ULA and MRA Antenna Array Comparison in Presence of Mutual Coupling

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Abstract

The article models and analyzes the Uniform Linear Array(ULA) and Minimum Redundance Array (MRA) beamforming arrays with taken into account the mutual coupling between the antenna array elements. The comparison shows the advantage of MRA over ULA in narrower beamwidth which is very attractive for adaptive antenna applications and direction of arrival determination. Simulation is performed for real antenna arrays built from wire dipoles and is shown that the sidelobe level is increasing for each array but for MRA the symmetry also distorted. Therefore for adaptive antenna applications is especially important the compensation of mutual coupling of antennas. Finally measured mutual coupling results are presented for microstrip antennas to show the importance of the effect analyzed .

Introduction

The MRA with adaptive beamformer results in performance superior by a comparable system based on ULA in terms of rejecting interferences. This behavior is based on the narrower beamwidth of MRA which advantage is decreases by the large sidelobes. The MRA is used mainly for radio astronomical purposes because of its narrow main lobe but is not in common use as simple beamformer in communications. By employing an adaptive beamforming system based on a MRA provides better rejection of interference. [1,4] The MRA is an asymmetric thinned array therefore in presence of mutual coupling the radiation pattern distorts non symmetrical. This effect will be shown in the following.

Minimum redundance array

A MRA of order M, is an array which allows the formation of all integer spatial correlations from 1 to N with the minimum number of antenna array elements.

Table 1. Possible MRA configurations

MRA configurations		
N	Length	Interelement spacing
1	-	
2	1	1
3	3	1,2
4	6	1,3,2
5	9	1,3,3,2
6	13	1,5,3,2,2
7	17	1,3,6,2,3,2
8	23	1,3,6,6,2,3,2

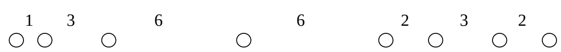

Fig. 1. Eight order MRA

Radiation Pattern

The radiation pattern for isotropic antennas is the array factor (*AF*) which is for general linear array:

$$AF = \sum_{n=1}^{N} I_n \exp\left(jkd_n \sin\Theta\right) \qquad (1)$$

where

I_n the excitation current of the *n*-th antenna, d_n the distance of the *n*-th antenna measured from reference
N the number of antenna elements in array, Θ the angle measured from array normal

The Fig. 2. and 3. present the radiation patterns for ULA and MRA with the same number of elements and *d* unit distance. The element positions are

$d_n = (n-1)\cdot d$ for ULA

$d_n = \{0, d, 4d, 10d, 16d, 18d, 21d, 23d\}$ for MRA

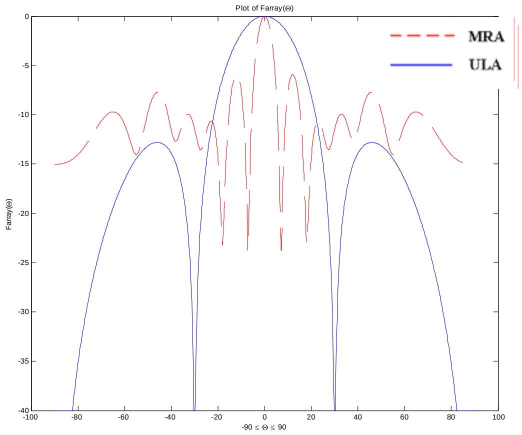

Fig. 2. Normalized AF for ULA and MRA
d = 0.25λ, N = 8

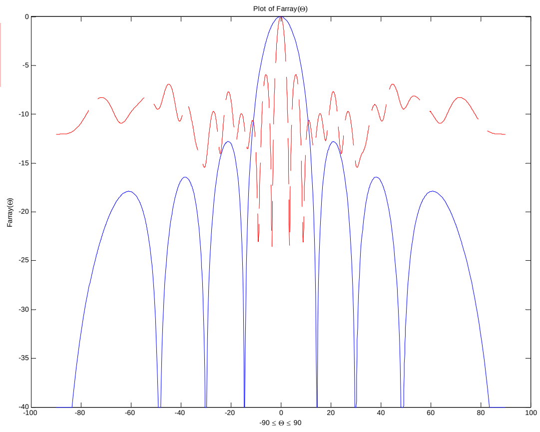

Fig. 3. Normalized AF for ULA and MRA
d = 0.5λ, N = 8

The MRA narrow beamwith is based on longer array distace and higher sidelobe is based on asymmetric geometry.

