Biconical Antennas for intrinsic characterization of the UWB Channel

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***Abstract*— The characterization of the UWB channel own behaviour 'without antennas' requires a huge measurement and processing work, which should be greatly and efficiently reduced with the help of low angular distortion antennas. Obviously, usual specifications for UWB channel measurements like particularly good matching, omni-directionality and a large frequency-independent horizontal main lobe have to be respected. Two UWB Bicone antennas designed with respect to these specifications and operating over two different bands have been designed and tested. Characterization tools in the Time Domain (TD) were used to analyze the distortion introduced by these antennas, and both antennas were found to be slightly distorting while comparing the radiated waveform to the excitation one, on one hand, and, more interestingly while comparing the radiated waveforms at different directions on the other hand.**

Index Terms— UWB antenna, UWB channel measurements, Time Domain Characterization Tools, Antenna Distortion.

INTRODUCTION

UWB communications need detailed information about the indoor propagation channel. The characterization of the UWB channel own behaviour 'without antennas' will allow to test the radio link "antenna-channel-antenna" for different kind of antennas. In order to get the intrinsic UWB channel measurements easily, low angular distortion measurements antennas are required. Antennas respecting this previous specification can be extracted from the global channel behaviour by removing an average antennas transfer function over valid angular range. This previous criteria is also needed for channel analysis that exploit the a-priori known signal waveform (Delay & Sum DOA method), where the signal distortion introduced by the antenna needs to be ideally as low as possible, or at least independent on the signal direction of arrival (DOA). Obviously, usual requirements on antennas for UWB channel measurements like good matching, omni-directional radiation and a large frequency-independent horizontal main lobe should be respected over an ultra-wide band. Characterization tools in the time domain (TD) that allow quantifying the distorting nature of an antenna will be presented and applied to two UWB biconical antennas. These antennas were designed with respect to the specifications listed above, and their design and performances are presented below.

ANTENNAS DESIGN

Ideal and finite bicone antennas behaviour is well known [2-4]. Practically finite size structure asks for some design optimisation. The proposed antennas with coaxial asymmetric feeding are derived from a previous work on the design of an UWB monocone-like antenna for UWB channel measurements [1] that has been carried out at ENSTA. This feeding guarantees perfect omni-directionality in azimuth. A shaping of the ground plane quasi-symmetrically compared to the radiation element of this monocone (Fig. 1 (a)), allows to bring the main lobe to the horizontal plane ; a suitable optimization of the radiation element, especially of its feeding zone, had to be carried out in order to obtain an ultra-wide band with a good matching to 50 ohms. In fact, the shape of the feeding is particularly critical [5], a smooth exponential (in fact elliptical) transition between guided and free space propagation gives good matching properties (Fig. 1). Thus, prototypes for two different Bicone antennas have been designed: Bicone1 has a (diameter x height) of (37 mm x 31 mm) and Bicone2 of (80 mm x 96 mm) (Fig. 1), and they are well matched ($|S_{11}|$ dB<−10) over [2.75-16] GHz and [0.85-13] GHz respectively. The simulation and realization of Bicone1 (made of brass) were done first; mechanical constraints on the feeding zone of this antenna require a handling with special care in order to avoid shock hazard. In order to reduce these constraints (that were expected to be more critical for Bicone2, designed to operate at lower frequencies, hence bigger in size), the inside portion of Bicone2, with low current distribution was removed.. Finally, Bicone2 was equipped with a plastic protection cover with foam (with very low permittivity) being added between the antenna and the cover in order to help make the antenna structure quite rigid (Fig.1 photos).

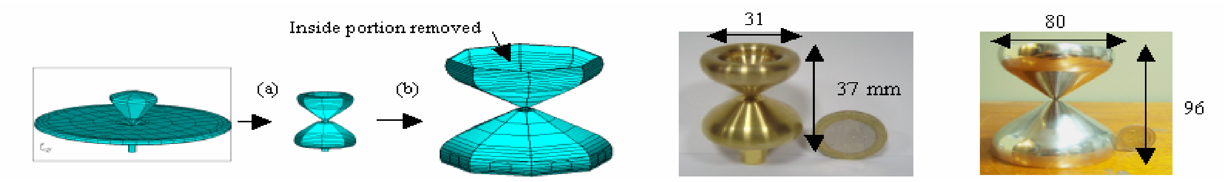


Fig. 1: (a) ground plane shaping, (b) scaling from Bicone1 (photo 1) to Bicone2 (photo 2) and their dimensions.

