Over the Air Calibration of Massive MIMO TDD Arrays for 5G Applications

L. J. Foged, L. Scialacqua, F. Saccardi
Microwave Vision Italy
Via dei castelli Romani 59, 00040, Pomezia, Italy
(lars.foged, lucia.scialacqua,
francesco.saccardi)@microwavevision.com

N. Gross, A. Scannavini
Microwave Vision Industries
17 avenue de Norvège. 91140 Villebon-sur-Yvette. France
alessandro.scannavini@microwavevision.com
nicolas.gross@mvg-world.com

Abstract— **This paper address the problem on how to accurately calibrate Massive MIMO system using time-division duplexing (TDD). In practical MIMO array implementations the transmission and reception path are different and hence a calibration mechanism, linking optimum receive array coefficients to optimum transmit coefficients is needed. We propose an Over-the-Air OTA calibration technique based on post-processing of the measured transmit and receive beam. The method is described and uncertainties linked to the method are investigated. A demonstration measurement on a representative array is presented to illustrate the application of the calibration method to realistic MIMO systems.**

Keywords—Massive MIMO; array; antenna; calibration; measurement;

I. INTRODUCTION

Massive MIMO has been put forward as one of the most promising potential technologies for the 5G mobile network [1]. The base stations can be implemented using a transceiver for each antenna element or as hybrid transceivers which use a combination of analog beamformers in the RF domain, together with a smaller number of digital beamformers in baseband. In massive MIMO, the applied beamforming is not a classical array beam-shaping aimed at maximizing gain and minimizing side-lobe or similar pattern properties. MIMO array beamforming is performed at signal quality level searching to obtain phase coherence between several incoming signals and eliminate disturbances.

In a reciprocal channel system, based on time-division duplexing (TDD) the determined receive coefficient of the array can be applied at the transmit coefficients proving the desired beam at the same frequency. However, when the actual transceiver hardware is taken into consideration, the channel reciprocity is broken since different components and RF paths are used in transmission and reception, hence a calibration mechanism, linking optimum receive array coefficients to the optimum transmit coefficients is needed to compensate the hardware non-symmetry.

Traditional calibration solutions require the measurement of each RF chain separately. This solution implies a dedicated setup and is time consuming. In this paper we investigate an Over-the-Air (OTA) calibration technique based direct post processing of a single transmit and receive beam.

II. PROPOSED CALIBRATION TECHNIQUE

The proposed calibration technique is based on a measurement of a single radiation pattern, or beam, of the array in transmit and receive mode. The realised complex coefficients at array element level is determined by the Equivalent Currents (EQC) technique. This technique was first applied to determine excitation errors in space-born array antennas [2].

The equivalent currents are determined initially on the full array [3]. Subsequently, thanks to spatial filtering of the currents it is possible to isolate each of the array elements and determine the associated radiation pattern. The element patterns include all mutual coupling effects of the array elements. From the element pattern, the realised complex excitation coefficients are determined from radiated power normalisation and relative phase comparison in the boresight direction.

Ideally, the determined realised excitation coefficients at array element level for transmit and receive should be identical. A sufficiently accurate knowledge of the realised excitation coefficients allows a proper calibration at RF chain level to compensate the hardware non-symmetry. In arrays with a strong mutual coupling it might be necessary to perform the transmit measurement more than once, using the transmit calibration coefficients to iterate a better estimate of the calibration matrix.

III. INVESTIGATION OF ACHIEVABLE CALIBRATION ACCURACY

The achievable calibration accuracy expresses as uncertainty on the determined array element excitation, has been investigated by a numerical experiment using an array of four Huygens sources with different element spacing (d=0.9λ, 0.7λ, 0.5λ and 0.25λ). The Huygens sources eliminate the mutual coupling and thus gives a measure of the achievable accuracy at single element excitation level. The statistical variation of the uncertainty for different excitation configurations has been determined by Montecarlo analysis.

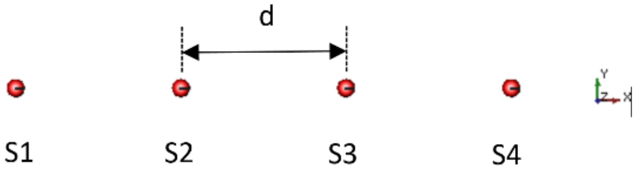
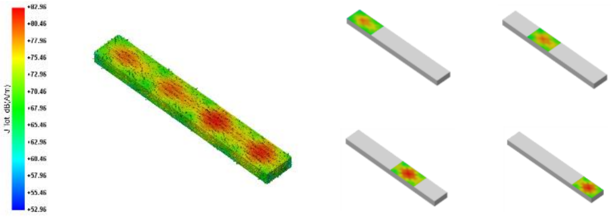


Fig. 1. : Numerical array of four Huygens sources.

