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An Innovative Spline-based Shaping Approach for Ultra-Wideband Antenna Synthesis

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Introduction

Antennas play a unique role in Ultra-wideband (UWB) systems because of their behaviour as a bandpass filter and the need of avoiding undesired distorsions in the spectra of the transmitted pulses. For this reason, traditional approaches for antenna characterization prove inadeguate, so innovative design procedures and measurement techniques are needed for antennas in UWB systems [1]. Up till now, the most common design approach (i.e., the *Parametrical Approach*) is based on the parametrization of some geometrical shapes and the optimization of their descriptors for fitting the requirements. The choice of the initial reference geometry is dictated by the *a-priori* knowledge on its range of application and achievable performance. In such a framework, examples of UWB antennas can be found in [2][3][4]. Another synthesis approach, called *Non-Parametrical Approach*, considers a description of the antenna structure in terms of a collection of elementary building blocks suitably-coded in an unknown array. In [5][6] some examples of antennas synthesized with such an approach and considering a binary encoding are presented. In this work, a novel UWB antenna design method is proposed in order to exploit the advantages of both the aformentioned approaches. In particular, some standard geometrical parameters (e.g., groundplane, feedline and substrate dimensions) are described according to a parametrical approach, while the design of the remaining features is obtained starting from a spline-based shape generator. This new design method exploits the simplicity of the classical parametric approach with the flexibility of the spline-based shape representation in order to obtain cheap and reliable antennas for UWB applications. In order to assess the effectiveness of the proposed approach, simulated and experimental results concerned with a representative UWB antenna design are presented and discussed.

Mathematical Formulation

With reference to the design of a microstrip monopole antenna, the proposed UWB synthesis approach can be summarized as follows:

Antenna Shape Description. The antenna geometry is described by modeling the boundary of the metallic patch through a B-spline representation [7] and the other geometrical features (i.e., feedline, groundplane and substrate) in terms of values (in a fixed range) of a set of parameters (e.g., length of the rectangular feedline). More in detail, the spline-based generator considers a linear combination

(a) (b)

Figure 1: Antenna prototype. (a) Front view. (b) Back view.

of third-degree polynomials $b_{m,3}$

$$\mathbf{S}(t) = \sum_{m=1}^{M} \mathbf{S}_m(t) \quad (1)$$

where

$$\mathbf{S}_m(t) = \sum_{k=0}^{3} b_{m,3}(\mathbf{P}_{m-3+k,t}) \quad (2)$$

$\mathbf{P}_m = (x_m, y_m, z_m)$ being the m-th control point and t is the curvilinear coordinate on the contour $\mathbf{S}$. Accordingly, the antenna geometry turns out to be described by means of the following array

$$\overline{x} = \{(x_m, y_m),\ m = 1, \ldots, M;\ w_1, \ldots, w_4\} \quad (3)$$

where (x_m, y_m) indicates the planar coordinates of the m-th control point, M being the total number of control points. Moreover, w_1 is the substrate length, w_2 is one half of the substrate width, w_3 is one half of the feedline width, and w_4 the length of the groundplane.

Parameters Optimization. In order to fit the antenna requirements concerned with the UWB impedance matching and absence of distortions, the array $\overline{x}$ in (3) is optimized by minimizing a suitable cost function $\Psi(\overline{x})$

$$\Psi(\overline{x}) = \Psi_{|S_{11}|}(\overline{x}) + \Psi_{|S_{21}|}(\overline{x}) + \Psi_{\angle S_{21}}(\overline{x}) \quad (4)$$

where the first term, $\Psi_{|S_{11}|}$ is concerned with the impedance matching

$$\Psi_{|S_{11}|}(\overline{x}) = \int_{f_1}^{f_2} \max\left\{0, \frac{|S_{11}(f)| - |\widetilde{S_{11}(f)}|}{|\widetilde{S_{11}(f)}|}\right\} df \quad (5)$$

f_1 and f_2 being the lower and upper frequencies of the band of interest, respectively; $\Psi_{|S_{21}|}$ and $\Psi_{\angle S_{21}}$ weight the effectiveness of the antenna as a distortionless system

$$\Psi_{|S_{21}|}(\overline{x}) = \max\left\{0, \frac{\triangle|S_{21}| - \widetilde{\triangle|S_{21}|}}{\widetilde{\triangle|S_{21}|}}\right\} \quad (6)$$

