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A Framework for Accelerated Optimization of Antennas Using Design Database and Initial Parameter Set Estimation

Keywords: Antenna design, design optimization, design database, electromagnetic simulation, EM-driven design.

Structured Abstract

Purpose

A design strategy that exploits a database of pre-existing designs to accelerate parametric optimization of antenna structures is investigated.

Design/methodology/approach

Usefulness of pre-existing designs for rapid design of antennas is investigated. The proposed approach exploits the database existing antenna base designs to determine a good starting point for structure optimization and its response sensitivities. The considered method is suitable for handling computationally expensive models which are evaluated using full-wave electromagnetic simulations. Numerical case studies are provided demonstrating feasibility of the framework for design of real-world structures.

Findings

Utilization of pre-existing designs enables rapid identification of a good starting point for antenna optimization and speeds-up estimation of the structure response sensitivities. The base designs can be arranged into subsets (simplexes) in the objective space and used to represent the target vector, i.e. the starting point for structure design. The base closest base point w.r.t. the initial design can be used to initialize Jacobian for local optimization. Moreover, local optimization cost can be reduced through utilization of Broyden formula for Jacobian updates in consecutive iterations.

Research limitations/implications

The study investigates the possibility of reusing pre-existing designs for acceleration of antenna optimization. The proposed technique enables identification of a good starting point and reduces the number of expensive electromagnetic simulations required to obtain the final design.

Originality/value

The proposed design framework proved to be useful for identification of a good initial design and rapid optimization of modern antennas. Identification of starting point for design of such structures is extremely challenging when using conventional methods involving parametric studies or repetitive local optimizations. The presented methodology proved to be

a useful design and geometry scaling tool when previously obtained designs are available for the same antenna structure.

Abstract

Electromagnetic-driven optimization is a necessary yet expensive step of the antenna design process. In this paper, a framework for accelerated parametric optimization of antenna structures has been presented. The proposed approach exploits a database of existing designs, presumably available from the previous work on a given antenna topology. Analysis of geometry of this base design set is conducted to produce a good initial design for further optimization. The latter stage is then expedited by estimating the antenna response sensitivities using, again, the database, as well as by incorporating the Jacobian update formulas into the optimization process. The proposed framework is illustrated using a unidirectional quasi-Yagi antenna, which is optimized for a required operating frequency and relative permittivity of the dielectric substrate, the structure is to be implemented on. A wide range of operating conditions for antenna optimization is demonstrated (3.0 GHz to 6.0 GHz for the center frequency, and 2.5 to 4.5 for permittivity). At the same time, using the proposed technique, the optimization process is concluded at the cost of just a few EM simulations of the antenna.

1. Introduction

Topological complexity of contemporary antenna structures has been steadily increasing over the years in order to meet more and more stringent specifications imposed on their electrical and field characteristics [1]-[4]. Satisfying various demands concerning broadband [5] or multi-band operation [6], circular polarization [7], [8], stable gain response [9], pattern stability [10], time-domain performance (i.e. pulse fidelity [11]), as well as additional functionalities (e.g. band notches [12], tunable performance [45]), while maintaining small physical dimensions [13], [14], requires development of unconventional geometries described by a large number of parameters that need to be tuned in order to obtain the best possible performance. At the same time, full-wave electromagnetic (EM) analysis is necessary to provide a reliable evaluation of antenna characteristics. Both of these factors make the design closure process challenging. This is not only due to sheer computational effort required to handle multi-dimensional parameter spaces but also difficulties in identifying reasonable initial designs for further (local) optimization. The latter call for global search methods [15]-[17] which increase the cost of parameter adjustment tremendously.

The challenges related to high-cost of antenna design can be addressed to some extent using surrogate-based optimization (SBO) methods. The basic SBO concept assumes that direct handling of the high-fidelity EM model is replaced by iterative construction and re-optimization of its faster representation referred to as a surrogate model [23]. The surrogate—represented in the form of a coarsely discretized EM simulation [18], or a approximation model [20] along with appropriate correction layer—is utilized as a prediction tool that facilitates identification of a better design. Meanwhile, the data accumulated from evaluations of the high-fidelity EM model featuring fine discretization help improving the surrogate model during the design process.

