Full 3D Spatial Time Domain Analysis of UWB Antennas

Elena Pancera* (1), Christian Sturm(1), Joaquim Fortuny-Guasch(2), Thomas Zwick(1), and Werner Wiesbeck(1)
(1) Universität Karlsruhe (TH), Karlsruhe, Germany
(2) Joint Research Centre of the European Commission, Ispra, Italy
E-mail: elena.pancera@ihe.uka.de

Introduction

In 2002 the FCC in the USA has regulated the usage of UWB devices, allocating a spectrum of 7.5 GHz in the 3.1 – 10.6 GHz frequency band. Since that time, various UWB antennas and arrays have been presented in literature. In the majority of cases, the analysis of these antennas is performed in the frequency domain. In this paper, a novel approach for the analysis of the time domain behavior of UWB antennas is presented. This time domain analysis is conducted not only in the main propagation direction, rather in the whole 3 dimensional (3D) space. This particular technique permits to investigate the transient behavior of UWB antennas in all angular directions and its effect on the UWB pulse e.g. distortion, pulse widening and ringing effects. Consequently it is possible to have a better understanding of the antenna properties and characteristics.

Frequency Domain Analysis

The measured parameter in the frequency domain is the transmission coefficient S_{21} between the antenna under test (AUT) and the reference antenna [1]. It can be calculated starting from the measured transmitted U_{tx} and received U_{rx} voltages, namely

$$S_{21}(\omega)=\frac{U_{\mathrm{rx}}(\omega)}{U_{\mathrm{tx}}(\omega)}=H_{\mathrm{ref}}(\omega)H_{\mathrm{AUT}}(\omega)\frac{j\omega}{2\pi rc}e^{-j\omega r/c} \tag{1}$$

where H_{ref} and H_{AUT} are the transfer functions (in terms of effective antenna height) of the reference antenna and of the AUT, respectively, and r is the distance between the two antennas. Starting from the S_{21}, it is possible to calculate the gain of the AUT as

$$G_{AUT}(\omega)=\frac{\omega^2}{\pi c^2}\left|H_{\mathrm{AUT}}(\omega)\right|^2=4\pi r^2\left|\frac{S_{21}(\omega)}{H_{\mathrm{ref}}(\omega)}\right|^2 \tag{2}$$

Time Domain Analysis

In the time domain, one of the interesting quantity is the transient response of the AUT. It can be derived starting from the analytic transfer function in the time domain, defined as [4]

$$H^{+}(\omega)=\begin{cases}2H_{\mathrm{AUT}}(\omega) & \omega>0\\ 0 & \omega\le 0\end{cases} \tag{3}$$

From that, it is possible to obtain the AUT's transient response as

978-1-4244-2042-1/08/$25.00 ©2008 IEEE

$$h_{\mathrm{AUT}}(t) = \mathrm{Re}\left[h^{+}(t)\right] \quad (4)$$

where $h^{+}(t)$ is the inverse Fourier Transform of $H^{+}(\omega)$. It is important to observe that H_{AUT} depends on both the angular directions θ and ψ. Consequently h_{AUT} depends not only by time, but presents also such angular dependence. Hence, in order to evaluate this angular direction dependence, a full 3D spatial measurement of the AUT has been performed.

Measurement Setup

The measurements have been performed at the EMSL laboratory of the Joint Research Centre of the European Commission in Ispra, Italy. A picture from the anechoic chamber can be seen in Figure 1. The chamber has a spherical shape with a diameter of 20 meters.

