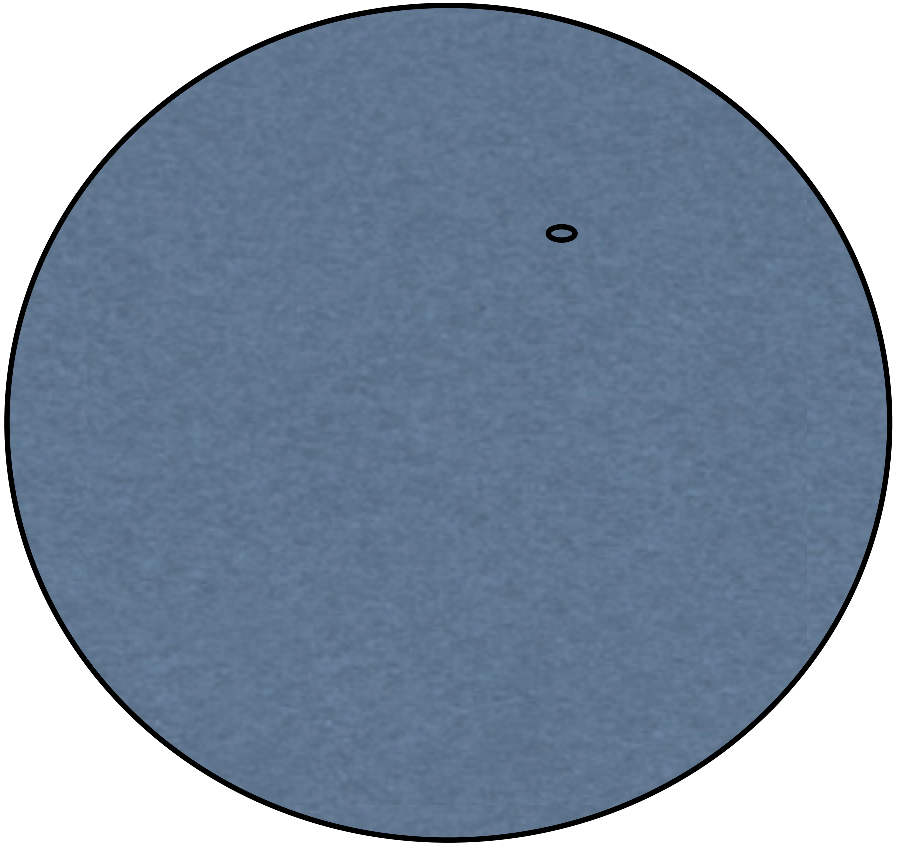
Problem Solving



Find solution in space of possible solutions.... Search

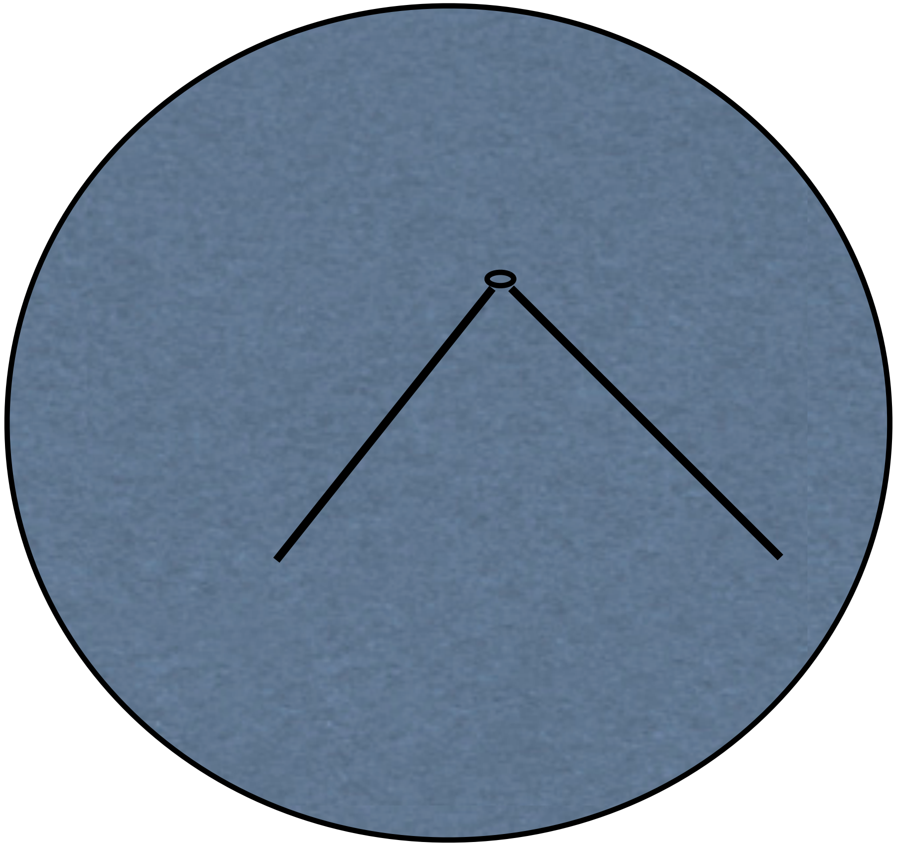
Tough Problem

- decode an encrypted message
- wrong key... garbage out
- 128 bit key
    - thousand billion, billion, billion keys

Problem Solving

- Look for successful approaches/analogies
  - with natural or other human activities