Both in case of direct optimization of the high-fidelity EM antenna model and surrogate-assisted procedures, especially those involving coarse-discretization low-fidelity models, lowering the computational cost of the optimization process requires reduction of the number of EM analyses (at either level of discretization). A possible way of achieving this is to utilize already existing designs of the same antenna structure, e.g. obtained for different operating conditions (such as operating frequencies) or implemented on different dielectric substrates. The purpose of this paper is to propose and demonstrate a conceptually simple but efficient technique that allows reusing such designs and, consequently, expedite the optimization process of antenna structures. The main contributions of the work include development of the approach for determination of a good starting point for antenna optimization, which is based on the analysis of the base set of pre-existing designs. Furthermore, the work introduces a modification to the trust-region-based gradient optimization process that substantially reduces the number of EM simulations required for antenna optimization. The latter is achieved by estimating antenna response sensitivities using the same set of pre-existing designs. The proposed methodology has been validated using a unidirectional quasi-Yagi antenna optimized for a maximum in-band gain within a range of operating frequencies and substrate permittivity values. The results indicate low design cost while ensuring reliability and satisfactory control over the performance figures of interest.

2. Related Work

A considerable research effort has been directed towards development of techniques that would speed-up the optimization processes. In the context of local optimization, utilization of adjoint sensitivities may bring significant benefits [18], [19], however, adjoints are not widely supported in commercial EM simulation packages. Over the recent years, a growing popularity of surrogate-based optimization methodologies has been observed [20]-[22]. The recent SBO include physics-based approaches such as space mapping [24], response correction methods [25], or feature-based optimization [26], as well as various algorithms involving data-driven (approximation) surrogates such as kriging [27], Gaussian process regression [28], or even polynomial-based response surfaces [29]. For statistical analysis and robust design applications, surrogate models exploiting polynomial chaos expansion have been gaining popularity [30], [31]. Proper tailoring of the SBO framework components to a particular problem may result in a dramatic reduction of the optimization costs [20]-[26]. In case of antennas, many surrogate-assisted methods involve underlying low-fidelity models obtained from coarse-discretization EM simulations [20], which is due to the lack of reliable alternatives (e.g. equivalent network representations).

Low-cost design optimization of contemporary antennas can be realized using approximation models or suitably corrected coarsely-discretized EM simulations [38], [39]. Approximation (or data-driven) models are particularly attractive for handling numerically demanding tasks such as multi-objective optimization [20], [27], [29], [46]. However, they also found applications for statistical analysis and material characterization [40]-[42]. In [40], kriging-based modeling was used for determination antenna substrate parameters based on the measurements of its impedance and bandwidth. A variation of the approach, oriented towards utilization of approximation-based modeling to obtain EM properties of textile materials, was proposed in [43]. Data-driven models are also useful for optimization of reflector antennas [44], or design of frequency-reconfigurable structures [45]. On the other hand, construction of accurate data-driven model requires a large number of training samples. Responses of the latter are typically expensive to obtain, even when evaluated at the low-fidelity level. Another problem is that the number of data samples required for model construction grows exponentially with the problem dimensionality [38], [46]. This hinders application of data-driven surrogates for design of multi-parameter antennas. Low-fidelity EM models proved to provide an interesting alternative for approximation-based design of high-frequency structures [39], [47], [48]. In [39], corrected physics-based surrogates were used for low-cost optimization of modern antennas. Rapid design of antenna arrays using a coarse model combined with response refinement method was considered in [47]. Also, design schemes that involve optimization of antenna responses expressed in terms of so-called response features proved to be useful for rapid design [48]. Regardless advantages, the main prerequisite for applying these design tools is that the region of interest for the problem or a starting point for optimization are available. In reality, however, such information may not be available, which increases the complexity of design problem.

3. Antenna Optimization Framework with Design Database

This section provides the details of the proposed accelerated antenna optimization using pre-existing design database. As mentioned in the introduction, the base designs might be available because of the previous design work with the same antenna structure (e.g. optimized for various operating frequencies or substrates). These can also be obtained specifically to accelerate future optimization runs. The following subsections introduce appropriate notation for the proposed methodology, describe analysis of the base designs geometry leading to generating a starting point for further optimization with respect to given operating conditions, as well as explain the accelerated optimization procedure. Illustration examples are provided in Section 4.

3.1. Design Database

Let F_k, $k = 1, \ldots, N$, denote the antenna operating conditions, material parameters or performance figures of interest (here, together referred to as objectives). Examples include operating frequency (or frequencies for multi-band antennas), operating bandwidth, permittivity and height of the substrate the antenna is implemented on, etc. A vector of adjustable parameters of the antenna will be denoted as $\boldsymbol{x}$, whereas $\boldsymbol{x}_b^{(j)}$, $j = 1, \ldots, p$, represents the database designs. These designs are optimized for objective vectors $\boldsymbol{F}^{(j)} = [F_1^{(j)} \ldots F_N^{(j)}]^T$. For practical purposes, it is desired that the vectors $\boldsymbol{F}^{(j)}$ more or less fill in the interval defined by the intended objective ranges $F_{k.\min} \leq F_k \leq F_{k.\max}$, i.e. a region in which the entire optimization framework is supposed to operate. Other than that, allocation of the base designs can be arbitrary.

