



Gentner, Philip, K., Hilton, G. S., Beach, M. A., & Mecklenbrauker, Christop, F. (2010). Analysis of ultra-wideband linear antenna arrays. (pp. 4 p). (COST 2100 TD(10)11045). COST (European Cooperation in Science and Technology).

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COST 2100 TD(10)11045  
Aalborg, Denmark  
June 2-4, 2010

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## **Analysis of ultra-wideband linear antenna arrays**

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# Analysis of ultra-wideband linear antenna arrays

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**Abstract**—This contribution presents the beamforming behaviour of ultra-wideband (UWB) arrays. The arrays consist of multiple ultra-wideband monopole antenna elements which are mounted on a groundplane. The beamforming behaviour is analyzed in the time- and in the frequency-domain. Especially in the UWB - Impulse Radio scenario the time domain characterization of the antenna arrays is very important. The target application of such UWB - Impulse Radio antenna arrays would be a smart antenna system with beamforming and beamsteering potential, to deliver high-definition video or uncompressed audio to mobile devices. Therefore, several antenna array types were set up experimentally and measured in an anechoic chamber as part of the COST 2100 Short Term Scientific Mission UWBeams II.

## I. INTRODUCTION

Wideband antenna arrays can be used in applications where a base station is needed, such as sensor networks or RFID readers. Together with the technology of Ultra-Wideband [1], the tracking of a sensor node or a RFID-tag can be established. A smart wideband antenna array can be summarized by the task, that the array can estimate and track the position of the target device and to form and steer a beam over a huge frequency bandwidth ([2] and [3]) towards the target.

In the past a lot of contributions were published which focused on antenna arrays and various positions of each element [4] and [5]. Here we present measurements with small planar wideband monopole antennas. The wideband antenna array design is also important for the increasing demand of bandwidth used by the different existing communication schemes.

In the first section of this paper, we summarize the measurements performed as a Short Term Scientific Mission for COST2100. In the following subsections the analysis methods are introduced, before the measurement results are shown.

## II. MEASUREMENTS PERFORMED IN UWBEAMS 2

As part of the STSM two ultra-wideband antenna array types were measured in an anechoic chamber. The

antenna elements are the elliptical slot monopole antenna from [6] and the small rectangular shaped monopole from [7]. Both monopole antennas show a good omnidirectional behaviour as single elements, presented in [8]. In Table I the performed measurements are listed. Two linear arranged array types were focused. The linear array has an equal spacing between all elements of  $d_i = 5\text{cm}$ .

The 4 element array is moved towards the reference horn antenna in steps of 0.5 meters. At every distance step, an angular resolved frequency sweep from 2.5GHz to 10.5GHz is performed with the network analyzer for the angles  $\phi = 45^\circ$ ,  $\phi = 90^\circ$ ,  $\theta = 45^\circ$  and  $\theta = 90^\circ$ . The purpose of this procedure is to analyze the beamforming behaviour of the antenna array at these different distances.

Investigations with different interelement distances are performed with a geometric arrangement of the wideband elements. The outer element distances are calculated for a certain frequency range (from  $f_{min} = 3\text{GHz}$  to  $f_{max} = 6\text{GHz}$ ). Following formula is used:

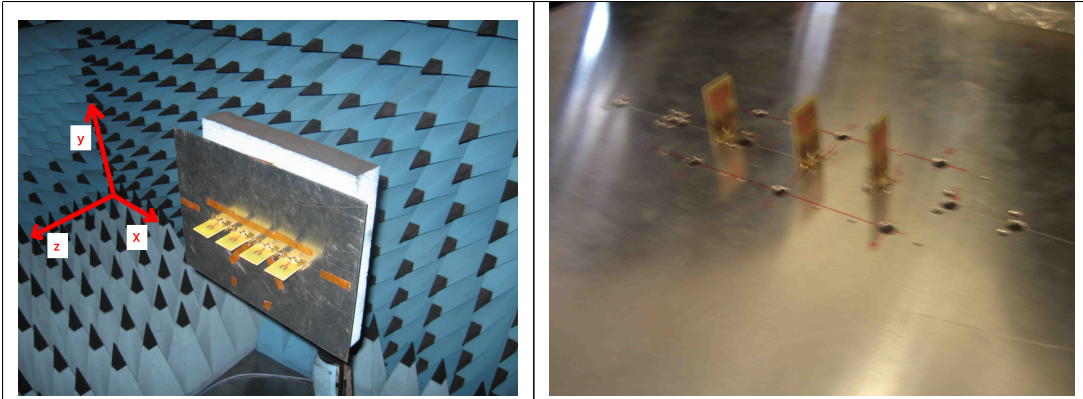
$$d_1 = \frac{\lambda_{max}}{2} \quad (1)$$