Problem Solving

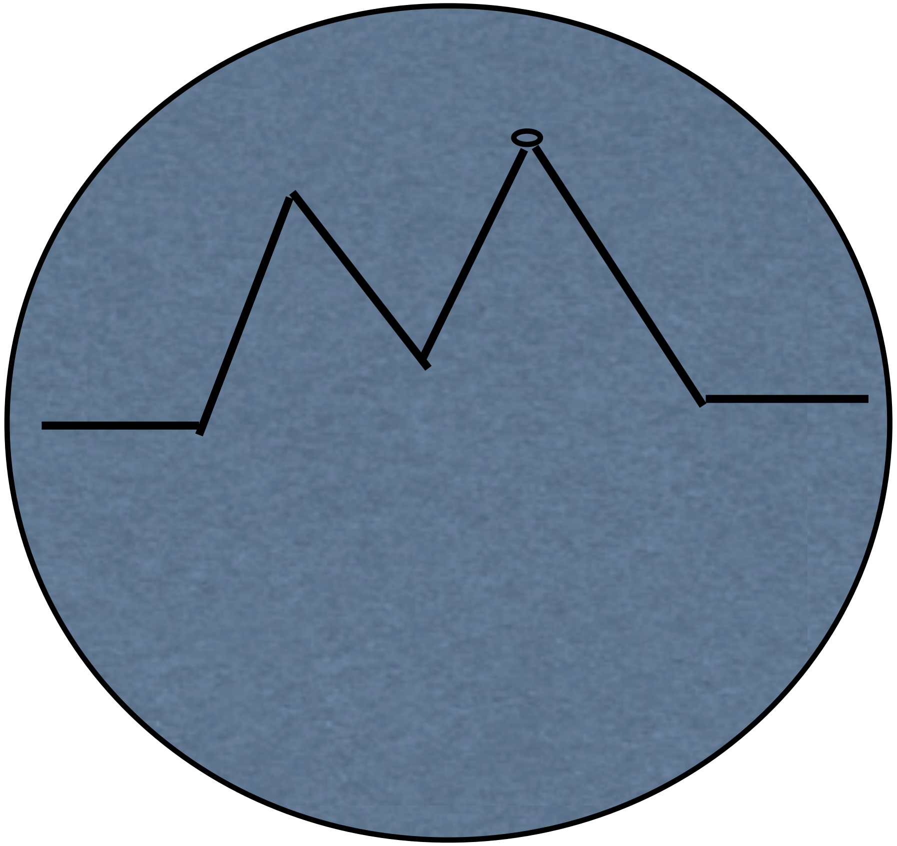


Suppose have some metric to measure how good a proposed solution is...... Hill Climbing

Easy Problem

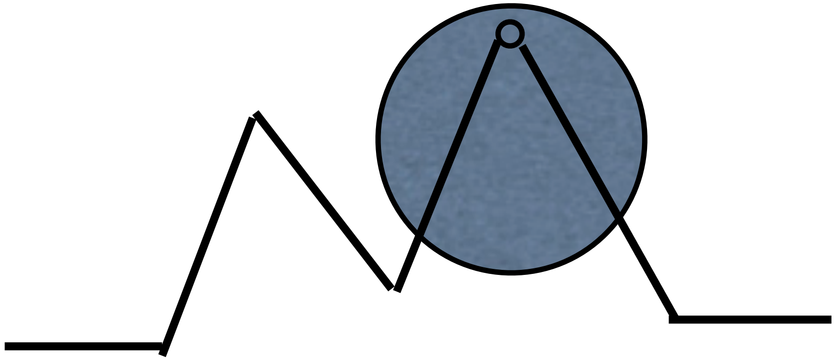
- Suppose when try a key, we know how many bits we have right
- key = start somewhere
  - while (not at key)
    - key = change bits until find one closer
- report the key k

Problem Solving



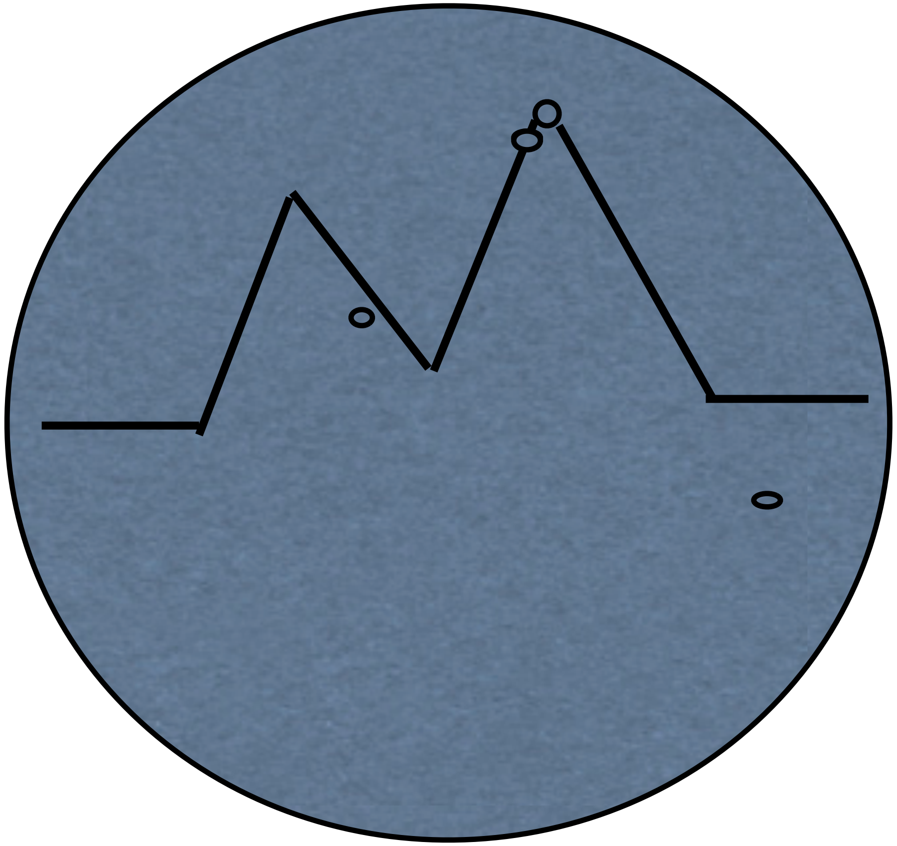
Hill Climbing .. many hills to climb.... and flats to cross

Problem Solving



Make the Problem Space smaller.....