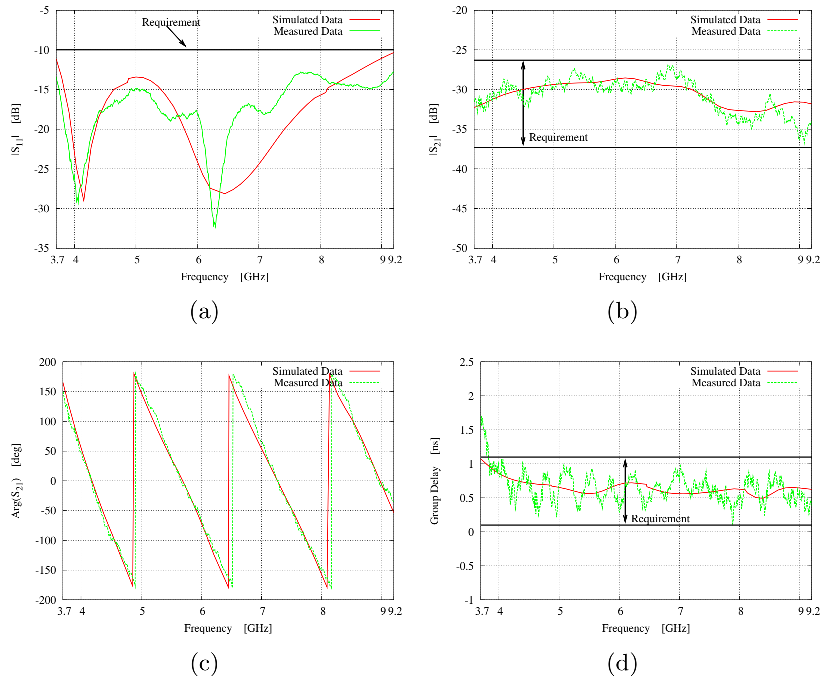


Figure 2: Simulated and measured antenna prototype parameters. (a) S_{11} magnitude. (b) S_{21} magnitude. (c) S_{21} phase. (d) Group delay.

$$\Psi_{\angle S_{21}}\left(\overline{x}\right) = \max\left\{0, \frac{\triangle\tau_g - \widetilde{\triangle\tau_g}}{\widetilde{\triangle\tau_g}}\right\} \quad (7)$$

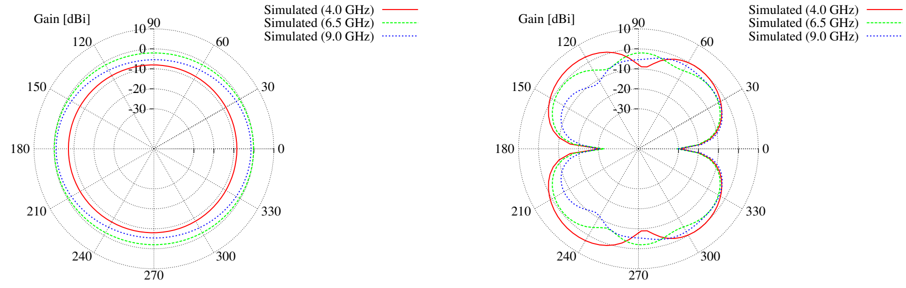
Towards this end, an effective PSO-based procedure is used [8].

Numerical Results

In order to validate the effectiveness of the proposed technique, several antenna prototypes have been synthesized and built. As a representative result, simulated and measured performance of the prototype in Fig. 1 are discussed. Figure 2 shows the behaviours of the S-parameters. Simulated and measured results are in a reasonable agreement and they fit the project requirements in the bandwidth from $f_1 = 3.7\,GHz$ up to $f_2 = 9.2\,GHz$. Moreover, the phase of the S_{21} turns out to be approximately linear with a group delay characterized by a maximum variation of the order of $1\,ns$. For completeness, Figure 3 shows simulated radiation patterns on the horizontal and vertical planes at 4.0, 6.5 and 9.0 GHz. As it can be noticed, the antenna behaves approximately as omnidirectional radiator in the horizontal plane and it presents lower gain values in the vertical plane at $0°$ and $180°$ with a broadside simmetry.

Conclusion

In this work an innovative spline-based approach for the UWB antennas synthesis has been proposed. The flexibility and accuracy of the method allows a re-



(a) (b)

Figure 3: Simulated antenna prototype radiation patterns. (a) Horizontal plane. (b) Vertical plane.

liable matching of UWB requirements. A representative design example described through the arising simulated as well as experimental electrical parameters has been presented in order to confirm the effectiveness of the approach.

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