UNIVERSITY
OF TRENTO

DIPARTIMENTO DI INGEGNERIA E SCIENZA DELL'INFORMAZIONE

38123 Povo – Trento (Italy), Via Sommarive 14
http://www.disi.unitn.it

SPLINE-SHAPED ULTRA-WIDEBAND ANTENNA OPERATING IN THE ECC RELEASED FREQUENCY SPECTRUM

F. Viani, L. Lizzi, R. Azaro, and A. Massa

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Spline-shaped ultra-wideband antenna operating in the ECC released frequency spectrum

F. Viani, L. Lizzi, R. Azaro, and A. Massa

A spline-shaped antenna for Ultra-Wideband (UWB) communications that operates in the Electronic Communications Committee (ECC) released band from 6 GHz up to 8.5 GHz is described. Selected simulated and measured data are reported to assess the achieved impedance matching over the whole band of interest, and the distortionless behavior as well as to show the omni-directional radiation properties.

Introduction: In correspondence with the increasing demand of high transmission data-rate, low power consumption, and wider bandwidth of wireless communication systems, the UWB technology has attracted a growing attention. Since 2002, when the Federal Communication Commission (FCC) released the use of the frequency band 3.1 - 10.6 GHz for communications [1], non-negligible research efforts have been devoted to the development of efficient and reliable UWB systems. Concerning the European situation, the ECC considers that "*the higher maximum power densities in frequency spectrum 6 - 8.5 GHz without additional mitigations will facilitate the UWB operations*" [2]. As regards to UWB antenna design, many geometries and shapes have been studied and proposed for different purposes and applications. As an example, small-size and omni-directional antennas have been presented in [3][4] for short-range indoor communications. Generally speaking, several antenna configurations are usually synthesized starting from a parameterization of reference shapes (e.g., planar triangular patch [5], circular disc [6] or rectangular slot [7]).

In this letter, a spline-shaped antenna is proposed in order to fit the last ECC UWB standard (July 2007) in the frequency range $6 - 8.5\,\mathrm{GHz}$. Likewise [8], where a generic UWB radiator has been optimized to preliminary assess the proposed approach, the antenna prototype is synthesized by further exploiting a spline-based procedure, but taking into account different and more realistic constraints. Unlike other parametric synthesis methods, the antenna geometry comes from the modification of a spline contour that describes the perimeter of the radiator. The result is a simple and easy-to-build configuration that satisfies both dimensional and electric requirements. To assess the fitting with project constraints, both simulated and measured performance indexes are presented and compared.

Spline-shaped antenna design: According to the ECC guidelines for UWB devices, the spline-shaped antenna has been designed in order to efficiently operate within the frequency spectrum $6 - 8.5\,\mathrm{GHz}$. Towards this end, In order to guarantee a distortionless transmission of time-domain UWB pulses, the following constraints have been imposed over the whole operating bandwidth: s_{11} amplitudes lower than $-10\,\mathrm{dB}$, flat behavior of s_{21}, and linear dependence of the phase of s_{21} on the frequency. The constrained parameters are the input reflection coefficient (s_{11}) and the forward transmission coefficient (s_{21}) of the two-port system composed by a pair of identical UWB antennas. As far as the geometric constraints are concerned, the antenna has been required to belong to a square area of side length of $80\,\mathrm{mm}$. Figure 1 shows the geometry of the UWB antenna resulting from the synthesis process. More in detail, $\varphi_1 = 67.5\,\text{mm}$ is the substrate length, $\varphi_2 = 12.3\,\text{mm}$ is one half of the substrate width, $\varphi_3 = 6.0\,\text{mm}$ is one half of the feedline width, and $\varphi_4 = 35.0\,\text{mm}$ is the metallic plane length on the back side of the substrate. Furthermore $\{P_i = (x_i, y_i); i = 1, \ldots 4\}$ are the control points, located at ($x_1 = 6.0\,\text{mm}$, $y_1 = 39.6\,\text{mm}$), ($x_2 = 8.5\,\text{mm}$, $y_2 = 40.3\,\text{mm}$), ($x_3 = 4.7\,\text{mm}$, $y_3 = 54.6\,\text{mm}$), and ($x_4 = 0.0\,\text{mm}$, $y_4 = 46.8\,\text{mm}$), which unequivocally define the contour of the antenna. Finally, the feeding port has been located at ($x_F = 0.0\,\text{mm}$, $y_F = \varphi_4$). These values have been determined at the convergence of an iterative procedure [8] aimed at updating the spline-based contour until a suitable matching with the user-defined requirements is reached. Such a procedure is based on the integration of a Method of Moment (MoM) electromagnetic simulator [9], able to estimate the electric parameters of the antenna, and a particle swarm optimizer (PSO) [10] used to define an evolution strategy for the trial antenna shapes.

Numerical and experimental results: A prototype of the antenna has been built to experimentally assess the reliability and efficiency of the synthesized shape (Fig. 1). The prototype has been printed on a Arlon dielectric substrate ($\varepsilon_r = 3.38$) of $0.78\,\text{mm}$ thickness with a photolithographic technology. Moreover, it has been equipped with a SMA connector and fed with a coaxial line. The electrical parameters (s_{11} and s_{21}) have been measured by means of an Anritsu Vector Network Analyzer in a non-controlled environment. Concerning the s_{21}, it has been evaluated by considering a two-port system composed by a pair of identical prototypes. A comparison between simulated and measured data is summarized in Fig. 2. As it can be noticed, the electric behavior of the synthesized antenna fits the project guidelines. More in detail, a good impedance matching over the whole ECC released frequency bandwidth ($6 - 8.5\,\mathrm{GHz}$) has been achieved (Fig. 2*a*). Moreover, as far as the s_{21} parameter is concerned, the flatness of $|s_{21}|$ (Fig. 2*b*) and the linear trend of $\angle s_{21}$ (Fig. 2*c*) assure a distortionless behavior of the system when UWB pulses are in transmitted and received. For completeness, Figure 2*d* shows the plot of the group delay τ computed as the ω-derivative of the phase of s_{21}. As it can be observed, a variation lower than $0.7\,\mathrm{ns}$ verifies in the measured data although they have been collected in a non-controlled environment. Finally, the radiation patterns computed at $f_1 = 6.0\,\mathrm{GHz}$, $f_2 = 7.25\,\mathrm{GHz}$, and $f_3 = 8.5\,\mathrm{GHz}$ are displayed in Fig. 3 to show the omni-directional behavior in the horizontal plane ($x - z$ plane). On the hand, as expected, the antenna behaves as a monopolar radiator in the vertical plane ($x - y$ plane).

