PSO-BASED TIME-DOMAIN ANTENNA SYNTHESIS FOR ENHANCED UWB COMMUNICATION SYSTEMS

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PSO-Based Time-Domain Antenna Synthesis for Enhanced UWB Communication Systems

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Introduction

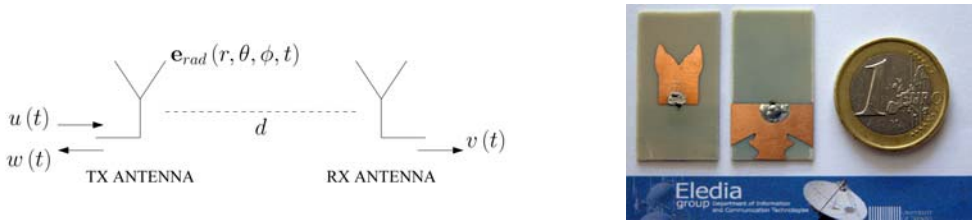
In Ultra-Wideband (UWB) communication systems, the design and the analysis of the radiating element is a very demanding task, since also the quality of the transmitted and received signals must be taken into account [1]. In general, the characterization of the antennas is carried out in the frequency domain, by analyzing some parameters such as gain, input impedance, efficiency or radiation patterns. However, these terms are functions of frequency, and their analysis results to be computationally inefficient dealing with signals characterized by very large bandwidths. Therefore, the analysis of UWB systems seems to be more natural in the time domain, where all the frequencies are treated together [2].

In this paper, a time domain approach for the synthesis of radiating systems suitable for UWB applications is presented. Such an approach is based on an optimization procedure aimed at fitting a set of time domain requirements. More in detail, the antenna efficiency as well as the system fidelity must be high in order to ensure the correct transmission of the information, while the radiation patterns of the antenna must have an omnidirectional behavior to be suitable for communication applications. The research for the optimal solution is carried out by means of a Particle Swarm Optimizer (PSO) able to select the best geometrical parameters of a spline-based antenna structure [3].

Time Domain Synthesis

Let us consider the UWB communication system shown in Fig. 1(*a*). In order to avoid an incorrect transmission of the information, such a system must be properly designed to fit a set of requirements. First, the antenna must be efficient, that is, it must be able to radiate as much energy as possible of the input signal $u(t)$. Towards this end, it is possible to define the *antenna efficiency* E as

$$E = 1 - \frac{\int_{-\infty}^{+\infty} \left| w(t) \right|^2 dt}{\int_{-\infty}^{+\infty} \left| u(t) \right|^2 dt} \tag{1}$$



(*a*) (*b*)

Fig. 1 – (a) the UWB communication system and (b) the prototype of the synthesized antenna.

where $w(t)$ is the reflected component of the input signal on the first antenna. Clearly, it must be required that E tends to 1 allowing for communication at higher distances.

Unfortunately, the antenna efficiency itself is not a sufficient parameter to guarantee the non-distorted reception of the transmitted waveform. A good measure of the signal distortion occurring during the transmission is given by the *system fidelity* F [4]

$$F = \max_{\tau} \int_{-\infty}^{+\infty} \hat{v}(t-\tau)\hat{u}(t)dt \tag{2}$$

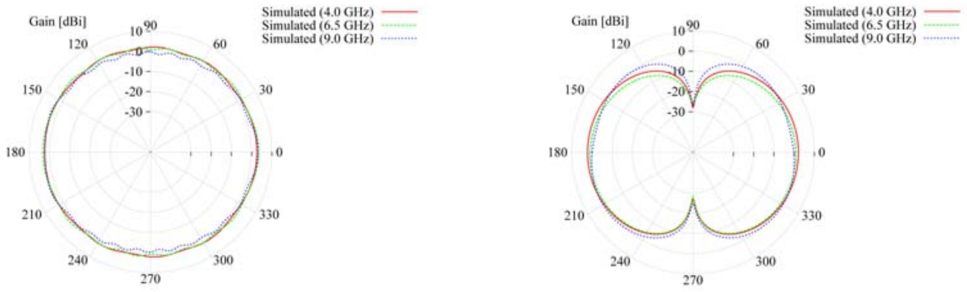
defined as the maximum of the cross-correlation between the energy normalized versions of the transmitted and received signals, denoted by $\hat{u}(t)$ and $\hat{v}(t)$ respectively. Again, it must be required to have an antenna systems having a system fidelity value approaching the unit.

