Human- and Machine Design: Resonant-Size Antennas

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Human- and Machine Design: Resonant-Size Antennas

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***Abstract*—Random-based global optimization algorithms have been widely used for antenna shape design, primarily in situations where a human-knowledge based solution is not available. In this contribution we study the behavior of random-based global optimization in situations where the design can be addressed with a standard human-based design approach and human-driven parameter tweaking via simulations. The present case study is a resonant patch-type antenna with probe feeding.**

I. Introduction

Automated antenna design encompasses many different instances and approaches, that vary from the very structured array synthesis down to common practitioner "parameter sweep" offered in commercial simulation suites. It can be always understood as an optimization problems, and sometimes it is convenient to phrase and implement it as such. The more the design instance is comprehensive, and the more it is algorithmic hard. Here we consider the full design of the antenna metal layout, that is, a shape optimization, with examples as in (e.g.) [1], [2]. This problem, like many other of practical relevance, is non-convex and non-linear. This implies the need to use, in general, global optimization algorithms, that are all random-based (like, e.g. the Genetic Algorithm, GA). A crucial problem is the attainment of the global optimum, so that one knows that if the algorithm does not converge the specifications are too tight and need to be relaxed. In general, there is no theoretical prove thereof.

A simpler, yet relevant, simplification would be having some proof that one gets a result that can be trusted.

Interestingly, random-based global optimization is typically applied to design situations where one is unable to provide a simplified model of the problem that leads to design formulas, and/or to few free parameters that are tuned via exhaustive search and simulation ("parameter sweep"). This of course is very logical.

The purpose of this contribution is different: we will address a design problem for which a "human knowledge" exist and that is routinely performed with the help of (parametric) simulations. The same design instance will be addressed as a "machine" design, i.e. a full shape optimization via a random-based global algorithm, the GA.

This will allow to make observations on the machine design, and hopefully giving indication for further use.

II. Study Case

We consider the design of a rectangular patch antenna, in air and probe-fed. Design are in most textbooks, and one usually ends the design by an exhaustive search for the probe position; this is what has been done with the results in Fig. 1 and Tab. I; a square patch has been chosen for further simplification. The serrated edges have no other meaning that allowing a higher degree of comparison with the machine design, described below.

The desing has been done (for simplicity only) at a single frequency; the impedance bandwidth has been examined a posteriori, with minor differences in all cases.

III. Machine Design

For the "machine" design we employ the GA-based algorithm and (tested) implementation described in [1], [2]. The surface of the patch is pixelated and metal pixels retained or left void, with a binary coding well suited for the GA. Pixels are hexagonal as in [2] to ensure unambiguous fabrication. The patch surface lies at a height $h = \lambda/15$ from a ground plane modeled as infinte; feeding is via a probe, simplified as a vertial strip of width $d_y = \lambda/50$; excitation is modeled as a voltage gap. The optimizaiton domain is a rectangle of size $L_x \times L_y = 0.85\lambda \times 0.55\lambda$, indicated as an overlay in Fig. 1; it has been chosen so that the probe feeding can result in a range corrsponding to that used in human design without having to move the pin junction.

In this resonant type of antennas sidelobes are not typically an issue; hence as performance indicators we initially consider: the gain at broadside, G; the input reflection coefficient Γ_{in} with respect to 50Ω, accounted via the realized gain

$$G_R = (1 - |\Gamma_{in}|^2)G \tag{1}$$

The objective (fitness) function to be maximized then follows directly as the realized gain; an example of the ensuing machine designed structure is in Fig. 3, with the gain reported in Tab. I. As it can be noticed, the gain does increase, but a larger area is occupied, with a typical tendency to form dendritic conductor shapes: this is opposite to the "human" design approach.

Hence, aperture efficiency emerged as the natural quality indicator and candidate objective function. We used the "total" effective area defined with respect to realized gain, and the *occupied area* A_{geom}, defined as the rectangle inscribing the overall metalization; this results in the "total" aperture effectiveness

$$A_{eff}^{tot} = \frac{\lambda^2}{4\pi} G_R, \quad \nu^{tot} = \frac{A_{eff}^{tot}}{A_{geom}} \tag{2}$$

Then we have optmized this total aperture efficiency, with the results in Fig. 4 and Tab. I. Finally, we have tried to force the machine design to produce more "compact" shapes; this can be done via algebric operations on the connettivity matrix of the pixels as derives from graph theory [3]. As clear from Tab. I the "external" forcing on the topology results only in adding stiffness, without overall improvement of the performance indicators.