3.2. Initial Design by Exploring Database Geometry

Let $\boldsymbol{F}_t = [F_{t.1} \ \ldots \ F_{t.N}]^T$ be a target vector, i.e. a set of objectives the antenna is to be optimized for. The first step of identifying the starting point for antenna optimization with respect to $\boldsymbol{F}_t$ is to arrange the base designs $\{\boldsymbol{F}^{(j)}\}_{j = 1, \ldots, p}$ into affinely independent subsets $\boldsymbol{S}^{(j)} = [\boldsymbol{F}^{(j.1)} \ \ldots \ \boldsymbol{F}^{(j.N+1)}]$. The affinely independent designs are those for which the matrix $[\boldsymbol{F}^{(j.2)} - \boldsymbol{F}^{(j.1)} \ \ldots \ \boldsymbol{F}^{(j.N+1)} - \boldsymbol{F}^{(j.1)}]$ is of full rank (in other words, the vectors $\boldsymbol{F}^{(j.l)} - \boldsymbol{F}^{(j.1)}$, $l = 2, \ldots, N + 1$ are linearly independent) [33]. Geometrically, the subsets $\boldsymbol{S}^{(j)}$ are $N + 1$ simplexes in the objective space.

For any $k = 1, \ldots, K$, the target vector can be uniquely represented as

$$\boldsymbol{F}_t = \sum\nolimits_{k=1}^{N+1} \alpha_k^{(j)} \boldsymbol{F}^{(j.k)} \tag{1}$$

where $\alpha_k^{(j)}$ are expansion coefficients such that $\Sigma_{k=1,\ldots,N+1}\alpha_k^{(j)} = 1$.

The foundation for finding the starting point is identification of the simplex $\boldsymbol{S}^{(j^*)}$ that satisfies the following conditions [34]:

- The target vector is possibly close to the center of $\boldsymbol{S}^{(j^*)}$, and
- The target vector $\boldsymbol{F}_t$ is possibly close to the vertices of $\boldsymbol{S}^{(j^*)}$ (i.e. smaller simplexes are preferred).

Clearly, these conditions are not rigorous to the extent that would permit a unique selection of $\boldsymbol{S}^{(j^*)}$. A possible quantification can be realized by defining the index j^* as

$$j^* = \min\{ j = 1, \ldots, K : std([\alpha_1^{(j)} \ \ldots \ \alpha_{N+1}^{(j)}]) \prod\nolimits_{k=1}^{N} d_k^{(j)} \} \tag{2}$$

Here, $std()$ stands for the standard deviation, and $d_k^{(j)} = ||\boldsymbol{F}_t - \boldsymbol{F}^{(j.k)}||$. Figure 1 shows several illustrative cases of the target vector $\boldsymbol{F}_t$ and $\boldsymbol{S}^{(j^*)}$ for an exemplary three-dimensional objective space.

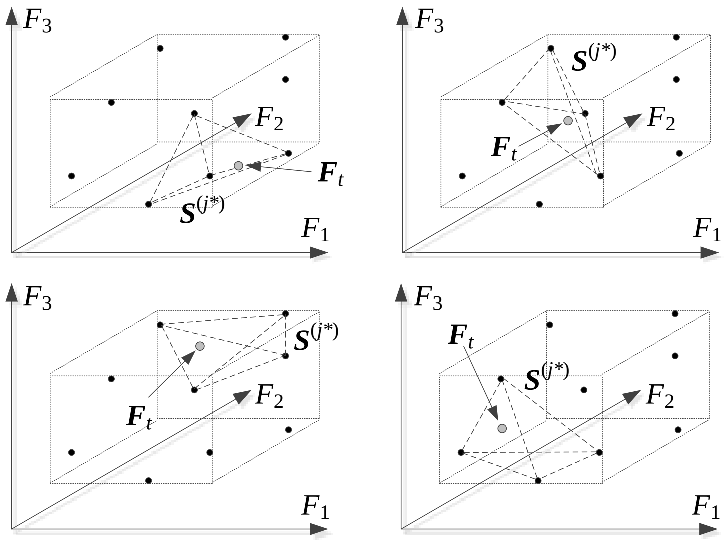


Fig. 1. Design database and objective space (here, assuming three operating conditions). Example allocation of base designs is shown using black circles, whereas several cases of example target vectors are marked using gray circles along with the corresponding selected simplexes $\boldsymbol{S}(^{j^*})$ (dashed lines).

