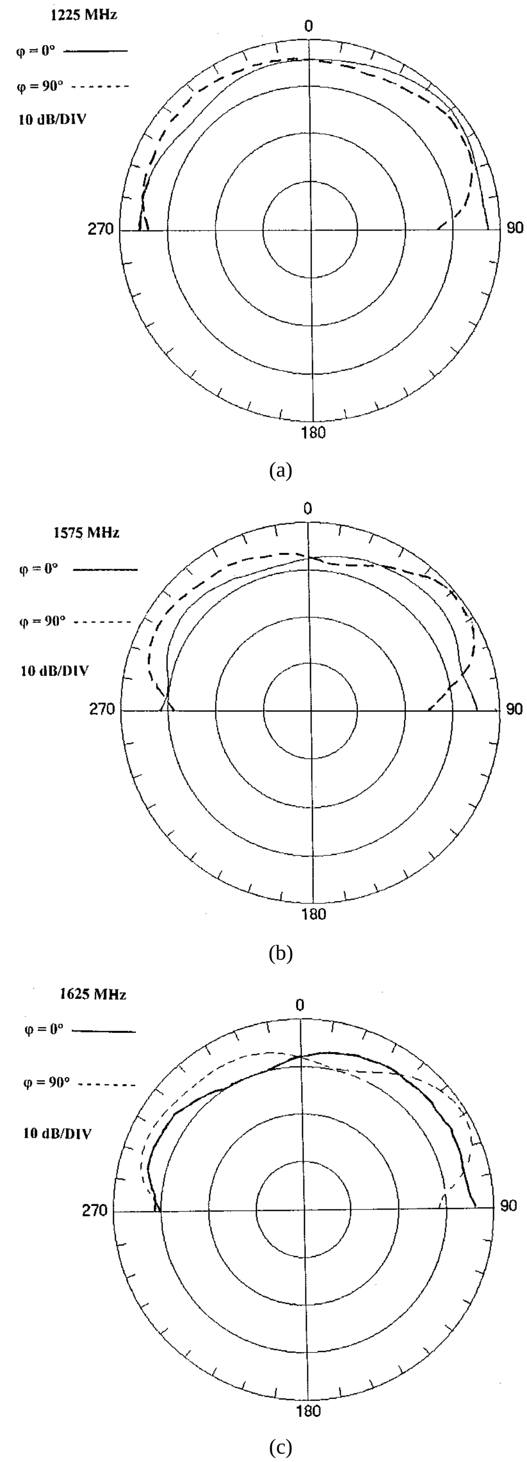


Fig. 2. (a) Computed $\theta$-plane circular polarization radiation pattern at 1225 MHz. (b) Computed $\theta$-plane circular polarization radiation pattern at 1575 MHz. (c) Computed $\theta$-plane circular polarization radiation pattern at 1625 MHz.

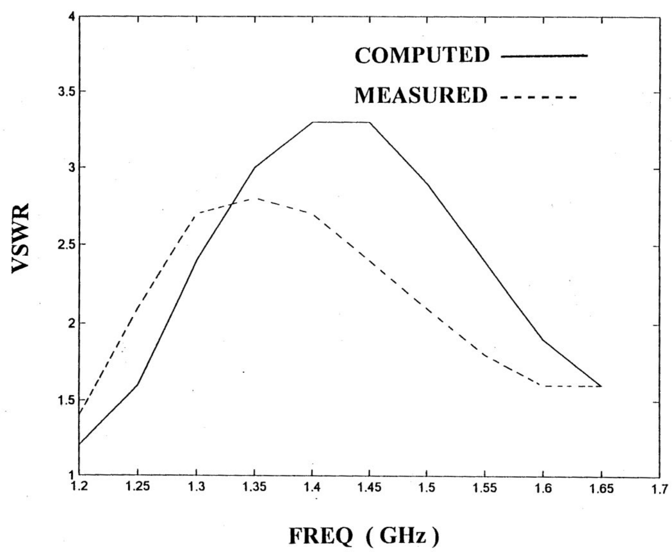


Fig. 3. Computed and measured VSWR's.

sum of the squares of the deviation of all measured points from the mean. It also computes the VSWR's at these frequencies. In equation form

$$\text{Score} = \sum_{\text{over all}\,\theta,\phi} (\text{Gain}(\theta,\phi) - \text{Avg. Gain})^2 + C$$

$$\text{where } C = \begin{cases} .1 & \text{VSWR} < 2.0 \\ 1 & \text{VSWR} \geq 2.0 \end{cases}$$

The GA's goal is to minimize this score. We chose to weight the radiation pattern more heavily than the VSWR since the pattern cannot be changed, whereas if the VSWR is high, it is still possible to use matching techniques to satisfy system requirements.