Finally, antennas for communication applications are usually needed to show omnidirectional radiation patterns at the operating frequency. Dealing with UWB systems, such a behavior must be guaranteed over a very large bandwidth. This requirement can be translated in the time domain by means of the *similarity factor* $S(\theta,\phi)$ [5]

$$S(\theta,\phi) = 1 - \frac{\int_{-\infty}^{+\infty} \left| \mathbf{e}_{rad}(r,\theta_0,\phi_0,t) - \mathbf{e}_{rad}(r,\theta,\phi,t) \right|^2 dt}{\int_{-\infty}^{+\infty} \left| \mathbf{e}_{rad}(r,\theta_0,\phi_0,t) \right|^2 dt} \tag{3}$$

that gives a measure of the changing occurring to the radiated pulse waveform along the different directions (θ,ϕ). More in detail, $\mathbf{e}_{rad}(r,\theta,\phi,t)$ denotes the radiated electric field and (θ_0,ϕ_0) is the direction of maximum radiation. From (3) it results that in order to guarantee an omnidirectional behavior, the antenna system must show a similarity factor tending to the unit.

The objective is now to develop an automatic synthesis procedure taking into account such time domain requirements. Towards this end, let $\mathbf{x}$ be the vector of parameters univocally describing a particular antenna configuration. The optimization of the antenna structure is then equivalent to the research for the best values of the parameter vector $\mathbf{x}$. Such a research is performed by the PSO by minimizing an ad hoc cost function $\Omega(\mathbf{x})$ defined as



(*a*) (*b*)

Fig. 2 – Simulated radiation patterns in the (a) horizontal and (b) vertical planes.

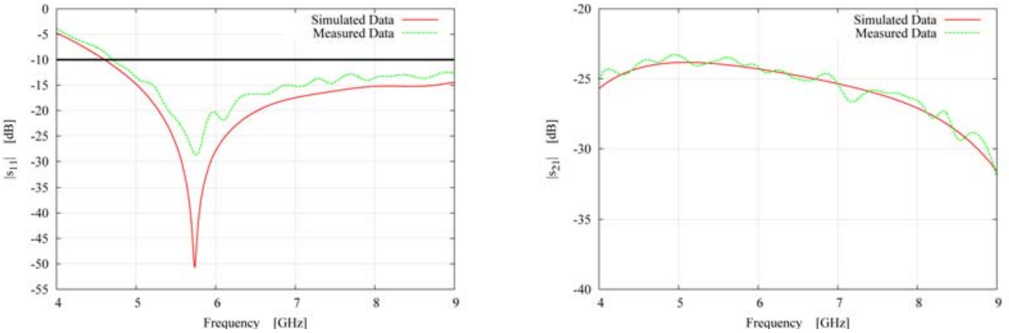
$$\Omega(\mathbf{x}) = \max\left[0,\frac{E^T-E}{E^T}\right]+\max\left[0,\frac{F^T-F}{F^T}\right]+\underset{\theta,\phi}{mean}\left\{\max\left[0,\frac{S^T(\theta,\phi)-S(\theta,\phi)}{S^T(\theta,\phi)}\right]\right\} \tag{4}$$

where the superscript ^{T} denote the target values according to the project specifics.

Experimental Validation

This section is aimed at presenting a representative result to demonstrate the effectiveness and the reliability of the proposed synthesis approach. The objective is the design of an UWB antenna system able to correctly transmit/receive a signal waveform of 1 ns duration, characterized by a frequency spectrum going from 4 to 9 GHz. In order to fit the time domain requirements, both the project constraints on the antenna efficiency and the system fidelity have been fixed to $E^T = F^T = 0.95$, while the similarity factor is required to be greater than $S^T(\theta,\phi)=0.95$ only in the horizontal plane of the antenna $(\theta=\pi/2,\phi)$.

A prototype of the synthesized antenna is shown in Fig. 1(*b*). As it can be seen, the antenna has a very small dimension of 30.1×8.1 mm^2. Concerning the performance, the optimized antenna is able to radiate the main part of the input signal energy, having an efficiency value equal to $E=0.98$. Also the resulting system fidelity is very high ($F=0.97$) ensuring for a correct reception of the transmitted waveform. Finally, as requested, the antenna presents an omnidirectional radiation pattern in the horizontal plane, as confirmed by values of similarity factors always greater than 0.95. This behavior is shown in Fig. 2 where the simulated radiation patterns at three different frequencies are reported.



(*a*) (*b*)

Fig. 3 – Simulated and measured values of the magnitude of (a) s_{11} and (b) s_{21} parameters.

In order to easily understand the meaning of the obtained results, they are translated into the frequency domain in terms of scattering parameters and compared to the measurements performed on the antenna prototype. As expected, the antenna shows a good impedance matching, being the magnitude of the s_{11} parameter always less than -10 dB apart from a small portion of spectrum going from 4 to 4.5 GHz [Fig. 3(*a*)]. Moreover, the distortionless behavior of the antenna system is confirmed by the small variation (less than 7 dB) of the magnitude of the s_{21} parameter [Fig. 3(*b*)].

Conclusions

In this paper, an approach for the synthesis of antenna systems suitable for UWB communication applications has been presented. The final antenna geometry is obtained by means of a PSO aimed at fitting a set of time domain requirements. Such requirements allow the radiating system to have an high efficiency, distortionless properties, and omnidirectional radiation patterns over the whole frequency range. An example of synthesized antenna has been shown as a preliminary assessment of the proposed approach.

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