Conclusions: The design of a spline-shaped planar antenna for UWB applications and operating in the ECC released $6 - 8.5\,\mathrm{GHz}$ frequency spectrum has been proposed. Simulated and measured electrical parameters over the whole band of interest as well as the radiation patterns confirm the effectiveness of the synthesized antenna prototype.

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Authors' affiliations:
F. Viani, L. Lizzi, R. Azaro, and A. Massa
ELEDIA Research Group
Department of Information and Communication Technology,
University of Trento, Via Sommarive 14, 38050 Trento – ITALY

Corresponding Author:
A. Massa
ELEDIA Research Group
Department of Information and Communication Technology
University of Trento
Via Sommarive 14
38050 Trento
ITALY
E-mail: andrea.massa@ing.unitn.it

Figure captions:

Fig. 1 - Antenna prototype

(*a*) Front view

(*b*) Back view

Fig. 2 - Comparison between simulated and measured values over the ECC frequency band:

(*a*) Magnitude of s_{11}

(*b*) Magnitude of s_{21}

(*c*) Phase of s_{21}

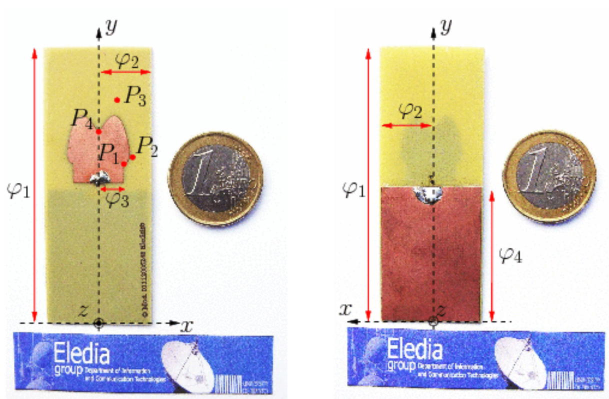
(*d*) Group delay

Fig. 3 - Simulated radiation patterns at $f_1 = 6.0\,\text{GHz}$, $f_2 = 7.25\,\text{GHz}$, and $f_3 = 8.5\,\text{GHz}$:

(*a*) Horizontal plane ($x - z$)

(*b*) Vertical plane ($x - y$)

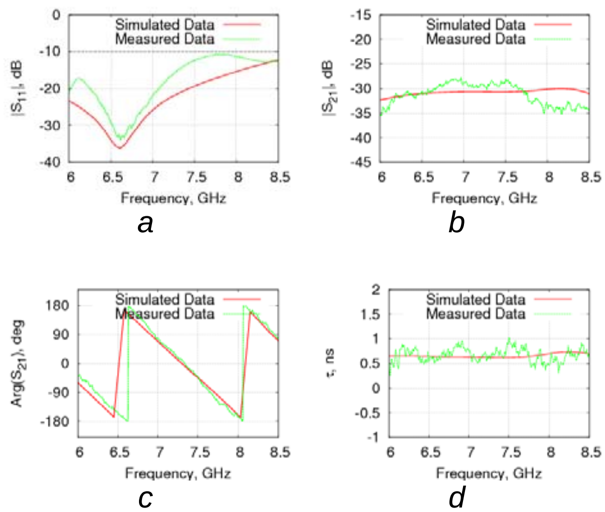
Figure 1



y
φ_2
P_3
P_4
P_1
P_2
φ_3
φ_1
z
x
Eledia
group
y
φ_2
φ_1
φ_4
x
z
Eledia
group

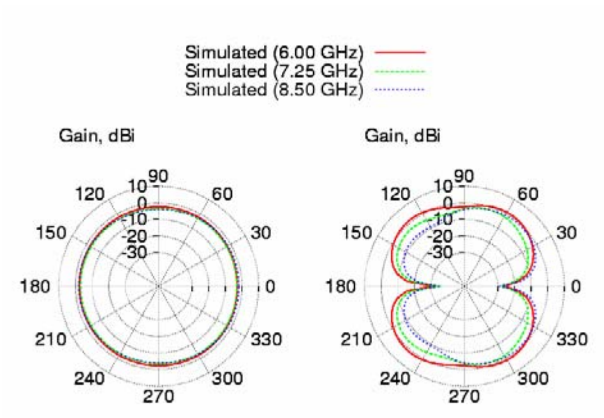
a *b*

Figure 2



Simulated Data
Measured Data
|S11|, dB
Frequency, GHz
a
|S21|, dB
b
Arg(S21), deg
c
τ, ns
d

Figure 3



Simulated (6.00 GHz)
Simulated (7.25 GHz)
Simulated (8.50 GHz)
Gain, dBi
90
60
30
0
330
300
270
240
210
180
150
120
10
0
-10
-20
-30
Gain, dBi
90
60
30
0
330
300
270
240
210
180
150
120
10
0
-10
-20
-30

a *b*