$$d_{N-1} = \frac{\lambda_{min}}{2} = d_1 \cdot q^{N-1} \quad (2)$$

For all geometric arranged monopole arrays an odd number of elements is used, to be able to place the center element in the origin of the measurement coordinate system. This geometric spacing of the antenna elements has the effect of a decreased overall array size.

### A. Calibration

The calibration is done by a single measurement. The transmission coefficient  $s_{21,ref}$  is captured after connecting the measurement cables  $L_1$  and  $L_2$  coming from the network analyzer. The gain  $G_1$  from the dual polarized horn antenna (Flenn DP240) is known by data sheet.  $G_2$  is the antenna array under test together with the wilkinson combiner loss ( $L_F$  is the free space loss).



| Linear array with equal spacing $d_i = 5\text{cm}$ |      |         |       | Linear array with geometric spacing |       |         |       |         |       |
|--|------|---------|-------|-------------------------------------|-------|---------|-------|---------|-------|
| 4x1  | 4x1  | 3x1     |       | 3x1                                 |       | 7x1     |       | 7x1     |       |
| ellipt   | rect | freq    | polar | freq                                | polar | freq    | polar | freq    | polar |
| 1m   | 1m   | theta45 | 3GHz  | phi45                               | 3GHz  | phi45   | 3GHz  | phi45   | 3GHz  |
| 1.5m   | 1.5m | theta90 |       | phi90                               | 5GHz  | phi90   | 5GHz  | phi90   | 5GHz  |
| 2m   | 2m   |         |       | theta45                             | 7GHz  | theta45 |       | theta45 |       |
| 5.4m   | 5.4m |         |       | theta90                             |       | theta90 |       | theta90 |       |

TABLE I  
MEASUREMENT SUMMARY PERFORMED AT UWBEAMS 2.

Following formula is embedded into the analysis routine of the post processing:

$$(G_2 + L_F) = s_{21,\text{DUT}} - s_{21,\text{ref}} - G_1 \quad (3)$$

### B. Correlation

To be able to benchmark the beamforming behaviour of the wideband antenna array a correlation method is used. A correlation of the measured data with the arrayfactor of an isotropic antenna array is performed. The arrayfactor of an N-element antenna array is known as:

$$E_{\text{beam}}(\theta, \phi) = \frac{\sin\left(\frac{N \cdot k \cdot d \cdot \sin(\phi) \cdot \sin(\theta)}{2}\right)}{N \cdot \sin\left(\frac{N \cdot k \cdot d \cdot \sin(\phi) \cdot \sin(\theta)}{2}\right)} \quad (4)$$

The correlation coefficient is calculated by:

$$\rho = \frac{\int_{-\pi}^{\pi} |E(\phi)| \cdot |E_{\text{beam}}(\phi)| d\phi}{\sqrt{\int_{-\pi}^{\pi} |E(\phi)|^2 d\phi \cdot \left(\int_{-\pi}^{\pi} |E_{\text{beam}}(\phi)| d\phi\right)^2}} \quad (5)$$

### C. Time Domain Analysis

An inverse fourier transformation is used to represent the beamforming behaviour of the antenna array in the time domain. Therefore the complex transmission coefficient is used. The measurement data is padded with zeros before it gets multiplied with a hanning window  $w(n)$ . The Pulse Delay Profile can be written as:

$$PDP = |F^{-1}(s_{21,\text{DUT}}(n) \cdot w(n))|^2 \quad (6)$$

## III. MEASUREMENT RESULTS

In Figure 1 the result of the 4x1 elliptical monopole antenna array is shown. The measurement is taken at  $\theta = 45^\circ$  and the calibration post processing is applied. In all contour plots we can see similar main beams in front and backfire at  $\phi = \pm 90^\circ$  within a frequency range from 2.5 GHz to 6 GHz. In the logarithmic scale, sidelobes are visible but lower than 15 dB in comparison to the main beam.

