Using Simulation and the NSGA-II Evolutionary Multi-Objective Algorithm in the Design of a Compact Dual-band Equatorial Helix Antenna

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Outline

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1. Antenna Requirements
   - Aim
   - Requirements
2. Experimental Work
   - Simulator
   - Meta-heuristics & NSGA-II
   - Results
3. Conclusions and Future Work

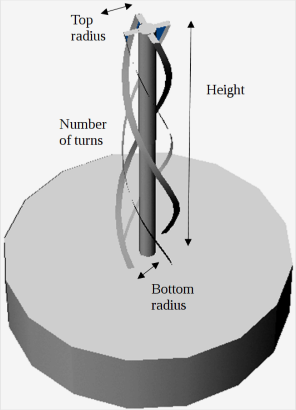
Antenna Design: Aim and Objectives

Antenna Design

To explore the application of

- simulation
- a multi-objective algorithm

to optimize the design parameters of an antenna with very stringent constrains.



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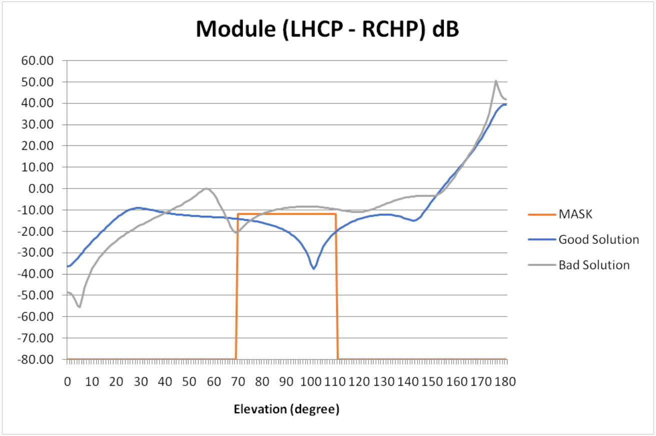
Requirements

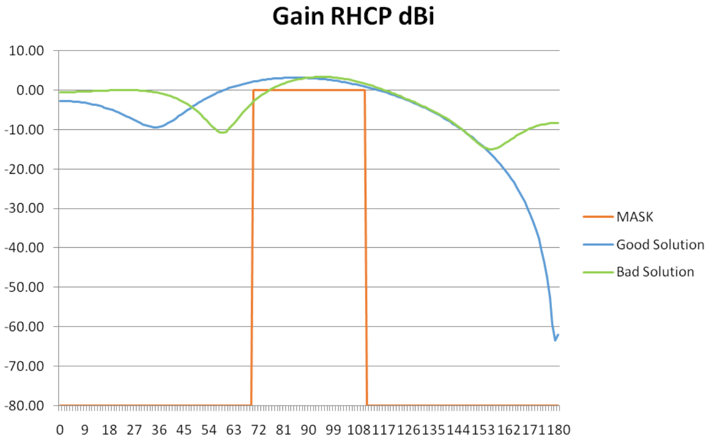
- Dual Band operation: 1.81GHz and 2.55GHz in the S Band
- Right hand circular polarization (RHCP), the main electrical field that radiates the antenna.
- Peak max gain greater than 2 dBi for RCHP polarization.
- Min gain of 0dBi in the range coverage for RHCP polarization.
- Cross-polar polarization level smaller than -12dB
- The above specifications in an equatorial radiation pattern had to be satisfied in the elevation angle with a range between 70 and 110 degrees.
- The weight of the prototype had to be as small as possible, therefore it was important to have small dimensions.

Requirements

Cross-polar Objective



Requirements
Gain Objective



Outline

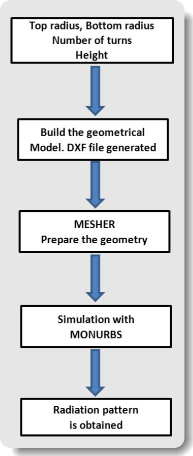
Simulator

Simulator

Explores the application of

- builds the geometrical model
- prepares the model to be simulated
- simulates the antenna to obtain the radiation patterns

to be processed by the multi-objective algorithm.