The initial design corresponding to $\boldsymbol{F}_t$ is obtained as

$$\boldsymbol{x}^{(0)} = \sum_{k=1}^{N+1} \alpha_k^{(j^*)} \boldsymbol{x}_b^{(j^*.k)} \tag{3}$$

where $\boldsymbol{x}_b{}^{(j^*.k)}$ are parameter vectors corresponding to the vertices $\boldsymbol{F}^{(j^*.k)}$ of the simplex $\boldsymbol{S}^{(j^*)}$ selected by (2). The expansion coefficients $\alpha_k{}^{(j^*)}$ are obtained from (1). Note that the formula (3) assumes linear dependence between the geometry parameters and the objective values. While this is obviously not the case in practice—as relationship between the design and feature spaces is nonlinear—it gives the best initial design that can be found using $N + 1$ base designs. It should be noted that accuracy of prediction from (3) is expected to increase for smaller simplexes, which is one of the motivations for choosing the particular form of (2).

3.3. Optimization Procedure

Starting from the design $\boldsymbol{x}^{(0)}$ obtained from (3), the antenna is further optimized by solving the minimization problem of the form

$$\boldsymbol{x}^* = \arg\min_{\boldsymbol{x}} U(\boldsymbol{R}(\boldsymbol{x})) \tag{4}$$

where $\boldsymbol{R}(\boldsymbol{x})$ is the EM antenna model. A definition of the cost function U depends on a particular design task. For example, when optimizing for best matching over a specified frequency range, say, from f_{min} to f_{max}, one may have $U(\boldsymbol{x}) = \max\{f_{min} \le f \le f_{max} : |S_{11}(\boldsymbol{x},f)|\}$. Whatever design constraints are imposed, they can be handled either explicitly or implicitly (e.g., using penalty functions) [36]. An illustrative example of the cost function definition will be given in Section 4 for the case study considered therein.

Because the initial design provided by equation (3) is normally good, local optimization is sufficient to carry out design closure. Here, a trust-region (TR) gradient search algorithm is used which produces a series of approximations $\boldsymbol{x}^{(i)}$, $i = 0, 1, \ldots$, to the optimum design $\boldsymbol{x}^*$. The optimization task is given as [37]

$$\boldsymbol{x}^{(i+1)} = \arg \min_{\boldsymbol{x};\, -\boldsymbol{d}^{(i)} \le \boldsymbol{x}-\boldsymbol{x}^{(i)} \le \boldsymbol{d}^{(i)}} U(\boldsymbol{L}^{(i)}(\boldsymbol{x})) \tag{5}$$

The linear model $\boldsymbol{L}^{(i)}(\boldsymbol{x}) = \boldsymbol{R}(\boldsymbol{x}^{(i)}) + \boldsymbol{J_R}(\boldsymbol{x}^{(i)})\cdot(\boldsymbol{x} - \boldsymbol{x}^{(i)})$ is obtained using antenna responses and sensitivities evaluated at the current point $\boldsymbol{x}^{(i)}$. The parameter $\boldsymbol{d}^{(i)}$ is a trust region size vector updated based on the gain ratio being the ratio of the actual and predicted improvement of the objective function [37]

$$\rho = \frac{U\left(\boldsymbol{R}\left(\boldsymbol{x}^{(i)}\right)\right) - U\left(\boldsymbol{R}\left(\boldsymbol{x}^{(i-1)}\right)\right)}{U\left(\boldsymbol{L}^{(i)}\left(\boldsymbol{x}^{(i)}\right)\right) - U\left(\boldsymbol{L}^{(i)}\left(\boldsymbol{x}^{(i-1)}\right)\right)} \tag{6}$$

The initial size vector $\boldsymbol{d}^{(0)} = 0.1(\boldsymbol{u} - \boldsymbol{l})$, where $\boldsymbol{l}$ and $\boldsymbol{u}$ are the lower and upper bounds of the parameter space. It is updated using standard rules, i.e. for $\rho < 0.3$, $\boldsymbol{d}^{(i+1)} = \boldsymbol{d}^{(i)}/3$ and $\boldsymbol{d}^{(i+1)} = 2\boldsymbol{d}^{(i)}$ for $\rho > 0.75$. The algorithm is terminated when either $||\boldsymbol{x}^{(i+1)} - \boldsymbol{x}^{(i)}|| < \varepsilon$ or $||\boldsymbol{d}^{(i+1)}|| < \varepsilon$, where ε is an user defined threshold (here, $\varepsilon = 10^{-3}$) [37]. The discussed setup proved to be relevant for a variety of test problems considered in the available literature [20], [22], [48].