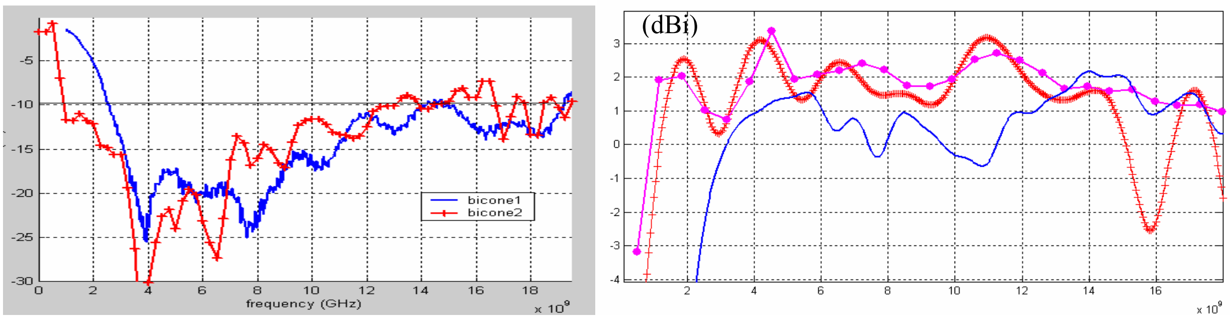
PERFORMANCES

Technical Approach

The MoM method tool WIPL-D™ [6] has been used for simulations. The return loss and the radiation pattern were measured in an anechoic chamber with an HP8510C® vector network analyser and a calibrated 1-18 GHz Log Periodic Dipole Array (LPDA) antenna [7]. The following results are de-embedded so that they only show the bicone antennas behaviour.

Frequency Domain Results

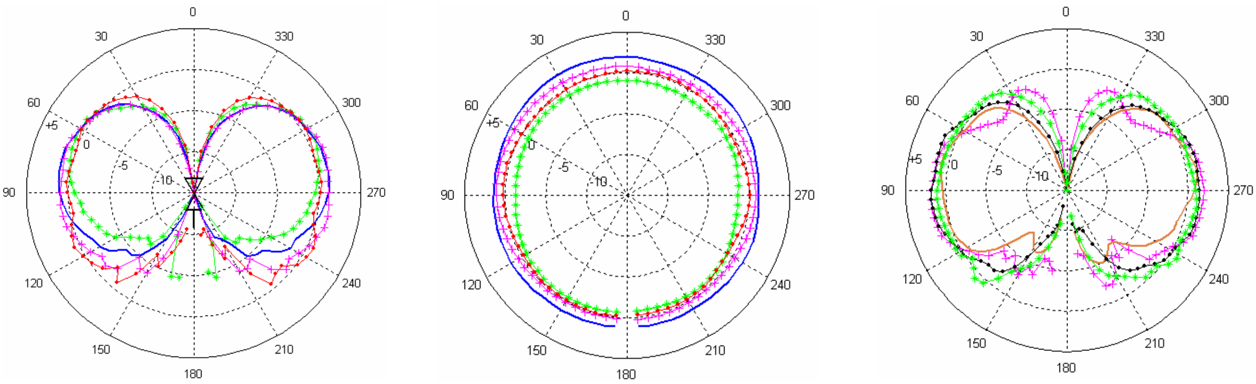
The measured return loss for both antennas is presented in Fig. 2a. The measured input bandwidth with respect to S_{11}<–10 dB is respectively 2.75-19.5 GHz for Bicone1 and 0.85-13 GHz for Bicone2.



(a) (b)

Fig. 2. (a) measured return loss for Bicone1(blue) and Bicone2(red) ; (b) Effective Gain at horizontal for Bicone2 simulation (magenta point), measured (red cross) and for Bicone1, measured (blue line).

The gain is weakly frequency dependent: 2 dBi (± 1 dB) for bicone2 and fewer for bicone1 due to its 2.5 times smaller size (0.5 dBi (± 0.75 dB)) over their respective whole VSWR bandwidth (Fig. 2b). Measurement (red cross) and simulation (magenta point) follows the same trends with slight deviations of maximum 0.5 dB in amplitude and 0.2 GHz in frequency, and that until 14.5 GHz. Note that the foam radome, and the cover effects are not taken into account in the simulation.



(a) (b) (c)

Fig. 3. Measured gain : (a) in elevation for Bicone1 (b) in azimuth for Bicone1 3 GHz (green asterisk), 4.5 GHz (blue line), 6 GHz (magenta cross), 7.5 GHz (red point) (c) in elevation for Bicone2. 1 GHz (orange line), 2 GHz (black point), 3 GHz (green asterik), 6 GHz (magenta cross)

The measurements in elevation (Fig. 3 (a)) are given for several frequencies (3, 4.5, 6, 7.5 GHz). As required, the frequency-independence of the radiation pattern is respected. The average −3 dB beamwidth (calculated on 3-10 GHz band) is 105°. The main lobe enlarges downwards up to 6 GHz. Above 12 GHz, a 'null' appears near θ=50° and the beamwidth decreases slowly with frequency, while the main lobe tilts downwards. These variations are essentially due to the fact that the antenna electrical size increases with frequency.

The measured radiation patterns in azimuth (Fig. 3b) show a quasi-perfect omni-directional behaviour (offset of, at worst, ± 0.6 dB for the lowest frequencies). The cross-polarization maximum level is always at least 20 dB below the co-polarization one.

Precise evaluation of an UWB omni-directional antenna efficiency is something difficult. For this bicone-like structure, the efficiency that takes into account metallic losses and those in the radome is expected to be high; that was confirmed by measurements.