Problem Solving



Search many times from different places.....

Problem Solving

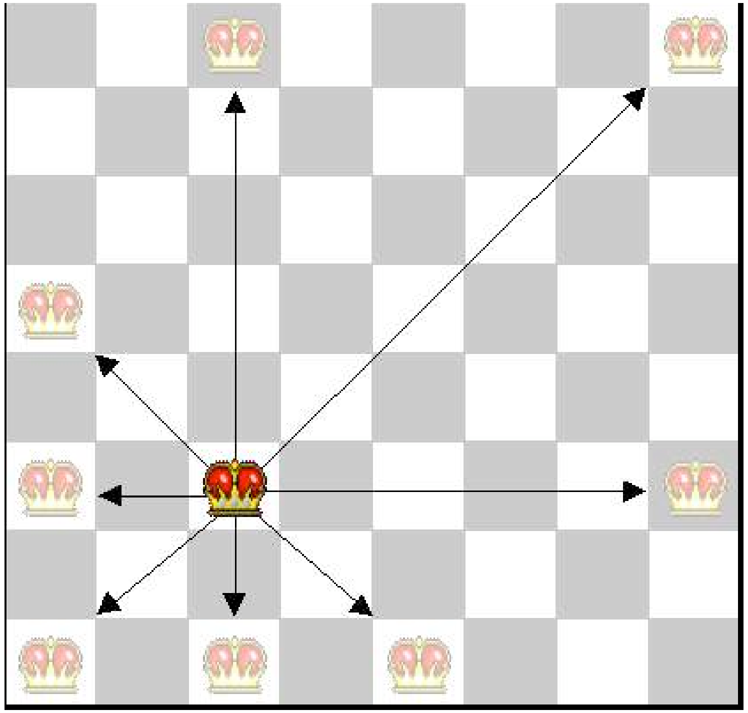
Let’s think of another analogy.......

evolution

proposed solution ... individual
fitness function .... environment
set of proposed solutions .. population

Problem Example

- 8 Queens Problem
  - place 8 queens on a chess board so that no two queens attack each other



Genetic Algorithms

- individual
  - represented by a linear *genotype*
    - genotype encodes a proposed solution

Genetic Algorithms

- 8 Queens Genotype
  - sequence of 8 integer values between 1 and 8, representing where in each column a queen is placed
    - example: 8 4 5 3 2 5 1 2

Genetic Algorithms

- Genetic Operators
    - *mutation* ... "small" change to genotype, as per error in genetic process
    - *crossover* ... combining two genotypes to create one or two new genotypes

Mutation

- 8 Queen Mutation
  - “add 1” to a random location
  - 6 3 7 3 2 5 1 4 -> 6 3 8 3 2 5 1 4
      -

Genetic Operations

- crossover
  - *point crossover*: pick location at random
    - and swap two parts..
  - *uniform crossover*: choose value for each
    - location at random from two genotypes

Crossover

- 8 Queens Point Crossover
  - 1 4 | 7 3 2 5 1 4
    - -> 6 3 7 3 2 5 1 4
  - 6 3 | 5 2 6 2 7 3

Genetic Algorithms

- Fitness Function   f
  - range from 0.0 to 1.0 (if normalized)
    - 0.0 is least fit... 1.0 is most fit

Fitness Function

- 8 Queens Fitness Function
  - $(56 - \sum_i(\text{attacks by queen}_i))/56$
    - i.e., percent of queen pairs not attacking

Genetic Algorithms

- Selection of Parents
  - directly related to relative fitness of individuals in the population
    - $p_i = f_i/\sum f_j$
      - p_i is probability that indiv. i is chosen
      - f_i is fitness of indiv i

Genetic Algorithm

```
• pop = generate random population
• epop = evaluate(pop, f);
• while( not done )
    • parents = select parents(epop)
    • pop = mutate(crossover(parents))
    • epop= evaluate(pop,f)
• report results
```

Genetic Algorithms

- to apply genetic algorithms must
  - determine genotype representation
  - define genetic operators
  - define fitness function
  - define selection function