Under typical circumstances (no adjoint sensitivities available), the Jacobian $\boldsymbol{J_R}$ is estimated using finite differentiation [37], which incurs the extra cost of n EM simulations (per iteration). In this work, the following two means are applied in order to reduce this cost (both justified by the presumably good quality of the initial design used for solving (4)):

- The Jacobian is initialized by using $\boldsymbol{J_R}$ from the closest base point;

- Jacobian updates for subsequent iterations are obtained by employing a rank-one Broyden formula [32].

Utilizing the Jacobian from the closest base point saves considerable computational effort otherwise necessary to perform finite differentiation. On the other hand, because the initial design is already good, updating Jacobian with the rank-one formula is sufficient.

Assuming availability of the design database, the proposed framework can be summarized as follows (see Fig. 2 for a flowchart):

1. Set the target vector $\boldsymbol{F}_t$;
2. Arrange base designs into affinely independent subsets $\boldsymbol{S}^{(j)}$ and find a simplex $\boldsymbol{S}^{(j^*)}$ which is suitable for determination of expansion coefficients $\alpha_k^{(j)}$;
3. Evaluate (3) to obtain the initial design $\boldsymbol{x}^{(0)}$ corresponding to $\boldsymbol{F}_t$;
4. Refine the design by executing (5).

As already indicated, the computational benefits of the proposed approach stem from utilization of the pre-existing designs for determination of the starting point. Furthermore, re-using the available derivative data and Broyden-based Jacobian updates are important factors for obtaining the final design at a limited number of EM simulations. As confirmed by the numerical results of Section 4, the cost of optimization using our method is low compared to conventional approaches.

4. Case Study and Results

The procedure of Section 3 is demonstrated using a unidirectional quasi-Yagi antenna. The antenna is optimized for maximum in-band gain within a wide range of operating frequencies and substrate permittivity values.

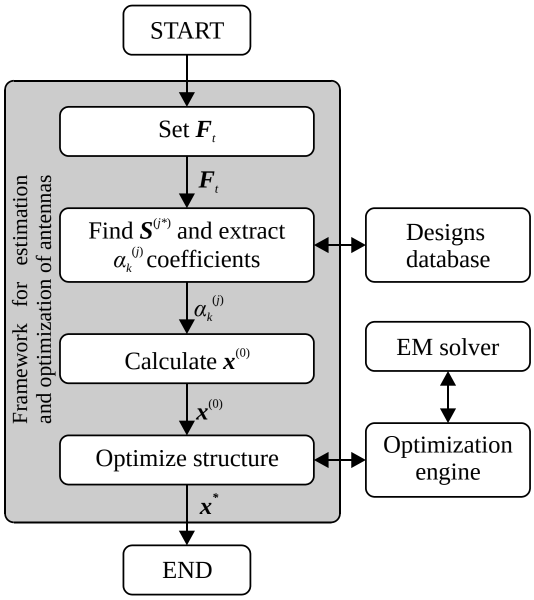


Fig. 2. A flowchart of the framework for estimation of initial design and rapid optimization of antenna structures.

4.1. Antenna Structure Design Problem

Consider a quasi-Yagi antenna shown in Fig. 3. The structure is implemented on a 0.81-mm-thick dielectric substrate. The geometry is described by the parameter vector $\boldsymbol{x} = [w_0\ l_g\ l_{g3r}\ g_f\ g_c\ l_c\ w_c\ l_{r1r}\ o\ w_d\ l_{dr}]^T$. The relative variables are $l_{g1} = 0.4l_g$, $l_{g2} = 0.6l_g$, $l_{g3} = l_{g2}l_{g3r}$, $l_{f2} = l_{g3}$, $l_{r1} = 0.5(w_0 – g_c)l_{r1r}$, and $l_d = w_0l_{dr}$. Dimensions $w_f = 1.8$ and $l_f = 13.7$ are constant. The unit of all parameters is mm, except those ending with r which are unit-less. The EM antenna model is implemented in CST Microwave Studio [35].