These results, while not considerable as fully general, tend to indicate a non optimality of the specific approach for an antenna of resonant size, and the very different nature of the human and machine approaches. This result however should not be taken as an indication of ineffectiveness of the machine design or the specific implementation; for example, in the (significantly) larger case of [2] aperture efficiencies of the order of 60% is comparable to reflectors, and thus a remarkable result.

TABLE I
SUMMARY OF PERFORMANCE RESULTS

	G_R [dB]	$S11$ [dB]	ν^{tot}
Square patch	6.4	-34.3	0.80
G_R only	8.1	-20.6	0.58
G_R + Connectivity	7.9	-16.1	0.55
ν^{tot} only	8.0	-17.0	0.56
ν^{tot} + Connectivity	6.9	-26.7	0.43

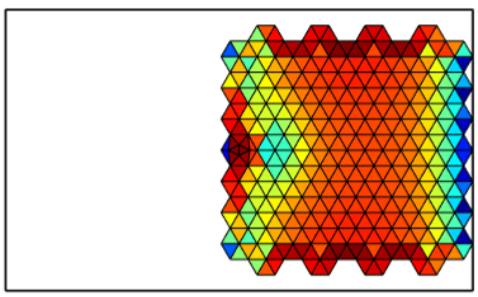

Fig. 1. Reference: square patch with optimized probe position; the rectangle overlay indicates the optimization domain used henceforth in machine design.

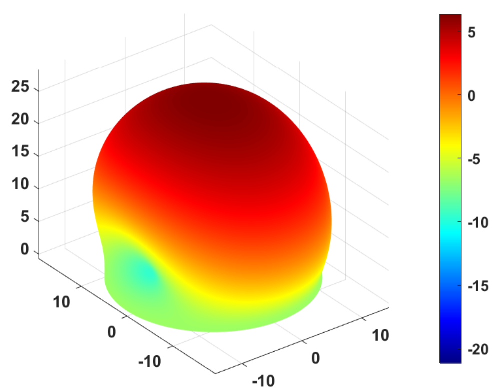

Fig. 2. Radiation Patten of reference patch

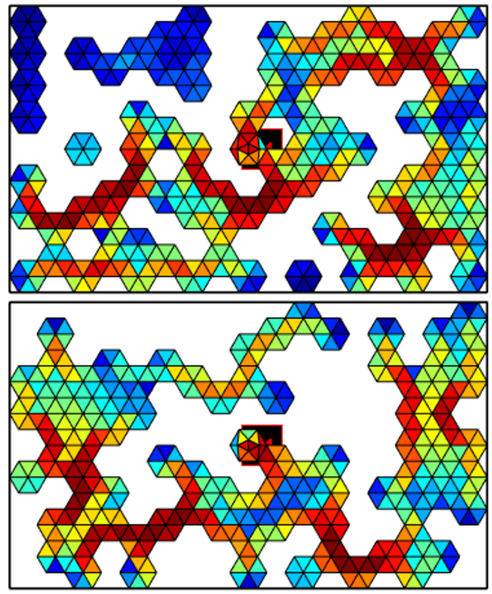

Fig. 3. Top: optimization of realized gain only; Bottom: optimization of the realized gain and simple connectivity together

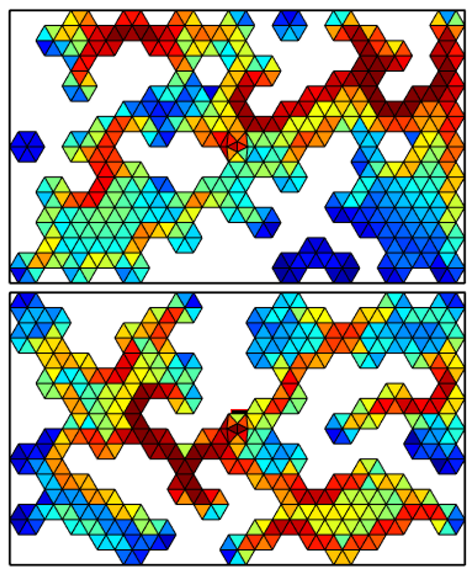

Fig. 4. Top: optimization of total aperture efficiency; Bottom: of total aperture efficiency and simple connectivity

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