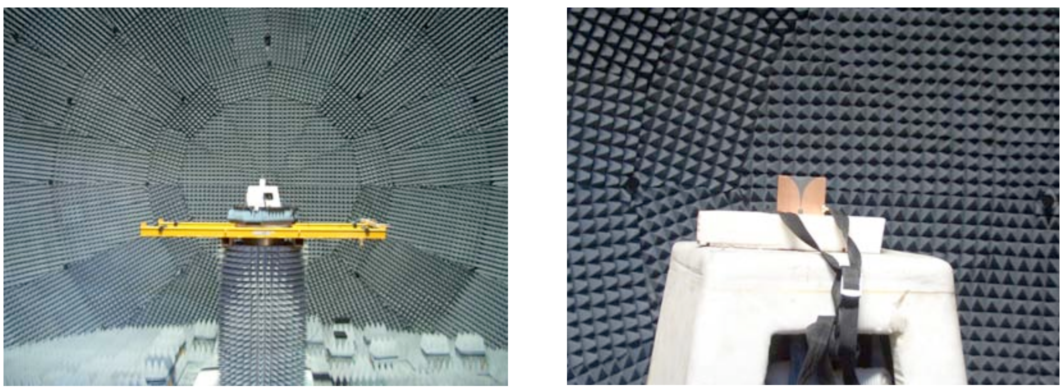

Fig. 1 Anechoic chamber and mounted Vivaldi antenna at the EMSL laboratory

The antenna under test is placed in the center of the sphere on a rotating tower. The azimuth angle is controlled by rotating the tower. The receiving antenna is a dual polarized horn antenna that is mounted on a carriage that can move along a rail to any desired elevation angle. In the conducted measurements the entire upper hemisphere has been measured with an angular resolution of 5 degree in both azimuth and elevation, which results in a total of 1296 measurement positions. For each position with a vector network analyzer the transfer coefficients have been measured over the frequency range from 2 to 18 GHz at 801 equidistantly spaced points for both horizontal and vertical polarization. In the analysis of the antennas always the total received power from both polarization components will be regarded. For the necessary calibrations of the setup also measurements with direct through-connection of the cables at the antenna feed-points and a transmission measurement between two identical horn antennas have been taken.

Investigated Antennas

In this paper measurements results for two commonly used types of planar UWB antennas will be presented, a Vivaldi antenna and a bow-tie antenna. Both antennas are fed by aperture coupling and optimized for the frequency range of the FCC UWB regulation. Both sides of the etched Vivaldi antenna substrate with outer dimensions of 78 mm x 75 mm are shown in Figure 2.

Fig. 2 Investigated Vivaldi antenna

The investigated bow-tie antenna is considerably smaller with dimensions of only 36 mm x 31 mm. Due to the small size the antenna radiates nearly omni-directional. A picture of the printed structure is shown in Figure. 3.

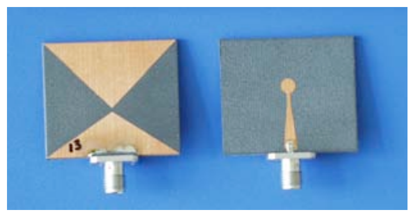

Fig. 3 Investigated bow-tie antenna

Measurement Results

In the measurements the antennas have been oriented with their main radiation direction to θ = 0°. In Figure 4 the absolute value of the analytic response resulting from the absolute value of the vector sum of both polarization components over the entire upper hemisphere is plotted at different time-steps for the Vivaldi antenna. The time-scale is calibrated to the feed point of the antenna. It can be seen that the radiation of energy is concentrated in a very short time interval of the order of only 0.3 ns. Nearly the entire upper hemisphere except for the elevation angles around $\theta = 90°$ is well covered by radiation.