4.2. Experimental Setup

The purpose is to design the antenna for a substrate with a given relative permittivity ε_r, and to operate with a fractional bandwidth B (defined by $|S_{11}| \leq –10$ dB), centered at a required frequency f_0. Within that band, the average realized gain G_A of the antenna is to be maximized. The ranges of interest for the center frequency and permittivity are as follows: 3.5 GHz $\leq f_0 \leq$ 5.5 GHz, and $2.5 \leq \varepsilon_r \leq 4.5$. For the sake of illustration, B is set to seven percent.

The objective function U defined to handle the design problem posed in the previous paragraph is formulated as

$$U(\boldsymbol{R}(\boldsymbol{x})) = -G_A(\boldsymbol{x}) + \beta \max\left\{\frac{\max\{f \in B : |S_{11}(\boldsymbol{x}, f)|\} + 10}{10}, 0\right\}^2 \quad (6)$$

The primary objective in equation (6) is maximization of the average gain, whereas the penalty term allows for maintaining required impedance bandwidth. The penalty coefficient β is set to 10, which is sufficient to control the condition $|S_{11}| \leq -10$ dB within the fraction of dB.

Following the methodology of Section 3, a design database has been prepared that corresponds to ten pairs of the operating frequency and substrate permittivity $\{f_0, \varepsilon_r\}$: {3.0, 2.5}, {3.0, 4.5}, {3.7, 2.9}, {3.6, 3.7}, {4.5, 2.5}, {4.6, 3.3}, {5.5, 3.5}, {6.0, 2.5}, and {6.0, 4.5}. Fig. 4 shows the antenna responses at the selected reference designs, whereas their corresponding dimensions are gathered in Table 1.

4.3. Results and Discussion

For verification purposes, the antenna of Fig. 3 has been designed for the following operating frequencies and substrate permittivity values: {5.3, 2.5}, {4.8, 4.1}, {3.5, 2.5}, {3.85, 4.3}, {3.5, 3.5}, and {4.65, 2.97}. Table 2 shows the optimized parameter values for all considered cases, whereas Fig. 4 shows the antenna responses (reflection and realized gain) at the initial design obtained by solving equation (3) as well as the optimized design. The average optimization cost is only about five EM simulations of the antenna. It should be noted that the quality of the initial design is already very good which is an important benefit of the proposed approach.

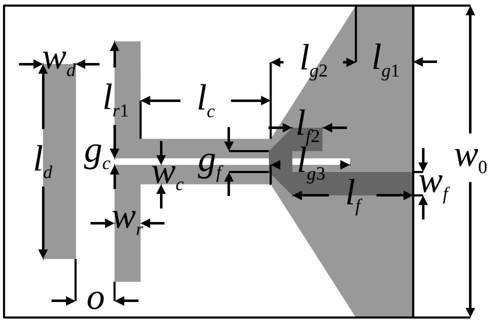


Fig. 3. Quasi-Yagi antenna with a director fed through a microstrip-to-coplanar stripline transition balun. Feed line marked using dark gray shade.

Table 1: Dimensions of selected base designs

		Base designs from database			
f_0 [GHz]		5.5	6.0	4.5	3.6
ε_r		3.5	2.5	2.5	3.7
Geometry parameters	w_0	25.33	24.38	31.61	36.79
	l_g	10.03	9.46	12.17	14.95
	l_{g3r}	0.95	0.89	0.92	0.93
	g_f	0.58	0.81	0.46	1.00
	g_c	0.20	0.20	0.56	0.68
	l_c	7.66	6.66	8.15	16.35
	w_c	3.00	2.49	4.15	5.00
	l_{r1r}	0.82	0.85	0.97	1.02
	o	5.00	5.18	6.59	7.50
	w_d	5.00	5.63	6.70	7.50
	l_{dr}	0.64	0.66	0.70	0.71

The proposed design framework has been compared to alternative methods in terms of the computational cost. The design goal in this study was to optimize the antenna of Fig. 3 for the objective pair $\{f_0, \varepsilon_r\} = \{5.3, 2.5\}$. The benchmark procedures include: (i) a conventional TR-based algorithm [37] launched from the database design corresponding to the pair {5.5 3.5} (cf. Table 1), and (ii) the conventional TR algorithm executed from the design obtained as described in Section 3.2. The results gathered in Table 3 indicate that the cost of the proposed approach is substantially lower than that of the benchmark methods. At this point, it should be reiterated that rendering a good initial design (cf. (3)) is an inherent part of the procedure. This—within the objective space region covered by the database designs—brings in quasi-global search capabilities. The latter is to be understood as releasing the user from the necessity of providing a reasonable starting point for further refinement.