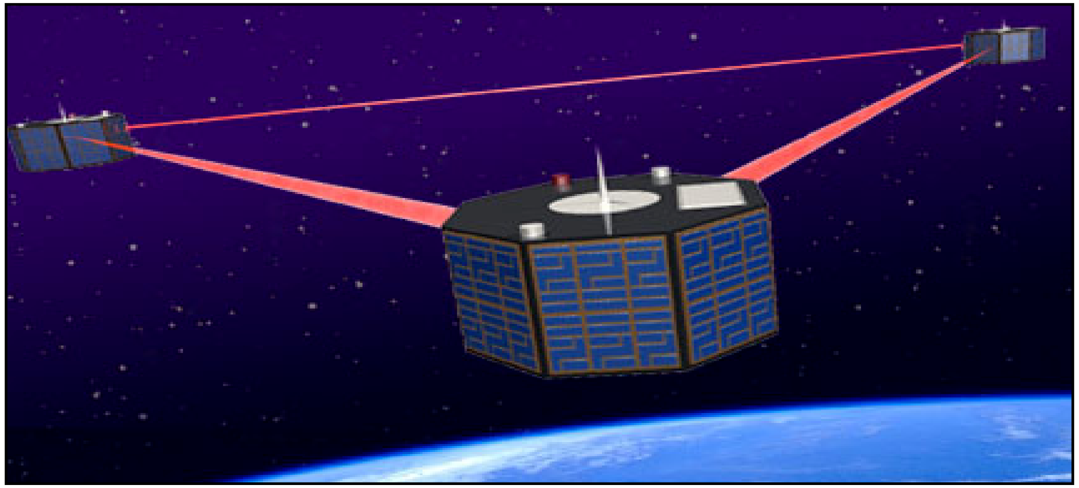
Genetic Algorithms

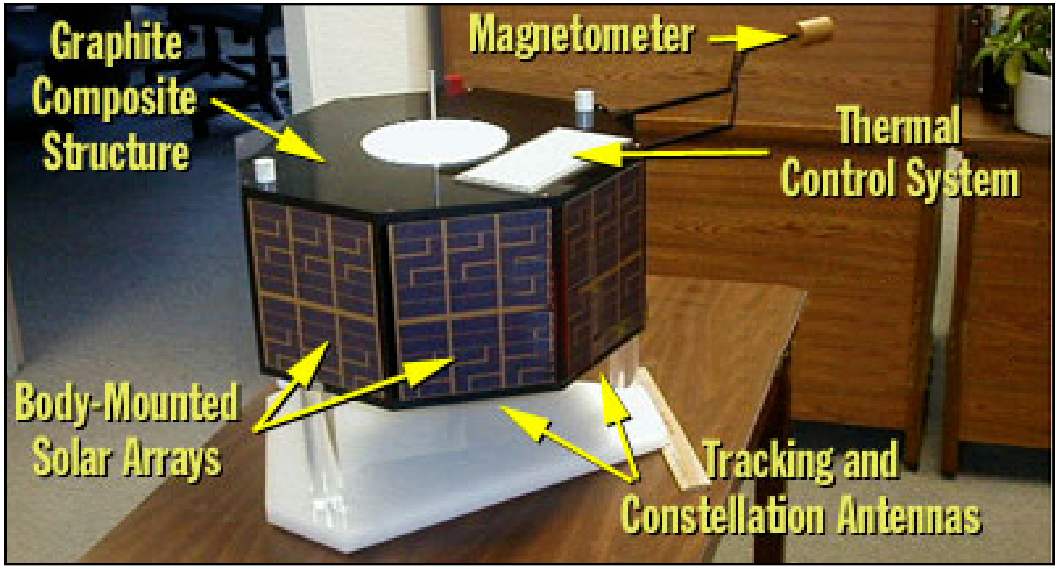
Can they to anything useful?

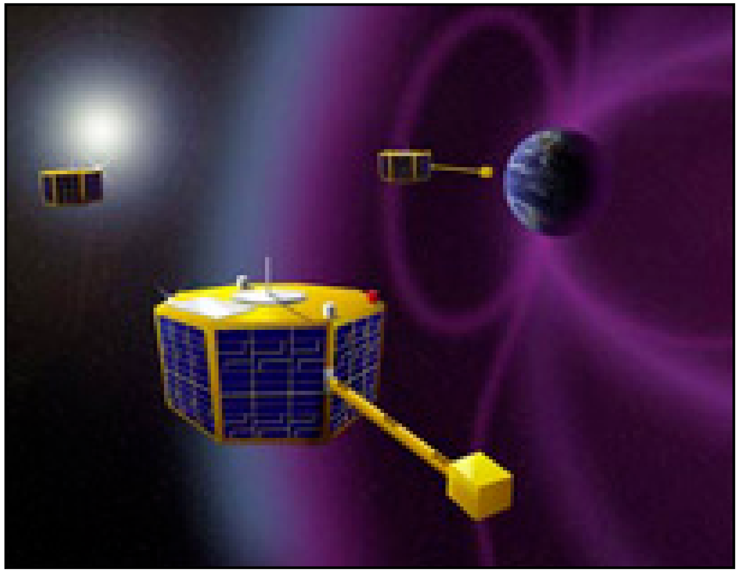
Can they do anything better than human experts?

