

EUROPEAN COOPERATION
IN THE FIELD OF SCIENTIFIC
AND TECHNICAL RESEARCH

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

EURO-COST

SOURCE: ¹ Institute of Communications and Radio-Frequency
Engineering, Vienna University of Technology
Gusshausstrasse 25/389, 1040 Wien, Austria
 ² Centre for Communications Research, University
of Bristol
Merchant Venturers Building, Woodland Road,
Bristol, United Kingdom

Analysis of ultra-wideband linear antenna arrays

Philipp K. Gentner¹, Geoff Hilton², Mark A. Beach², Christoph F. Meck-
lenbräuker¹
Gusshausstrasse 25 - 29 / 389
1040 Wien
AUSTRIA
Phone: +43 1 58801 78938
Fax: +43 1 58801 38999
Email: Philipp.Gentner@nt.tuwien.ac.at

Analysis of ultra-wideband linear antenna arrays

Philipp K. Gentner¹, Geoff Hilton², Mark A. Beach², Christoph F. Mecklenbräuer¹

¹ *Institute of Communications and Radio-Frequency Engineering, Vienna University of Technology
Gusshausstrasse 25/389, 1040 Wien, Austria*

² *Centre for Communications Research, University of Bristol
Merchant Venturers Building, Woodland Road, Bristol, United Kingdom
philipp.gentner@nt.tuwien.ac.at*

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:

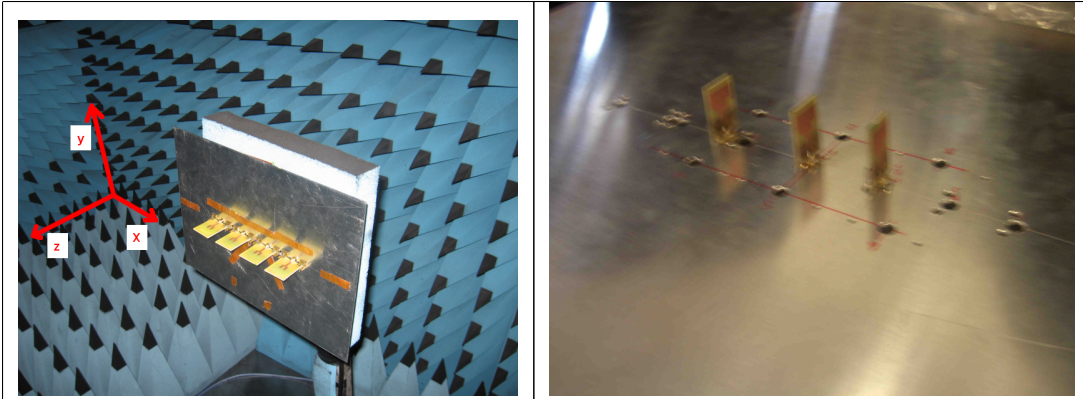
$$d_1 = \frac{\lambda_{max}}{2} \quad (1)$$

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

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:

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

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:

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

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:

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

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

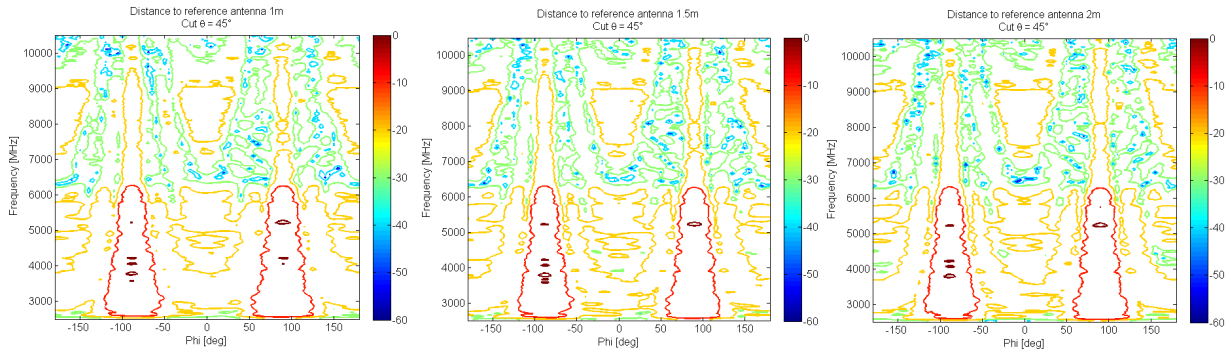


Fig. 1. The contour plots show the frequency resolved measurements versus ϕ of a 4 element elliptical monopole array. On the left side is 1 meter, middle 1.5 meter and on the right side is 2 meter measurement distance from the array under test to the reference horn antenna. The main lobes (front and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

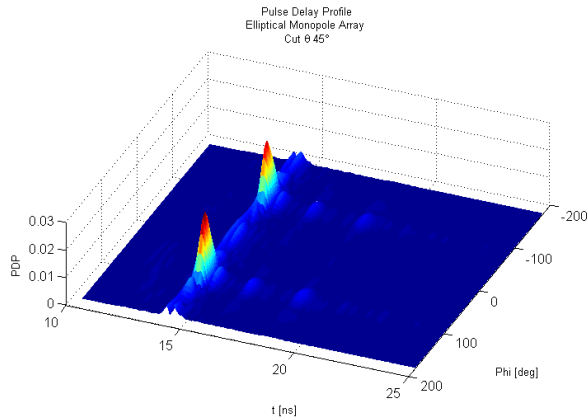


Fig. 3. Pulse Delay Profile of the 4x1 elliptical monopole array at 1 meter measurement distance

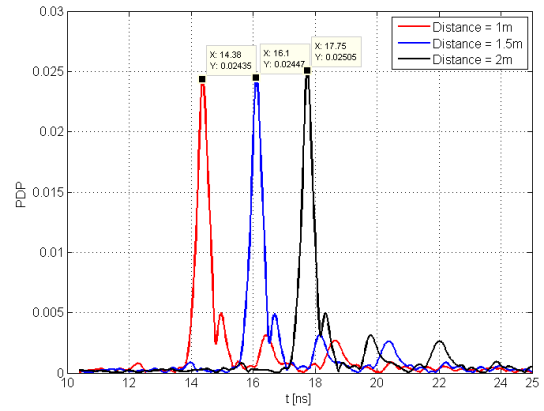


Fig. 4. Pulse shapes at $\theta = 45^\circ$, $\phi = 90^\circ$ of the 4x1 elliptical monopole array.

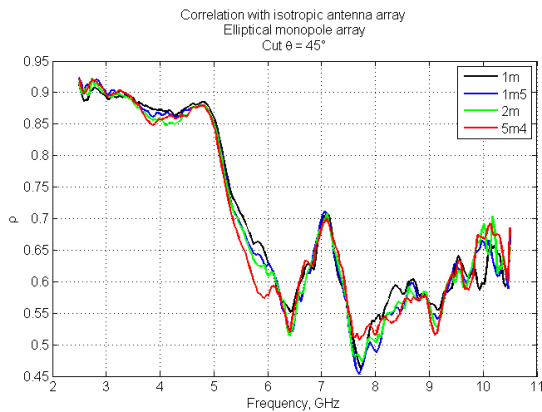


Fig. 2. Correlation of the measured data (elliptical monopole array) with a 4 element isotropic array.

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 ϕ 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.