Table 2. Quasi-Yagi antenna: results of design optimization

Operating conditions and geometry parameters		Verification Case					
Center frequency	f_0 [GHz]	5.3	4.8	3.5	3.85	3.5	4.65
Substrate permittivity	ε_r	2.5	4.1	2.5	4.3	3.5	2.97
Geometry parameters	w_0	27.06	28.12	37.66	33.61	37.40	29.37
	l_g	10.49	12.84	14.42	14.32	15.41	11.65
	l_{q3r}	0.91	0.91	0.92	0.92	0.93	0.94
	g_f	0.68	0.43	0.76	0.56	0.92	0.61
	g_c	0.34	0.56	1.08	0.85	0.68	0.45
	l_c	7.24	7.71	14.57	11.79	16.72	8.81
	w_c	3.09	3.57	3.96	4.09	4.77	3.59
	l_{r1r}	0.89	0.89	1.15	0.96	1.05	0.92
	o	5.72	6.63	8.55	7.73	7.87	6.08
	w_d	6.01	6.33	8.59	7.55	7.81	6.11
	l_{dr}	0.68	0.63	0.79	0.68	0.73	0.68

Table 3: Quasi-Yagi antenna: benchmark

Design method	No of algorithm iterations	No. of EM simulations	Design cost [h]
(i)	16	201	13.4
(ii)	6	64	4.3
This work	4	5	0.3

5. Conclusion

In the paper, a novel technique for expedited design optimization of antenna structures is proposed. The approach utilizes a database of reference designs and information therein to find a good initial set of geometry parameter values and accelerate the optimization process. The latter exploits estimated sensitivity extracted from the database along with the updating formulas. The proposed method can be used for rapid and reliable optimization of structures with respect to multiple performance figures. Moreover, the latter can be controlled within a wide range of operating conditions. In this work, the performance of the approach was demonstrated using a quasi-Yagi antenna optimized with respect to center frequency, bandwidth and realized gain. The presented methodology can be a useful design and geometry scaling tool, especially in situations when previously obtained designs are available for the same antenna structure. The future work will include generalization of the method for variable-fidelity simulation models.