ST5 Mission

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







Original ST5 Antenna Requirements

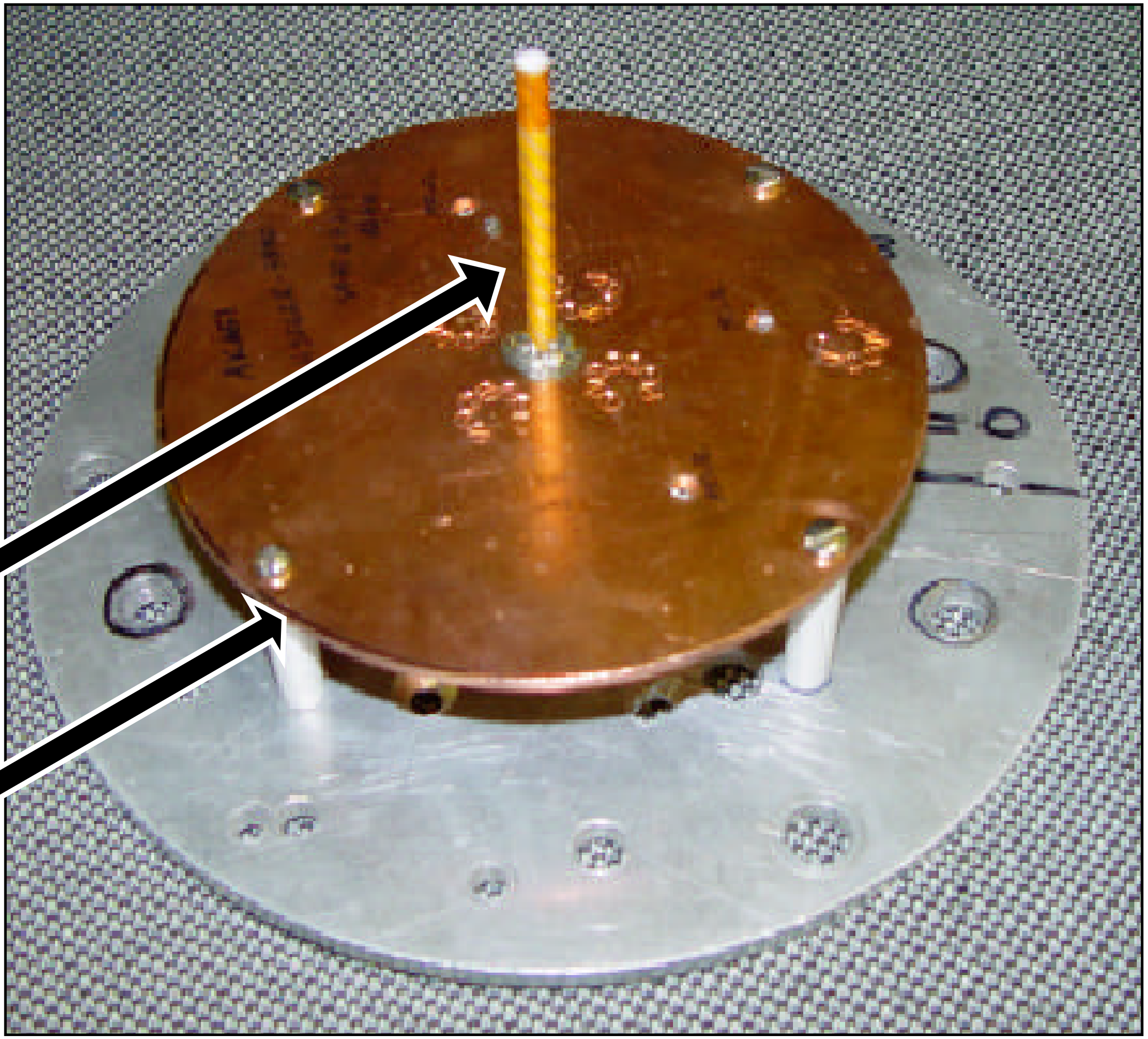
- Transmit Frequency: 8470 MHz
- Receive Frequency: 7209.125 MHz
- Antenna RF Input: 1.5W = 1.76 dBW = 31.76 dBm
- VSWR: < 1.2 : 1 at the antenna input port at Transmit Freq, < 1.5 : 1 at the antenna input port at Receive Freq
- Antenna Gain Pattern: Shall be 0 dBic or greater for angles 40 <= theta <=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

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

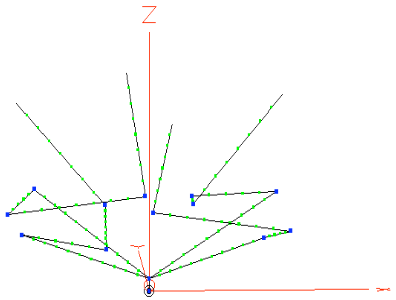
Ultimate Goal

- 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 ob ained with the antenna mounted on the ST5 mock) shall be 0.0 dBic (relati to anisotropic cularly ized reference) for angles 4 heta < 0 < <= where theta and phi are angles as defined in th ntennas, with acecraft top deck. in reference to a right
- Desi a = 80, 4 dBic for theta = 90,
- Antenna Input mpeda 50 at the a enna input port
- Magnetic dipole mome t: < 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.

Requirements

Algorithm

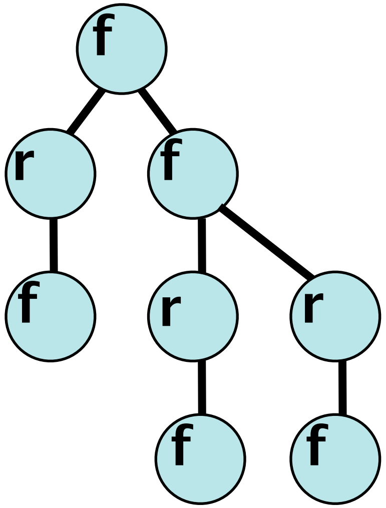
Small Amount of Antenna Design Expertise