Outline

Meta-heuristics

- **Meta-heuristics** are a family of approximate optimization techniques for solving the computational problem.
- **Evolutionary algorithms (EAs)** are particularly desirable to solve **Multi-Objective Optimization problems (MOOPs)**
  - Those that involve multiple and conflicting objective functions.
  - There are multiple valid solutions that are defined using the *Pareto front*.

The set of non-dominated solutions, also known as *Pareto-optimal*, constitute the *Pareto front*, i.e., a set of solutions for which no objective can be improved without worsening at least one of the other objectives.

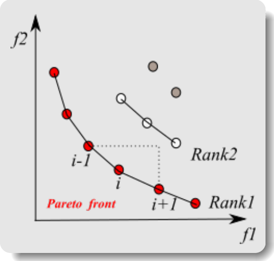
NSGA-II

Non-dominated Sorting Genetic Algorithm-II

NSGA-II (Non-dominated Sorting Genetic Algorithm-II) is the most popular and still state of the art multi-objective algorithm developed by Deb et al.

The population individuals are evaluated (i.e. assigned fitness values) in relation to:

- How close they are to the *Pareto front*
- A *crowding* measure. NSGA-II also considers the sparsity (density) of the individuals belonging to the same rank using a crowding measure (the Manhattan distance among individuals).



NSGA-II

$P \leftarrow$ **makeInitalRandomPopulation**() ▷ Initial Population of size N
antennaSimulation(P) ▷ Call the simulator
$t \leftarrow 0$
while $t \leq max\_generations$ **do**
    $Q \leftarrow$ **makeNewPopulation**(P)
    antennaSimulation(Q)
    $R \leftarrow P \cup Q$ ▷ Combine parent and offspring populations
    $\mathcal{F} \leftarrow$ **fastNonDominatedSort**(R) ▷ Compute *Pareto Ranks*, $\mathcal{F}_1, \ldots, \mathcal{F}_l$
    $P \leftarrow \emptyset \wedge i \leftarrow 1$
    while $|P| + |\mathcal{F}_i| \leq N$ **do** ▷ While population size is not full
        $P \leftarrow P \cup F_i; \;\; i \leftarrow i + 1$ ▷ Include the ith rank into the population
    end while
    if $|P| \neq N$ **then**
        crowdingDistance($\mathcal{F}_i$) ▷ Calculate crowding measure in $\mathcal{F}_i$
        $P \leftarrow P \cup$ **bestCrowdingSols**($\mathcal{F}_i, |P| - N$) ▷ Add $|P| - N$ best solutions
    end if
    $t \leftarrow t + 1$
end while
$\mathcal{F} \leftarrow$ **fastNonDominatedSort**(R) ▷ Compute *Pareto Ranks*, $\mathcal{F}_1, \ldots, \mathcal{F}_l$
return $\mathcal{F}_1$ ▷ Return the best *Pareto rank*

Execution parameters

Antenna Ranges

- No. of turns: [0.2, 3]
- Bottom radius: [0.01, 0.067]
- Top radius: [0.01, 0.067]
- Height: [0.01, 0.5]

NSGA-II Parameters

- Population size: 50
- Max no. of iterations: 100
- Simulated binary crossover
  - Crossover probability: 90%
  - Crossover distribution index: 20
- Polynomial mutation
  - Mutation distribution index: 20
  - Mutation probability: 25%

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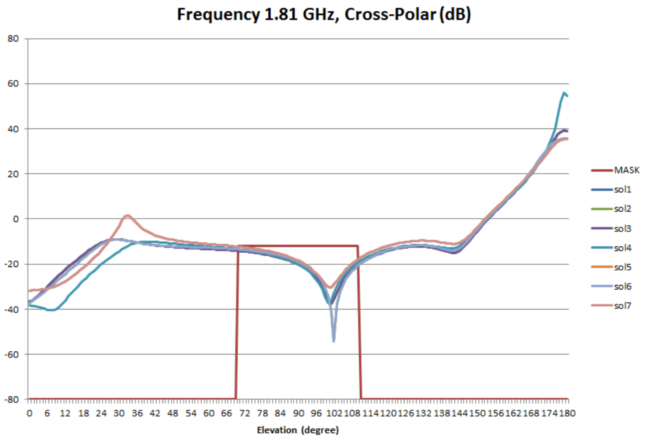
Results

