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38123 Povo – Trento (Italy), Via Sommarive 14
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A Time-Based Approach for the Synthesis of Antennas for UWB Communication Systems

M. Benedetti*, L. Lizzi, F. Viani, R. Azaro, P. Rocca, and A. Massa
ELEDIA Group - Department of Information Engineering and Computer Science
University of Trento, Via Sommarive 14, I-38050 Trento, Italy
E-mail: andrea.massa@ing.unitn.it, Web-page: http://www.eledia.ing.unitn.it

Introduction

In Ultra-Wideband (UWB) Communications, the design of the radiating system is a very demanding task. Since high data rates are obtained by transmitting very short temporal pulses, the correct reception of the transmitted waveforms plays a fundamental role to guarantee the reliability of the whole UWB system. Under these hypotheses the design of the antennas as independent devices is no more acceptable. Consequently, customized synthesis techniques are needed [1] as well as appropriate analysis tools for an accurate description of the behavior of the antennas in the time domain [2].

In this paper, an innovative approach for the design of antennas compliant to the UWB requirements is presented. In such an approach, the whole system constituted by both transmitting/receiving antennas and the communication channel is modeled in order to allow an accurate characterization of the whole set of interactions and mutual effects. Besides a good impedance matching over the operating bandwidth, UWB antennas are characterized by distortionless propagation properties suitable to assure a correct reception of the UWB waveforms. Towards this end, a Particle Swarm Optimizer (PSO) [3] is suitably integrated into a time-domain (FDTD) electromagnetic simulator.

Antenna Design

Let us consider a generic antenna geometry described by a set of representative parameters

$$\underline{p} = \{p_n; n = 1, \dots N\}. \tag{1}$$

The design problem is then formulated as the optimization of $\underline{p}$ to fit the UWB requirements:

$$\hat{\underline{p}} = \arg\min_{\underline{p}} \{\Phi(\underline{p})\}. \tag{2}$$

Towards this end, the cost function Φ is minimized by means of a customized PSO logic. More in detail, the cost function measures the degree of fitting to the requirements of each trial solution. Since the objective of the design process is

to obtain (*a*) a good impedance matching of the antennas over the whole band of interest and (*b*) the non-distortion of the UWB waveform, such a function is defined as follows

$$\Phi(\underline{p}) = \Phi_1(\underline{p}) + \Phi_2(\underline{p}) \tag{3}$$

where

$$\Phi_1(\underline{p}) = \int_{f_1}^{f_2} \frac{\left|s_{11}(f)\right| - \left|s_{11}^T(f)\right|}{\left|s_{11}^T(f)\right|} df \tag{4}$$

and

$$\Phi_2(\underline{p}) = \frac{F^T - F}{F^T} \tag{5}$$

As far as the impedance matching condition is concerned, $\Phi_1(\underline{p})$ requires the antenna to have the magnitude of the return loss $\left|s_{11}(f)\right|$ less than a fixed target value $\left|s_{11}^T(f)\right|$ within the frequency range of interest $f_1 < f < f_2$. The distortionless system condition is formulated in terms of the fidelity F that should be greater than a target value F^T. The fidelity is given by

$$F = \max_{\tau} \int_{-\infty}^{+\infty} v(t - \tau) u(t) dt \tag{6}$$

and it measures how accurately the received signal $v(t)$ reproduces the transmitted signal $u(t)$. A fidelity of $F = 1$ indicates a perfect match between $v(t)$ and $u(t)$.

In order to evaluate the electrical characteristic of the system as well as of the received signal, the whole system composed by the transmitting antenna and the receiving one, and the propagation channel is modeled by means of a FDTD simulator. The use of a simulator working in the time domain is a natural choice because of the very large bandwidth involved in UWB communications. As a matter of fact, the use of a frequency-based simulator would result in a non-negligible computational cost.

Experimental Validation

In this section, a representative result is reported to preliminary shown the reliability and the efficiency of the proposed synthesis approach. The design process is aimed at synthesizing an UWB antenna working in the frequency range from $f_1 = 4\,GHz$ up to $f_2 = 11\,GHz$. In order to fit the UWB requirements, the project constraints have been fixed to $\left|s_{11}^T(f)\right| = -10\,dB$ and $F^T = 0.9$.