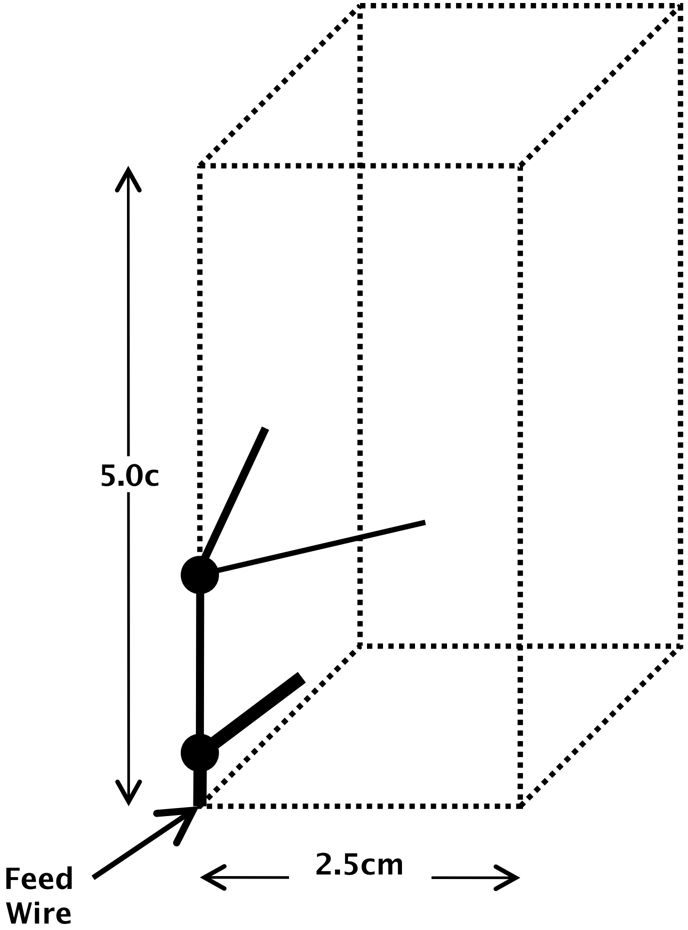


Antenna Design

Antenna Genotype

- Genotype is a tree-structured encoding that specifies the construction of a wire form
- Genotype specifies design of 1 arm in 3-space:



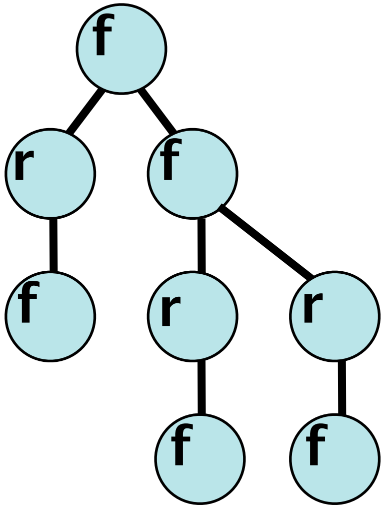


- Branching in genotype results in branching in wire form

Antenna Construction Commands

- Commands:
    - forward(length radius)
    - rotate_x(angle)
    - rotate_y(angle)
    - rotate_z(angle)

- Forward() command can have 0,1,2, or 3 children.
- Rotate_x/y/z() commands have exactly 1 child (always non-terminal).



Genetic Algorithm

- Generational.
- Rank-based selection with elitism of 2.
- Population=200 (sometimes seeded w/ individuals from previous run).
- Recombination, mutation mutually exclusive.
- Recombination: 1pt, 50%.
- Mutation: 50%:
  - Add/delete node (for adds: terminals remain terminals),

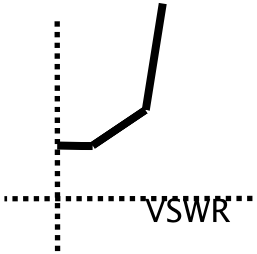
  or

  - Mutate node type/parameter.

Fitness Function

- Antenna designs are evaluated by NEC4 running on Linux Beowulf supercomputer (80 processors)
- 4 evaluations (3 w/added noise) for each design
- Fitness function (to be minimized):

  F = VSWR_Score * Gain_Score * Penalty_Score
- VSWRs from both freqs are scaled and multiplied