The result of the correlation method is shown in Figure 2. With this representation we see that there is no big difference in the beamforming behaviour across the different measurement distances. The correlation coefficient decreases suddenly at 5 GHz; the measured array starts to differ from the ideal isotropic array. An explanation for this behaviour could be, that the used wilkinson combiner is not matched well in this frequency range.

In Figure 3 the Pulse Delay Profile of the elliptical monopole array with 4 elements is shown. The measurement distance is 1 meter and the interelement distance is 5 cm. As expected from the frequency resolved plots, one can see the envelope signal of a pulse at  $\phi = \pm 90^\circ$ . Some ringing after the pulse (later in time) gets visible. The pulses in Figure 4 are also similar in shape across the measurement distances.

The comparison investigation of the equal and different spaced antenna array is done with the rectangular shaped monopoles. The monopoles were fixed at the positions calculated with (1) and (2) for N=3 elements. The Pulse Delay Profile is calculated and presented in

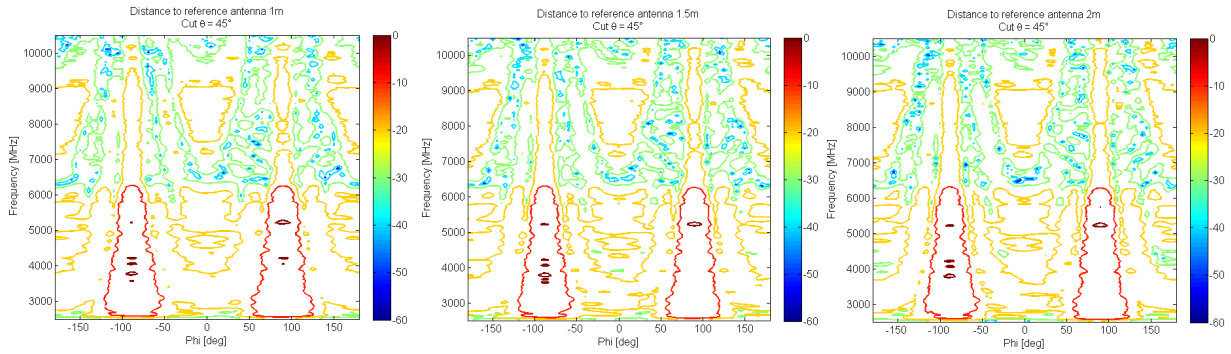


Fig. 1. The contour plots show the frequency resolved measurements versus  $\phi$  of a 4 element elliptical monopole array. On the left side is 1 meter, middle 1.5 meter and on the right side is 2 meter measurement distance from the array under test to the reference horn antenna. The main lobes (front and backfire) are visible at  $\phi = \pm 90^\circ$

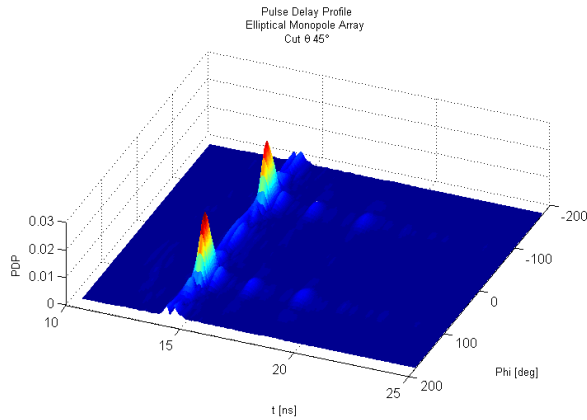


Fig. 3. Pulse Delay Profile of the 4x1 elliptical monopole array at 1 meter measurement distance

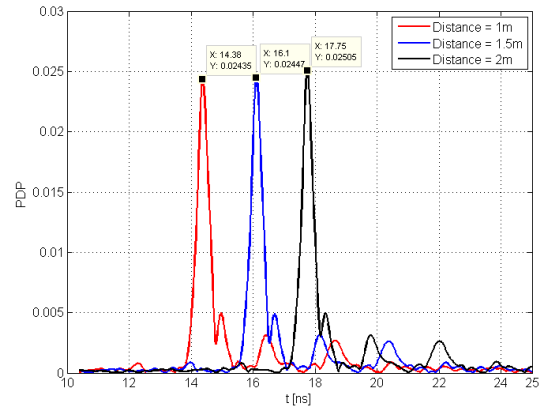


Fig. 4. Pulse shapes at  $\theta = 45^\circ$ ,  $\phi = 90^\circ$  of the 4x1 elliptical monopole array.

