Multiobjective Patch Antenna Design by using Achievement Scalarization Function with Nonlinear Programming Algorithm

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Patch Antenna: Introduction

- A patch antenna is a low profile, surface mountable and easy to integrate microstrip antenna
- It consists of planar rectangular, circular, triangular or any geometrical patch of metal on the substrate
- This paper focuses on rectangular patch antennas

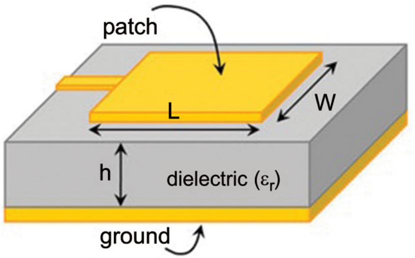


Figure: A Rectangular Patch Antenna

Patch Antenna: Features

- Good perfomance
- Low cost of fabrication cost and the substrate
- Small size and less bulky
- Can operate at microwave frequencies
- Easy construction of antenna arrays

Patch Antenna: Operation

- Operate based on the principle of radiating electromagnetic waves
- When a RF frequency strikes the patch, it generates electric and magnetic fields leading to the emission of electromagnetic waves
- To maximize the radiation efficiency, patch antennas are designed to operate at resonating frequency
- Resonance occurs when the wavelength of the RF signal matches the dimensions of the patch

Patch Antenna: Applications

- Mobile and satellite communications
- Global Positioning System (GPS)
- Radio Frequency Identification (RFID)
- Medicinal Applications (Treatment of malignant tumours)

Patch Antenna: Problem Definition

- Microstrip antennas are preferred by the engineers due to their applicability range and easily manufacturing
- But, one of their weaknesses is their narrow bandwidth
- For designing an antenna at a desired resonant frequency, we should determine the exact values of the width (w), length (l), height/thickness (h)
- Minimizing the thickness of the metal in a patch antenna reduces weight, profile, and manufacturing costs and improves flexibility and resonance properties
- The optimum values for the above values have a direct effect on the well designed device

Patch Antenna: Objectives

1. Optimize the dimensions of the rectangular patch antennas for desired frequency i.e.,
   Minimize $|f_{r_{desired}} - f_{r_{calculated}}|$ (variables: w, l, h)
2. **Minimize** the thickness of the metal patch (variable: h)

The resonant frequency of the antenna is given by:

$$f_{r_{calculated}}(W, L, h) = \frac{c_0}{2(L+\Delta W)\sqrt{\epsilon_e(W)}}$$

Patch Antenna: Objectives (Continuation)

Where,

- c_0 is the speed of light in vacuum
- $\epsilon_e(w)$ is the effective dielectric constant

The effective dielectric constant is given by:

$$\epsilon_e(W,h) = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2(1+\frac{10h}{W})^{0.5}}$$

Where,

- ϵ_r is the dielectric constant of the substrate

The parameter ΔW is given by:

$$\Delta W = 0.412h\frac{(\epsilon_e(W)+0.3)(W/h+0.264)}{(\epsilon_e(W)-0.258)(W/h+0.813)}$$

Methods To Achieve Objectives

To achieve the above objectives, we can use:

1. Achievement Scalarization Function can be used to convert the above objectives into a single objective.
2. The single objective (NLPP with 3 variables) can be minimized using Sequential Quadratic Programming

Plan of Action

1. Implement the mentioned algorithm (ASF + SQP) in python
2. Test the algorithm on ZDT1 and ZDT2 benchmark problems
3. Verify the Pareto Fronts of the benchmark
4. Test the algorithm on the actual antenna problem (data from the paper)
5. Verify the results from the paper (error and optimum values of parameters)

Implementation

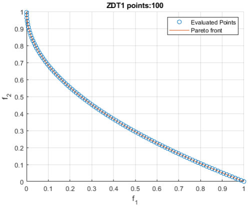
A MATLAB code is written based on the achievement scalarization function and Sequential Quadratic programming algorithms.

Benchmark problems: ZDT

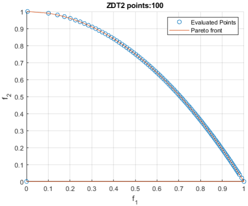
1. Series of optimization problems commonly used in the field of multi-objective optimization
2. Employed as benchmark test cases to evaluate the perfomance of different optimization techniques
3. Have different features like non-convexity, non-linearity and prescence of multiple Pareto-optimal Fronts
4. Each problem has two conflicting objectives
5. Goal of optimization is to find a set of solutions that represent a trade-off between both objectives.
6. ZDT1 has a convex Pareto front while ZDT2 has a concave Pareto front

Results on Benchmark problems

Results obtained after applying the algorithm on ZDT1 and ZDT2 for 100 reference points:



(a) ZDT1



(b) ZDT2

Antenna configurations

Table: Different antenna configurations

Ant.	$f_v(GHz)$	ϵ_r
1	6.2	2.55
2	8.45	2.22
3	7.74	2.22
4	3.97	2.22
5	5.06	2.33

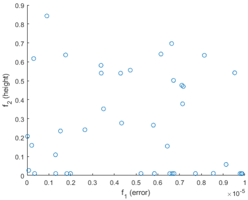
Results on Antenna

Table: Obtained optimal dimensions for all the antenna configurations in Table 1

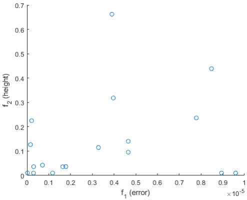
Ant. No.	length (mm)	width (mm)	height (mm)	Error
1	15.3660	23.2010	0.0100	5.1e-8
2	11.9422	17.8914	0.0100	5.33e-7
3	13.0150	6.6325	0.0100	1.71e-6
4	25.0000	25.000	0.0573	5.8e-2
5	19.4751	2.2548	0.0100	2.22e-7

Results on Antenna

Values of objective functions of antennas (1) and (2):



(a) The values of objective functions for antenna (1)



(b) The values of objective functions for antenna (2)

Conclusion

1. In this study, the application of Achievement Scalarization Function (ASF) with Sequential Quadratic Programming (SQP) to address the challenge of optimizing patch antenna design is studied.
2. The implementation of ASF+SQP was validated by applying it on two standard benchmark problems, ZDT1 and ZDT2.
3. One notable advantage of ASF is its incorporation of a reference point set, which allows a better way of exploring the solution space.
4. In conclusion, the combination of ASF and SQP is an effective approach for solving optimization problems in antenna design.