Solutions found by using jMetal and MONURBS

Algorithm	Turns	Bottom	Top	Height
GD	0.831	1.945	1.022	13.8
NSGA-II 1:	0.786665455	2.45821492	1.373155458	10.007858
NSGA-II 2:	0.786665455	2.33895369	1.373155458	10.1971342
NSGA-II 3:	0.786665455	2.45821492	1.373155366	10.007675
NSGA-II 4:	0.7907970555	2.45791823	1.450520708	10.007858
NSGA-II 5:	0.7765074908	1.92872455	1.407211304	11.449133
NSGA-II 6:	0.786665455	2.33895355	1.373155366	10.1971342
NSGA-II 7:	0.7765074910	1.92872635	1.407211304	11.449401

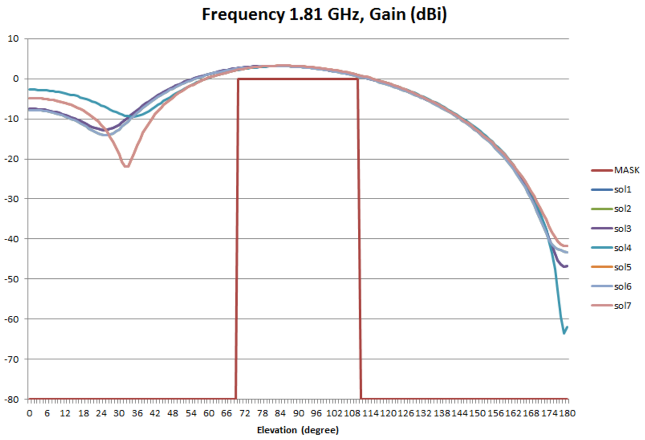
Results

Results for cross-polar objectives for frequency 1.81 Ghz



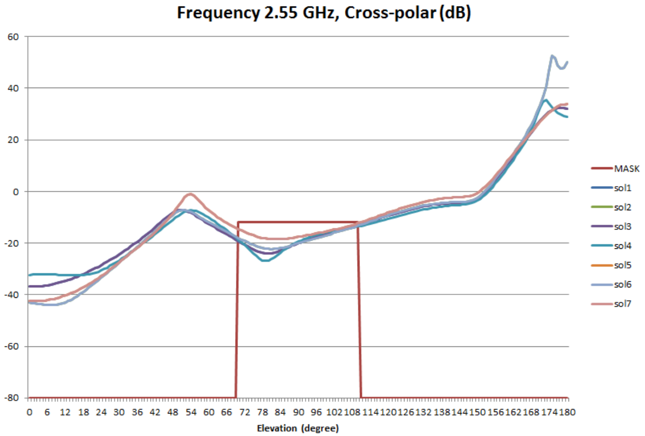
Results

Results the gain objective for frequency 1.81 Ghz



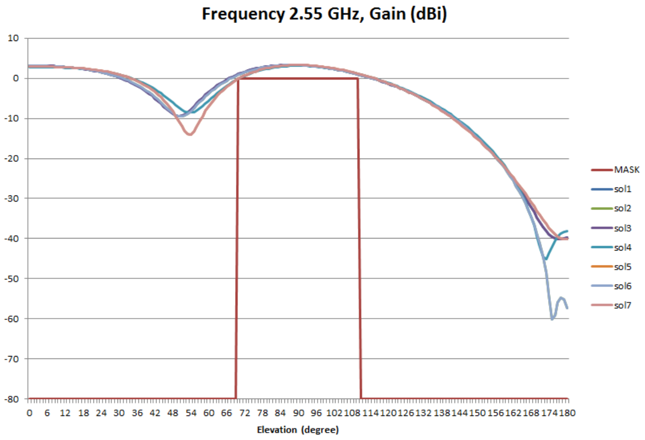
Results

Results for cross-polar objectives for frequency 2.55 Ghz



Results

Results for the gain objective for frequency 2.55 Ghz



Conclusions and Future Work

Conclusions

- We presented an antenna design process
- Effective way to find parameters
- Multiple solutions that allow telco engineers some design flexibility

Future Work

- Explore other multi- and many-objective algorithms
- Optimize execution times
  - Algorithms and communication
  - Clusters and multiprocessors

Thank you for your attention!