## III. Results

The resulting antenna, which we refer to as a "crooked wire genetic antenna" [6], was quickly designed using the GA. We allowed the GA to run for 60 generations. Each optimization took about 10 h. We repeated the process about ten times. We used the configuration that had the best score. A sketch of this very unorthodox antenna, along with its coordinates in centimeters, is shown in Fig. 1. It is seen that it fits in a volume of about 10 cm $\times$ 10 cm $\times$ 15 cm and, thus, has a cross section that is about a half wavelength at the highest frequency and a height that is slightly greater. We have conducted a thorough computational analysis of this antenna and have built and tested it. Circular polarization radiation patterns in the $\theta$-plane of the antenna over an infinite ground plane were computed at azimuth angles of 0°, 30°, 60°, 90°, 120°, and 150°, for the frequency range from 1225 to 1625 MHz at intervals of 100 MHz and also at 1575 MHZ. The input VSWR was computed for the same frequencies. The antenna was made out of $3/32$-in (2.38 cm)-diameter copper tubing. Radiation patterns and VSWR's were measured with the antenna over a 4 ft $\times$ 4 ft (1.2 m $\times$ 1.2 m)-square ground plane at the same frequencies.

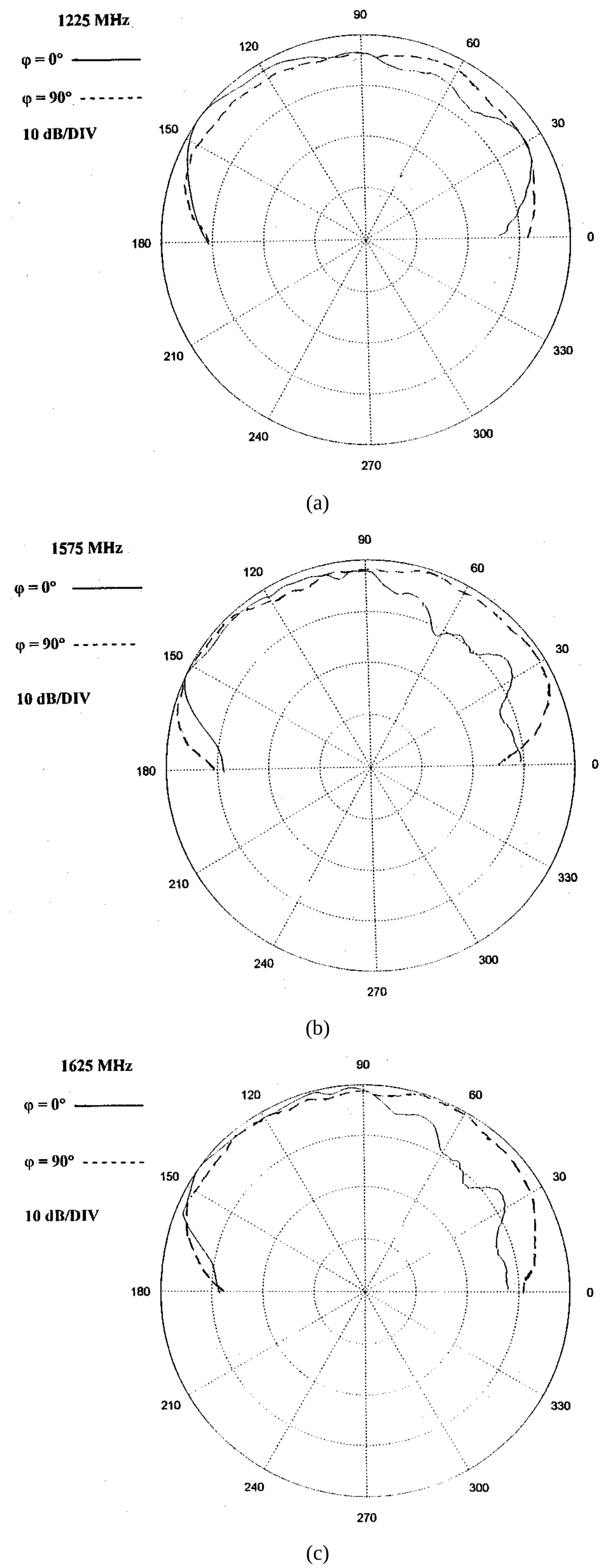


Fig. 4. (a) Measured $\theta$-plane circular polarization radiation pattern at 1225 MHz. (b) Measured $\theta$-plane circular polarization radiation pattern at 1575 MHz. (c) Measured $\theta$-plane circular polarization radiation pattern at 1625 MHz.