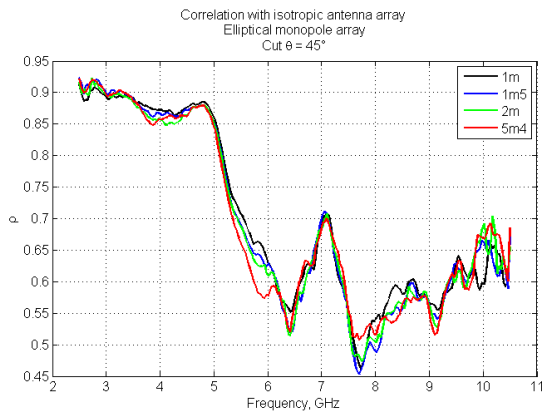


Fig. 2. Correlation of the measured data (elliptical monopole array) with a 4 element isotropic array.

Figure 5 for the equal spacing of 5cm, and Figure 6 for the geometric arranged monopoles  $\theta = 45^\circ$ . It seems to be that the pulswidth in time and in the angle  $\phi$  does

not change for this different kind of array. But in endfire of the geometric arranged array we can observe more energy than in the regular spaced array.

#### IV. CONCLUSIONS

Two different kinds of antenna element arrangements have been measured in the STSM UWBeams II. With this data we were able to develop tools to analyse the behaviour of wideband antenna arrays, such as the Power Delay Profile and the correlation method with the arrayfactor. In this contribution we have compared the beam behaviour of ultra-wideband antenna arrays in a distance resolution in the time and in the frequency domain. Within the observed distances we see no change in wideband beamwidth. Also, irregular spacing like the geometric arrangement of wideband monopoles can be used without performance degradation of the wideband antenna array.

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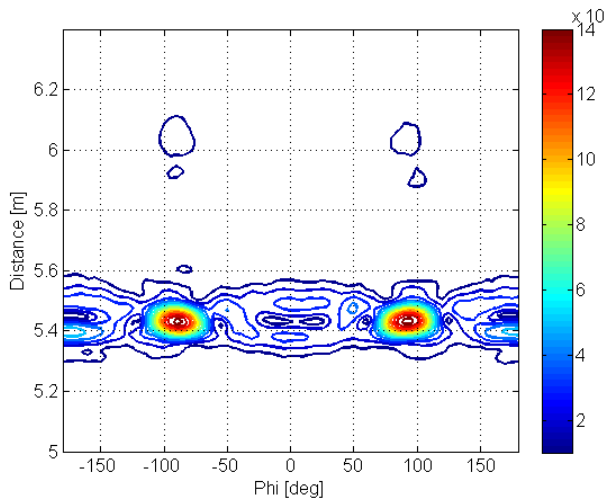


Fig. 5. 3x1 regular spaced antenna array with  $d_i = 5\text{cm}$ .

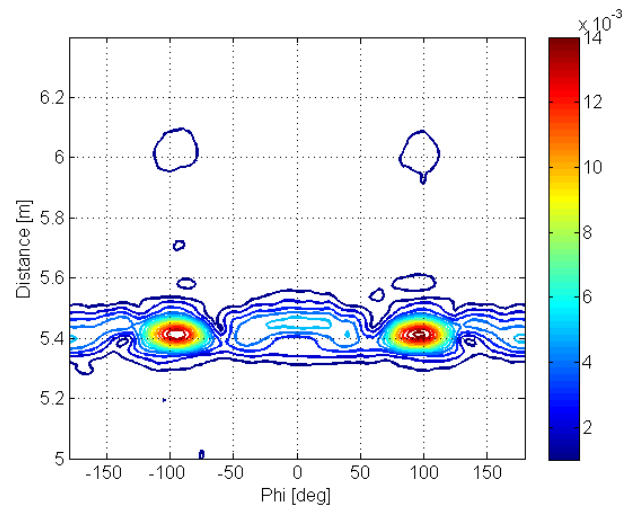


Fig. 6. Geometric arranged elements in a 3x1 linear array

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