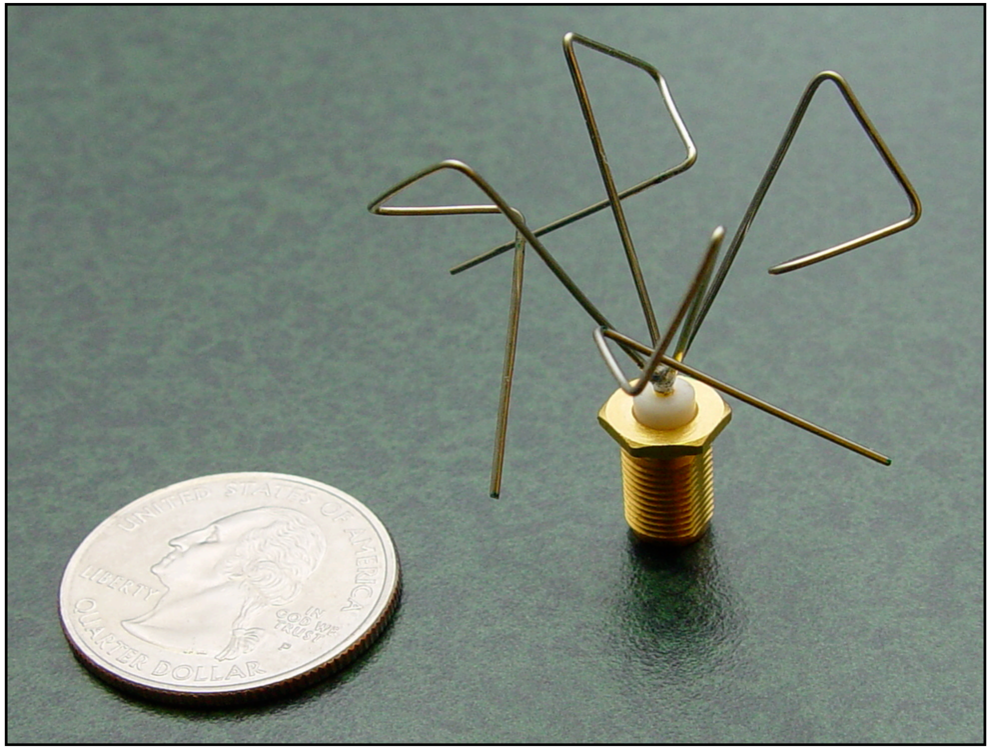


- Gain is sampled at 5 degree increments between theta=40 and theta=90

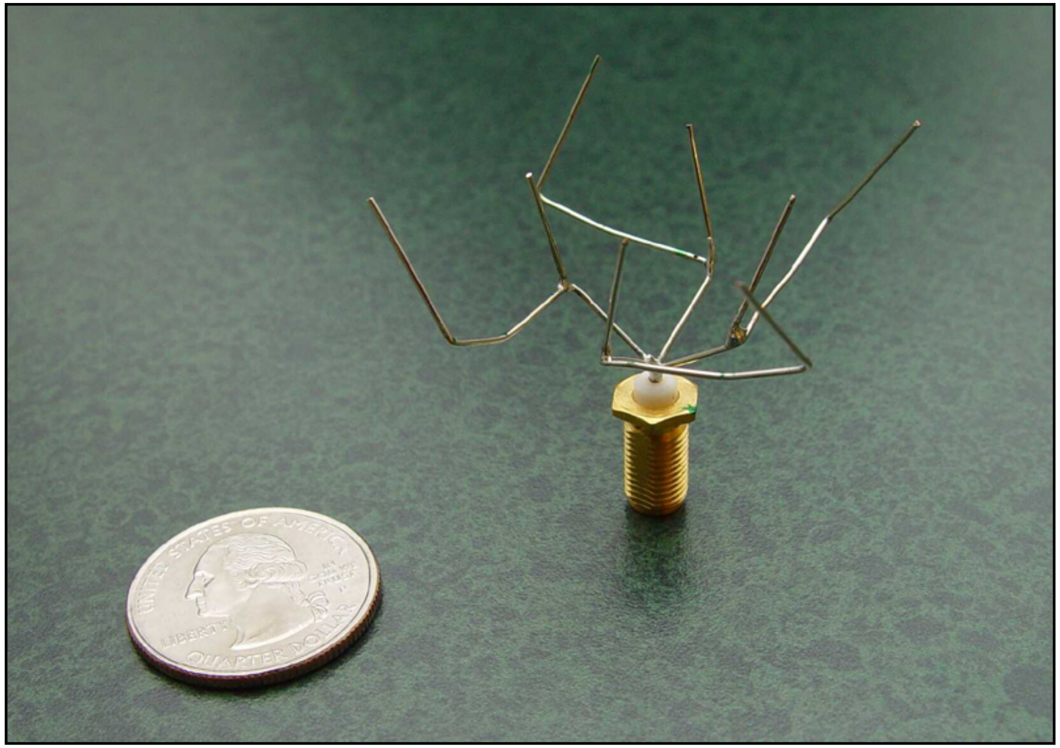
  f = 0 if gain > 0.5 dB

  f = 0.5 – gain if gain < 0.5 dB
- Penalty: proportional to # gain samples less than 0.01 dB

1st Set of Evolved Antennas



Non-branching:
ST5-4W-03



Branching:
ST5-3-10

Mission Changed

- **Launch vehicle change:** spacecraft will go into LEO (low-earth orbit)

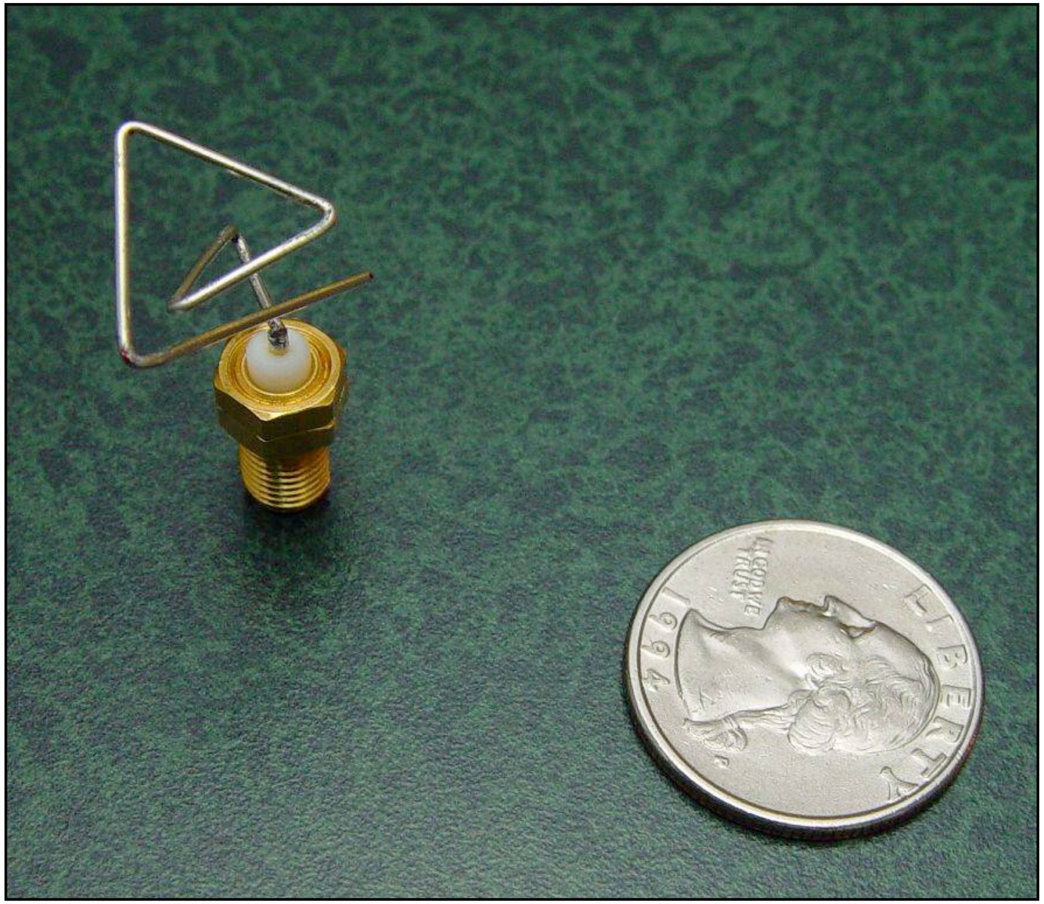
- **New antenna requirements:**
  - Deep null at zenith not acceptable, so no way to salvage original design
  - Desire to have wider range of angles covered with signal:
  - Gain:
    - >= -5dBic, 0 to 40 degrees
    - >= 0dBic, 40 to 80 degrees