REFERENCES

- [1] M. G. Di Benedetto, T. Kaiser, A. F. Molisch, I. Oppermann, C. Politano, and Domenico Porcino: "UWB Communication

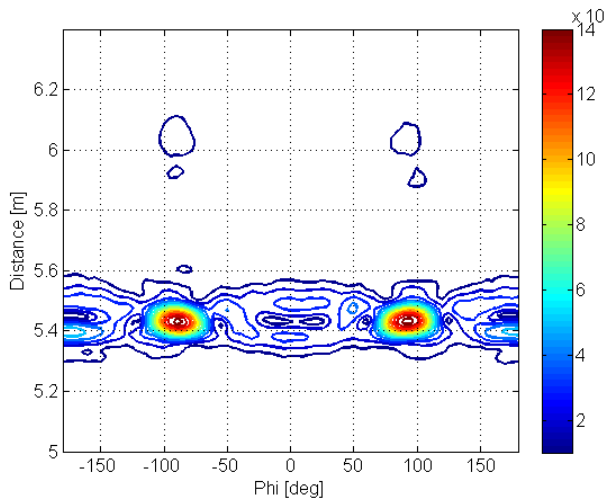


Fig. 5. 3x1 regular spaced antenna array with $d_i = 5\text{cm}$.

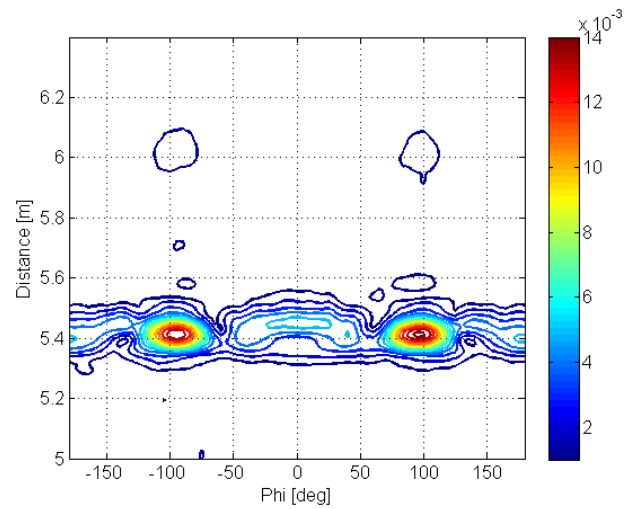


Fig. 6. Geometric arranged elements in a 3x1 linear array

Systems: A Comprehensive Overview", Eurasip Signal Processing and Communications, ISBN 9775945100, 2006.

- [2] H. Hashemi, T. Chu, and J. Roderick; "Integrated True-Time-Delay-Based Ultra-Wideband Array Processing", 2008, IEEE Communications Magazine, September 2008, pp. 162 - 172
- [3] S. Ries, and T.Kaiser: "Highlights of UWB impulse beamforming", Proceedings EUSIPCO 2004, Vienna 2004.
- [4] P.S. Hall: "Multioctave bandwidth log-periodic microstrip antenna array", IEE Proc., Vol.133, No. 2, April, 1986.
- [5] Y. I. Abramovich, N.K. Spencer, A.Y. Gorokhov: "Detection-Estimation of More Uncorrelated Gaussian Sources than Sensors in Nonuniform Linear Antenna Arrays-Part 1: Fully Augmentable Arrays", IEEE Trans. on Sig. Proc., Vol. 49, No. 5, May 2001.
- [6] P. Li, J. Liang and X. Chen: "Ultrawideband printed elliptical slot antenna fed by tapered microstrip line with Ushaped tuning stub", Microwave Opt. Technol. Lett., Vol. 47, No. 2, pp. 140143, 2005
- [7] J. Jung, W. Choi and J. Choi, P. Miskovsky, C. Ibars, J. Mateu, M. Navarro; "A small Wideband Microstrip-fed Monopole Antenna", 2005, Microwave and Wireless components Lett., Vol. 15, No. 10, pp. 703-705
- [8] P. K. Gentner, W. Gartner, G. Hilton, Mark A. Beach, C. F. Mecklenbräuker: "Towards a Hardware Implementation of Ultra-Wideband Beamforming TD(10)10034", 2010, 10th COST Management Meeting, Athens.