Starting from the Near Field (NF) radiation patterns the equivalent currents are calculated on a simple reconstruction geometry. In this investigation, we use a box. An example of equivalent currents distribution for an array configuration with element spacing 0.9λ is shown in Figure 2(a). Thanks to the spatial filtering capabilities of the EQC, the single array elements can be isolated as shown in Figure 2(b). From the EQC of each element, the correspondent realised complex excitation coefficients are determined from radiated power normalisation and relative phase comparison in the boresight direction.



(a) (b)

Fig. 2. : (a) Example of electric equivalent currents reconstruction for an array of frour Huygens sources, d = 0.9 λ at the operative frequency; (b) Array element EQC distributions to determine the realised complex coefficients.

The uncertainty from the Montecarlo analysis for the arrays with different spacing are shown in Table 1. The uncertainties are expressed as 1σ variation with respect to the nominal value. As can be expected, the uncertainty increase with diminishing distance between the elements. This is due to the finite accuracy of the expansion functions. Worst deviation is approximately 1dB/8° for 0.25λ element spacing. In addition to the method uncertainty, the finite measurement accuracy must be added. These values are acceptable for what is achievable in standard OTA calibration.

TABLE I. ARRAY ELEMENT EXCITATION UNCERTAINTY (1 SIGMA)

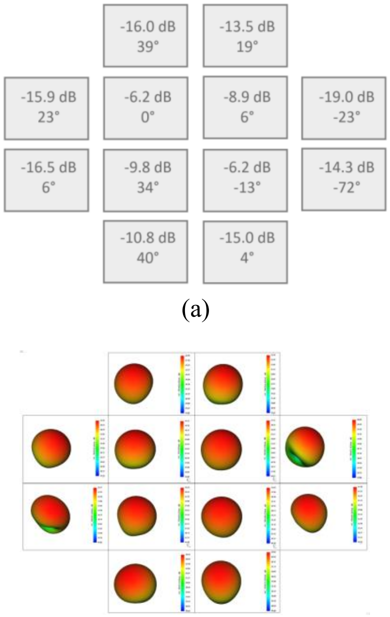
Element Spacing	*Amplitude [dB]*	*Phase [°]*
d = 0.9λ	0.26	3.83
d = 0.7λ	0.60	6.15
d = 0.5λ	0.80	7.19
d = 0.25λ	1.02	7.93

IV. MEASUREMENT OF REPRESENTATIVE MIMO ARRAY

The proposed calibration technique has been demonstrated by measurement of a patch array at 5.8GHz in a standard spherical near-field multi-probe system, SL18GHz from MVG [4]. The measurement setup is shown in Figure 3.

Fig. 3. : Patch antenna in the StarLab18GHz measurement system [4]. Only one of the separate arrays is measured.

The antenna is composed of two separate arrays, both in LHCP polarisation, for transmit and receive. Low directive material is used for the substrate and the spacing between the elements is 0.6λ and 0.8λ along the two principal array axes. In this example, we will show the results for one 12-element array only. The realised element excitation coefficients in amplitude and phase of the array have been obtained by the proposed technique. The results are shown in Figure 4.



(a)

(b)

Fig. 4. : Patch Array antenna : (a) complex coefficients (Amplitude [dB] and Phase [°]) determined by the proposed calibration technique; (b) E-field radiated by the single array element, 30dB dynamic range.

V. CONCLUSIONS AND FUTURE WORK

A simple OTA calibration method for TDD based MIMO arrays has been proposed. Numerical investigations show the method to be accurate and fast. The technique has been demonstrated on a representative array antenna using CW signals but it can be also used with modulated signals using phase recovery [5]. Future works include the application of the technique to an actual MIMO array using modulated signals.

REFERENCES

[1] T. Marzetta, “Noncooperative cellular wireless with unlimited numbers of base station antennas,” Wireless Communications, IEEE Transactions on, vol. 9, no. 11, pp. 3590–3600, Nov. 2010.

[2] L. Salghetti Drioli, L.J. Foged, F. Saccardi, L. Scialacqua, “Verification of Complex Excitation Coefficients from Measured Space Array Antenna by the Equivalent Current Technique” AMTA, 12-17 October 2014, Tucson, Arizona, USA.

[3] http://www.mvg-world.com/products/field_product_family/antenna-measurement-2/insight (MVG INSIGHT software).

[4] L.J. Foged, A. Scannavini, “Efficient testing of wireless devices from 800MHz to 18GHz, Radio Engineering Magazine, Vol 18, No 4, December 2009.

[5] L.J. Foged, A. Scannavini, “Efficient testing of wireless devices from 800MHz to 18GHz, Radio Engineering Magazine, Vol 18, No 4, December 2009.