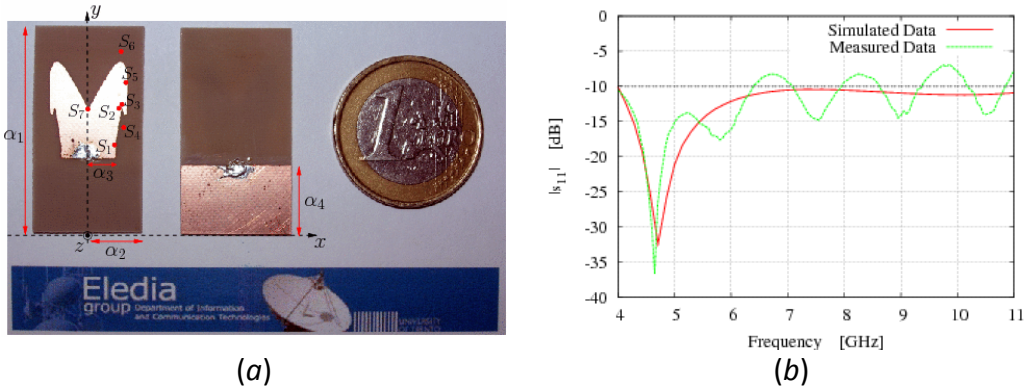(a)   (b)

Fig. 1 – (a) Antenna geometry and (b) simulated/measured values of the s_{11} magnitude

The set of parameters describing the antenna geometry is shown in Fig. 1 (a). In such a case, the set of unknown variables is constituted by some geometrical parameters and by the position of 7 control points generating the spline curve that defines part of the front-side of the antenna shape [4]. Accordingly, it turns out that

$$\underline{p} = \{p_n; n = 1,\dots N\} = \{\alpha_i; i = 1,\dots 4; (x_j, y_j); j = 1,\dots 7\}. \tag{7}$$

After the optimization, the following values have been determined: $\alpha_1 = 32.0\,mm$, $\alpha_2 = 8.6\,mm$, $\alpha_3 = 4.0\,mm$, $\alpha_4 = 11.8\,mm$, $x_1 = 4.0\,mm$, $y_1 = 13.9\,mm$, $x_2 = 4.8\,mm$, $y_2 = 19.6\,mm$, $x_3 = 5.3\,mm$, $y_3 = 20.0\,mm$, $x_4 = 5.5\,mm$, $y_4 = 16.7\,mm$, $x_5 = 5.9\,mm$, $y_5 = 23.6\,mm$, $x_6 = 5.0\,mm$, $y_6 = 28.3\,mm$, $x_7 = 0.0\,mm$, and $y_7 = 18.7\,mm$.

In order to verify the performance of the synthesized antenna over the whole bandwidth of $7\,GHz$, the results are shown in the frequency domain. As far as the condition of distortionless system is concerned, it has been evaluated in terms of the s_{21} parameter. More in detail, the correct reception of the transmitted UWB waveform is assured if $|s_{21}|$ presents a flat behavior and the s_{21} phase is linear over the band of interest. Figure 1(b) shows the simulated and measured values of $|s_{11}(f)|$. As it can be observed, the synthesized antenna fits the project guidelines since the simulated return loss is less than $-10\,dB$ from $f_1 = 4\,GHz$ up to $f_2 = 11\,GHz$. Moreover, the widest variation of the magnitude of s_{21} is less than $7\,dB$ [Fig. 2(a)], while the phase behavior is linear [Fig 2(b)].
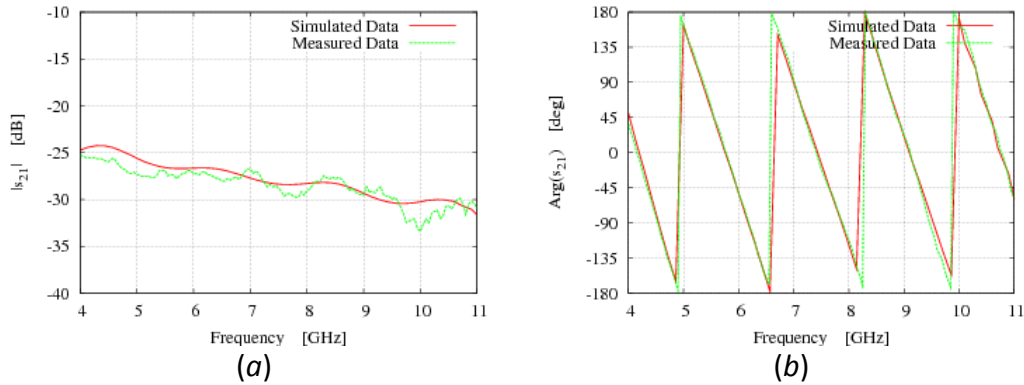
Fig. 2 – Simulated and measured values of (*a*) the magnitude and (*b*) the phase of s_{21}.

Conclusions

In this paper, an innovative approach for the synthesis of antennas fitting the requirements of an UWB communication system has been presented. Such an approach allows one to design UWB antennas with distortionless propagation properties as well as good impedance matching over the whole band of interest. As expected, the use of a time-domain technique permits the accurate modeling of the antennas, the communication channel, and of the mutual interactions.

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