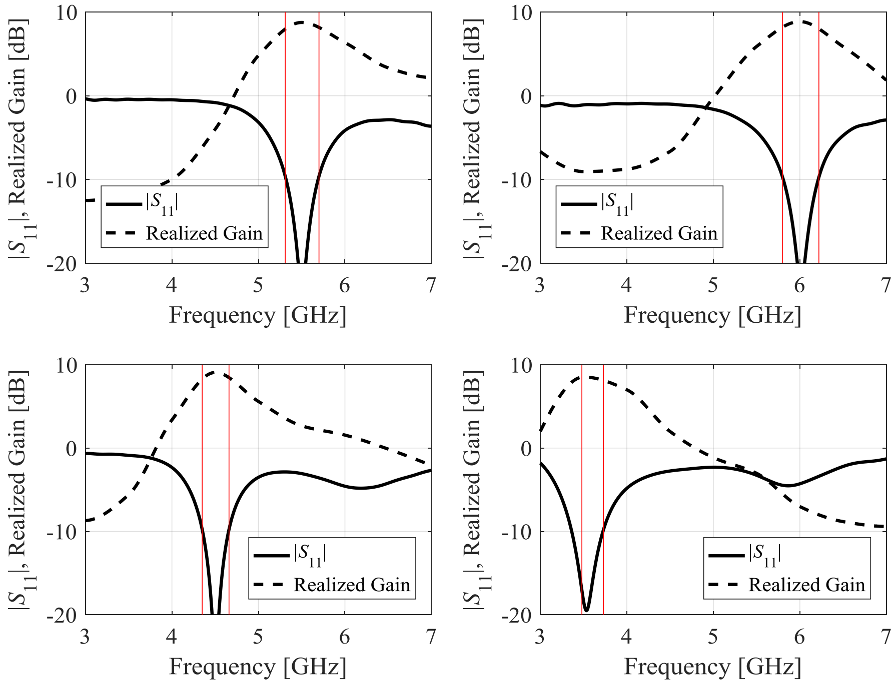
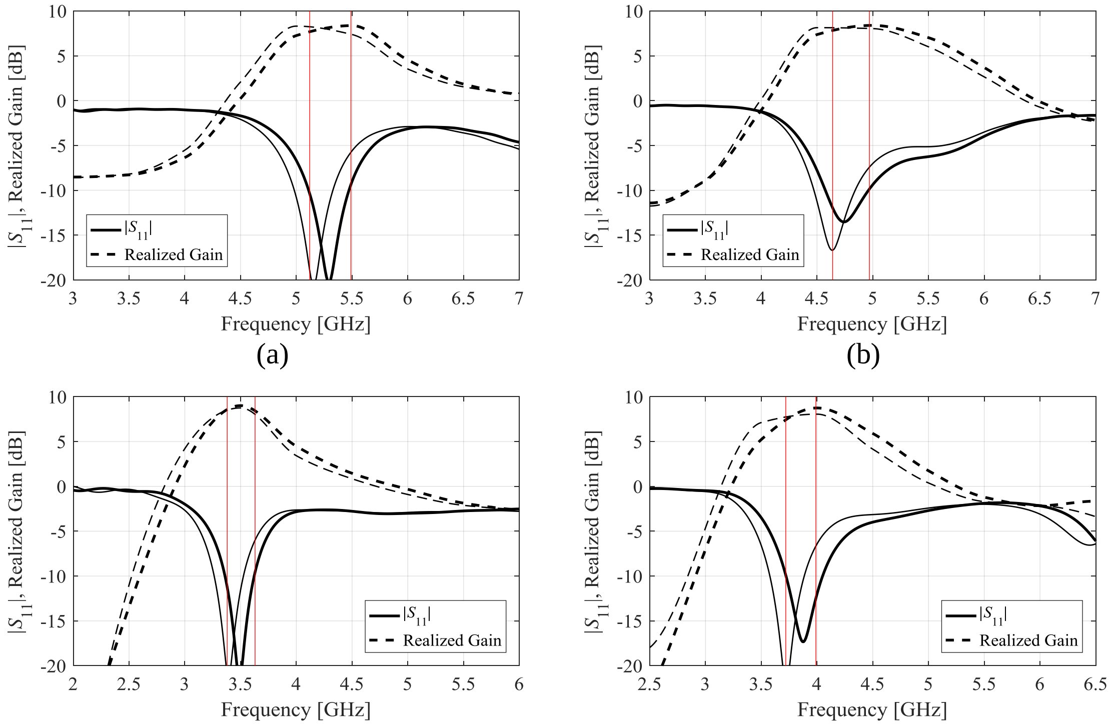
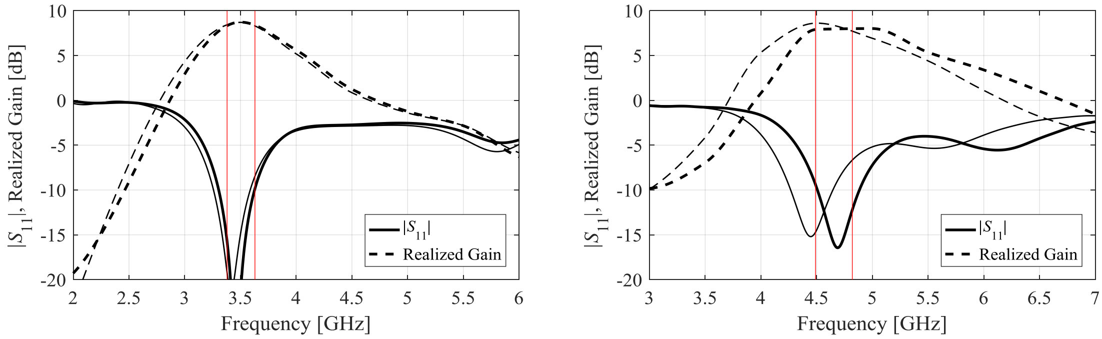


Fig. 4. Responses of antenna of Fig. 3 at selected reference designs, corresponding to—from top-left to bottom-right—the following operating frequency and substrate permittivity pairs $\{f_0,\varepsilon_r\}$: {5.5, 3.5}, {6.0, 2.5}, {4.5, 2.5}, and {3.6, 3.7}.



(c) (d)



(e) (f)

Fig. 5. Responses of the antenna of Fig. 3 at the verification designs obtained using the proposed methodology. Thin lines correspond to the initial design obtained from (3), whereas thick lines are for final (optimized) design: (a) f_0 = 5.3 GHz, ε_r = 2.5, (b) f_0 = 4.8 GHz, ε_r = 4.1, (c) f_0 = 3.5 GHz, ε_r = 2.5, (d) f_0 = 3.85 GHz, ε_r = 4.3, (e) f_0 = 3.5 GHz, ε_r = 3.5, (f) f_0 = 4.65 GHz, ε_r = 2.97. Required operating bandwidth marked using vertical lines.

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