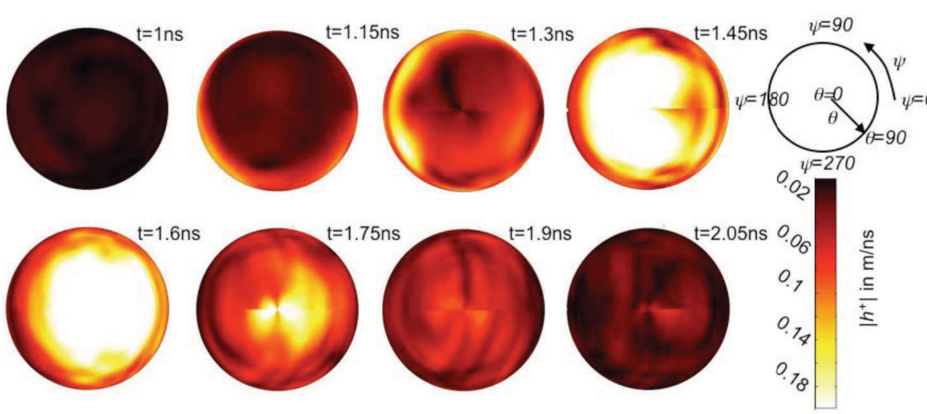

Fig. 4: Measured transient response of the Vivaldi antenna.

Furthermore, it can be noticed that the pulse arrives in advance for the elevation angles around $\theta = 90°$. This results from the fact that antenna placement in the chamber was not aligned with the antenna center of radiation. In fact, it lies somewhere within the antenna structure but the antenna position in the chamber has been aligned to the upper edge of the antenna structure. Since a time delay of 0.1 ns corresponds to a displacement of only 3 cm, the center of radiation has to be known very precisely in order to avoid this effect.

In Figure 5 the results for the bow-tie antenna are shown. Also this antenna provides a very concentrated radiation over time similar to the Vivaldi antenna. However, the bow-tie antenna provides a better illumination at the elevation angles around $\theta = 90°$ and hence is more suitable for omni-directional coverage.

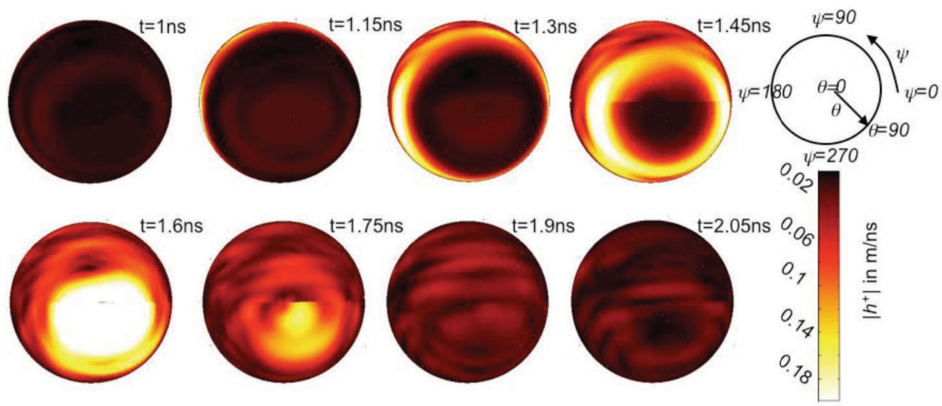

Fig. 5: Measured transient response of the bow-tie antenna.

Conclusions

In an innovative measurement approach time domain antenna characterization has been combined with full 3D radiation pattern characterization. With this approach transient antenna responses can be measured over the entire hemisphere and hence the antenna under test can be comprehensively characterized for UWB impulse applications in both time and spatial domain. The method has been applied to a Vivaldi and a bow-tie antenna. It has been shown that both antennas concentrate energy in the time domain very well and provide a large coverage area with slightly higher directivity of the Vivaldi antenna.

References:

[1] W. Soergel, F. Pivit, W. Wiesbeck, "Comparison of Frequency Domain and Time Domain Measurement Procedures for Ultra Wideband Antennas", Proc. 25th Annual Meeting and Symposium of the Antenna and Measurement Techniques Association (AMTA '03), Irvine, California, USA, Oct. 2003.

[2] W.Soergel, W.Wiesbeck, "Influence of the Antennas on the Ultra-Wideband Transmission", *EURASIP Journal on Applied Signal Processing*, vol. 3, 2005.