### *A. Computations*

Ideally, we would like the antenna gain to remain reasonably uniform over most of the hemisphere and then drop sharply at an elevation angle of about 5°. Since this coverage is not generally possible to achieve in practice and since coverage over a 150° sector is considered acceptable for most applications, we specifically examined the antenna patterns for coverage for 5°, 10° and 15° above the horizon. We found that the response to a circularly polarized wave changed only gradually as a function of both angle and frequency. Therefore, computations at increments of 30° in angle and 100 MHz in frequency provided results that we believed were representative of antenna performance. We found that for 150° coverage (15° above the horizon) there is a maximum variation of 8 dB in gain at 1225, 1575, and 1625 MHz. For 160° coverage, there is a variation of less than 9 dB. Finally for 170° coverage the variation in gain is under 12 dB.

Elevation cuts corresponding to azimuth angles of 0° and 90° and frequencies of 1225, 1575, and 1625 MHz, which are representative of all angles, are shown in Fig. 2(a), (b), and (c), respectively. We note that for almost all patterns the minimum level of radiation occurs at the low elevation angles so coverage is excellent over most of the hemisphere. It should be mentioned that true circular polarization is not achievable for wide angular coverage. From a practical standpoint, we have elliptical polarization for which the magnitudes of the orthogonal signals approach unity and their respective phases approach quadrature. Note that as long as the receiving antenna has the same sense polarization as the transmitter, the maximum polarization loss of 3 dB occurs when the receiver is linearly polarized. If the receiving antenna has the opposite sense polarization, the polarization loss will become very large. The VSWR's, as shown in Fig. 3, were under 2.0 at the design frequencies of 1225 and 1625 MHz; the value at 1525 MHz was slightly higher.

### B. Measurements

The genetic antenna shown in Fig. 1 was built and tested. This was hand made to an accuracy of about ±2 mm as compared to the computed model. We expect that the accuracy should not significantly affect the results since the antenna is not highly resonant. The measurements were conducted at the same frequencies and azimuth angles as the computations. The main difference between computations and measurements was that the computations were done for the antenna over an infinite ground plane while the measurements were made over a finite ground plane. This difference affects both the antenna pattern and the VSWR [7]. The finite size of the reflector produces two effects on the pattern: it decreases the radiation at the lower elevation angles and the reflection off the edge causes a ripple in the pattern. The edge reflection also affects the VSWR.

In Fig. 4(a), (b), and (c), we show the 0° and 90° elevation cuts of the measured antenna patterns at frequencies of 1225, 1575, and 1625 MHz, respectively. The larger variability in signal level over that which was computed was partially due to the finite ground plane. The range of power showed a variation of about 7, 9, and 11 dB for 150°, 160°, and 170° coverage, respectively, at 1225 MHz. The coverage at 1575 and 1625 MHz was somewhat poorer due to low radiation at the low elevation angles at an azimuth angle of 0°. At these angles, the power was about 12 dB down from the peak at both frequencies. Note that the coverage for an azimuth angle of 90° was excellent. The VSWR's were under 2.0 at the design frequencies but slightly over 3.0 at other frequencies across the band. These VSWR's are plotted in Fig. 3 along with the computed values.

## IV. Summary

We have demonstrated that it is possible to design a relatively broad-band antenna having nominal circular polarization and near hemispherical coverage using a genetic algorithm. Four GPS receiving antenna designs have been previously examined; a circularly polarized patch antenna, an array of square helical antennas, a quadrifilar helical antenna, and a conical spiral antenna [1]. The top priorities in GPS antenna design were dual-frequency operation, the radiation pattern slope near the horizon and circular polarization. The conical spiral antenna provided the most promising results. However, this antenna had to be placed on lossy absorbing material and was about two wavelengths in height. The genetic crooked-wire antenna has characteristics that are comparable to those of the conical spiral at both GPS L1 and L2 bands and also operates over the IRIDIUM band of 1610–1626.5 MHz. In addition, it is much smaller than the conical spiral and does not need absorbing material. It is a very inexpensive antenna since it is fed directly from a coaxial cable and does not require multiple inputs or a phasing network. We believe that this new process may revolutionize the design of wire antennas.

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