  - Quadrifilar helical antenna still ok

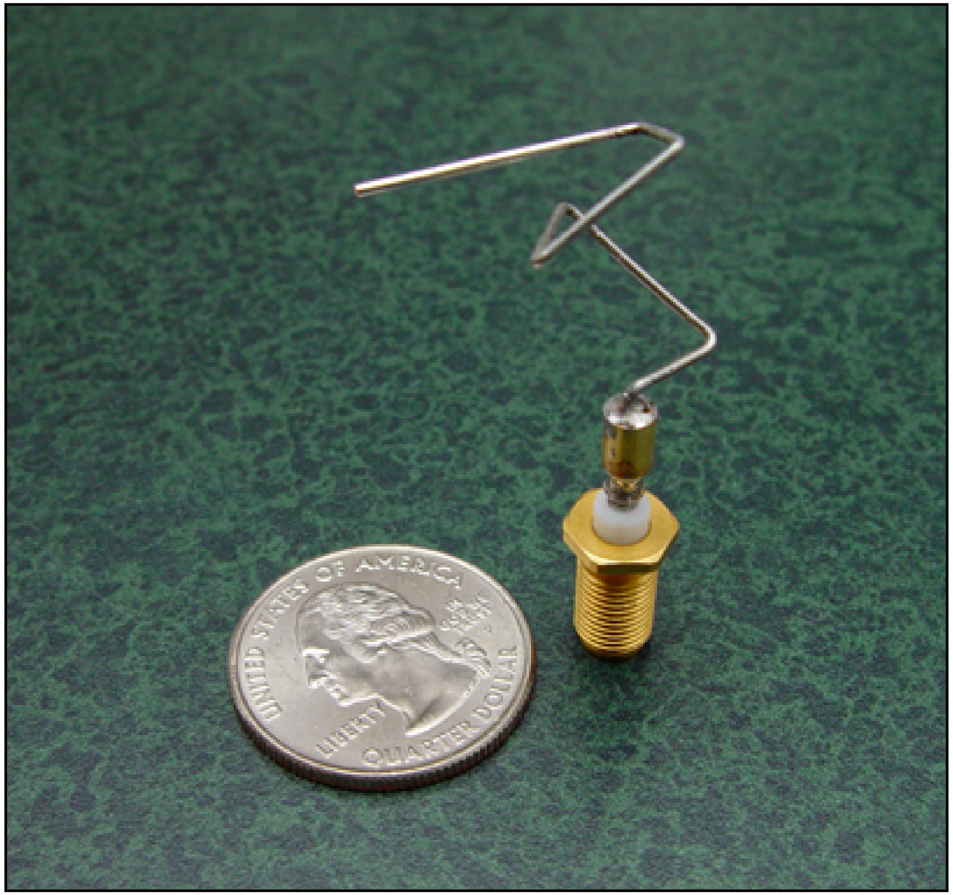
Rapid Response to Changing Requirements

- Within 4 weeks they re-evolved new antennas & had prototype hardware
- Initial testing leads us to believe that these antennas may yield better coverage

2nd Set of Evolved Antennas



EA 1 – Vector of Parameters



EA 2 – Constructive Process

Conclusion

- Evolved an antenna for ST5:
  - Meets mission requirements.
  - Better than conventional design.
  - Meets space qualification.

- Evolutionary design/optimization:
  - Fast design cycles save time/money.
  - Fast design cycles allow iterative “what-if”.
  - Can rapidly respond to changing requirements.
  - Can produce new types of designs.
  - Able to produce designs of previously unachievable performance.

Problem Solving

- Other “nature-based” Analogies
  - ant colonies
  - neural networks

Ant Colonies

- ants go out and search
  - choosing which way to go based on pheromone strength .. more strength more likely to go that way
  - depending on what they find they leave a trail of pheromone.. better results, more pheromone

Artificial Neural Networks

- neurons in a network
  - neuron activation level is function of sum of inputs
  - neuron output based on activation level
  - inputs based on connection weight and neuron output traversing the link
  - input, output and feedback neurons

Learning in Artificial Neural Networks

- given an input activation
  - network passes activations through “hidden layers” to outputs
  - get feedback on output activations
  - increase/decrease weights slightly to approach desired output activations