Time Domain Results

The main purpose of a Time Domain (TD) approach is to characterize the distortion introduced by the antenna, in terms of the angular coordinates and the excitation waveform [8]. The UWB antenna is excited by an incident signal whose waveform undergoes a distortion induced by the antenna fig (5a); this distortion can be quantified using the correlation between the incident signal and the radiated one in certain direction, which illustrates the fidelity of the antenna in that direction. It is possible to take into account this antenna distortion (e.g. a pre-distortion at the transmit side or a matched filter at the receiver side) **at the critical condition that this distortion wouldn't be strongly dependent on the radiation angular direction**. This is crucial in some applications like the channel analysis using for example a 'Delay & Sum' DOA method, that exploits the a priori known signal waveform ; this is also interesting to extract from "Antenna_Tx-Channel-Antenna_Rx" measurements the mean antennas'influence without knowing the DOA and the Direction Of Departure (DOD).

Consequently, a more relevant information to characterise an UWB channel measurement antenna, consists in considering the distortion deviation into the lobe, in other words, the correlation between signals radiated at different elevations in the main lobe (formula *DF*). If this correlation is relatively strong over the whole main lobe, one will be able to remove an average distortion due to the antenna, and subsequently to characterize the channel own behaviour without antennas.

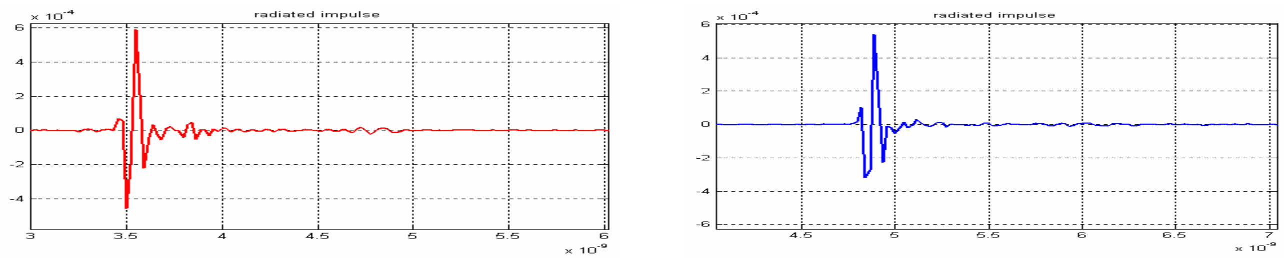


Fig. 5. Impulse Response in the horizontal direction calculated from Frequency Domain measurement on a [0.25-20] GHz with Hanning filtering for bicone1 (blue) for bicone2 (red).

Fig. 6 shows fidelity deviation (*DF*) in elevation for Bicone1 (blue line) and Bicone2 (red cross) excitated with a cardinal sine waveform over [0.25-20] GHz. This diagram gives a relevant characterization about the angular validity domain of mean distortion. Notice that over [0.25-20] GHz band, Bicone1 (blue) has a constant distortion on a larger beamwidth than Bicone2 (red). Nevertheless the required constraint on angular distortion is respected for both bicones over a wider angular range than that of measured echoes in channel measurement. This TD tool allows the comparison between different antennas over given frequency band as regards to the distortion deviation.

$$DF(\theta,\varphi)=\frac{\max_{\tau}\left|\mathcal{R}_{ee_m}(\tau)\right|}{\max_{\tau}\left|\mathcal{R}_{e_m e_m}(\tau)\right|}$$

where $\mathcal{R}_{xy}$ is the (x, y) inter-correlation function, $e = e(\theta, \varphi, t)$ is the electrical field waveform in the (θ, φ) direction and $(\theta_{max},\varphi_{max})$ is the direction of the minimum of distortion with respect to the excitation signal s, in other words, that maximises the following expression :

$$\max_{\tau}\left|\mathcal{R}_{es}(\tau)\right|$$

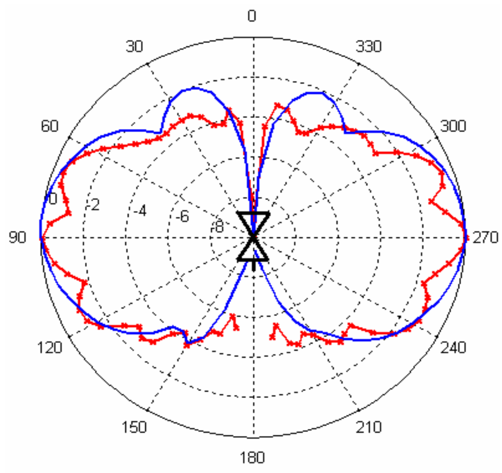


Fig. 6. : Diagram of fidelity deviation (dB) into the beam for Bicone1 (blue) for Bicone2 (red cross).

CONCLUSION

Experimental results have demonstrated that the two UWB Bicone-like antennas achieve the main requirements needed to perform UWB channel measurements. A TD tool characterizes how wide an antenna respect hypothesis of low distortion angular deviation needed to extract antennas influences from "antennas-channel" Impulse Response. More details on the antennas design, technical approach and results will be given during the conference.

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