Mutual coupling

The antenna elements always have mutual effects on each other and this phenomena can be characterised by the mutual impedance and the N port impedance matrix.
The antenna array impedance matrix $\underline{\underline{Z}}$ is given by

$$\underline{U} = \underline{\underline{Z}}\,\underline{I} \qquad (2)$$

where

$(\underline{U})_n$ the voltage on port n, $\quad (\underline{I})_n$ the input current of port n

The mutual impedance calculation was performed for an N=8 element ULA and MRA built up with 0.5λ dipoles with d=0.25λ distances. Method of moments was used to determine the antenna currents [2,5] and the impedance matrix elements are:

$$(\underline{\underline{Z}})_{ij} = \left.\frac{U_i}{I_j}\right|_{I_k=0,k\neq j} \qquad (3)$$

Direction estimation methods

The general problem of direction estimation considers sensors (antennas) with arbitrary locations in a noise and/or interference environment to determine the incident wave directions. The methods mainly based on the spatial covariance matrix of the measured

$$\underline{x} = \underline{\underline{A}}\,\underline{s} + \underline{n} \qquad (4)$$

vector of the antenna output signals, where

$\underline{\underline{A}}$ the complex steering matrix, $\underline{\underline{A}} = [\underline{a}(\theta_1)\underline{a}(\theta_2)...\underline{a}(\theta_N)]$

$\underline{s}$ the incident wave amplitude and phase, $\underline{n}$ the noise vector.

The $\underline{\underline{R}}$ spatial covariance matrix

$$\underline{\underline{R}} = \underline{\underline{A}}\,\underline{s}\,\underline{s}^*\underline{\underline{A}}^* + \underline{n}\,\underline{n}^* \qquad (5)$$

The conventional beamformer (BF), the Capon's method (CAP) and MUSIC (Multiple signal characterization) were investigated and compared for ULA and MRA geometries with or without mutual coupling taken into account between antennas at the simulations. The BF, Capon and MUSIC direction estimation methods maximize the following spatial DOA spectrum expressions

$$P_{BF}(\theta) = \frac{\underline{a}^*(\theta)\hat{\underline{\underline{R}}}\underline{a}(\theta)}{\underline{a}^*(\theta)\underline{a}(\theta)} \qquad P_{CAP}(\theta) = \frac{1}{\underline{a}^*(\theta)\hat{\underline{\underline{R}}}^{-1}\underline{a}(\theta)} \qquad P_{MUSIC}(\theta) = \frac{1}{\underline{a}^*(\theta)\underline{\underline{E}}_N\underline{\underline{E}}_N^*\underline{a}(\theta)}$$

where

$\hat{\underline{\underline{R}}} = \frac{1}{T}\sum_t x_t x_t^*$ covariance matrix estimation, $\underline{\underline{E}}_N$ the noise subspace eigenvectors.

The spatial DOA spectra were calculated using MATLAB programs.

RESULTS

Our first results are on the radiation pattern of ULA and MRA in presence of mutual coupling. To determine the radiation pattern first the excitation currents were calculated, using the $\underline{\underline{Z}}$ mutual impedance matrix as

$$\underline{I} = \underline{\underline{Z}}^{-1}\underline{U} \qquad (6)$$

The currents $(\underline{I})_n = I_n$ are substituted into (1) calculating the AF.

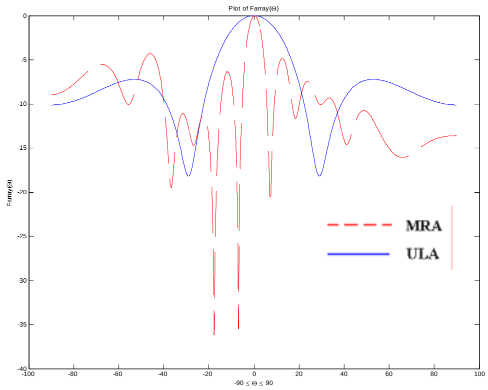

Fig. 4. Normalized AF for ULA and MRA with mutual coupling, *d* = 0.25λ, *N* = 8

The effect of mutual coupling affect also the ULA and MRA but because of the different (symmetric/asymmetric) geometry the ULA has increased sidelobe level the MRA radiation pattern results not only in increased sidelobe level but heavily asymmetric pattern.
Finally the DOA spectra were investigated for N=8 element ULA and MRA.
For **Fig. 5, 6, 7, 8.** the two wave have identical amplitude and the incidence angles are -3 and +3 degrees.

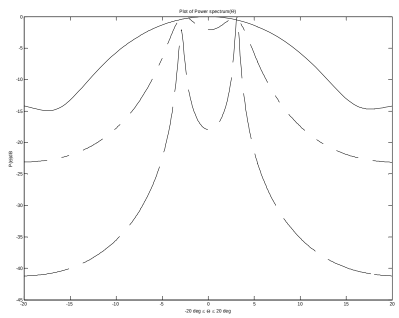

Fig. 5. Spatial DOA spectra, no mutual coupling ULA , *N* = 8 , *S/N*=14 dB, *d* = 0.5, Solid - BF, dash dot - CAP, dashed line - MUSIC

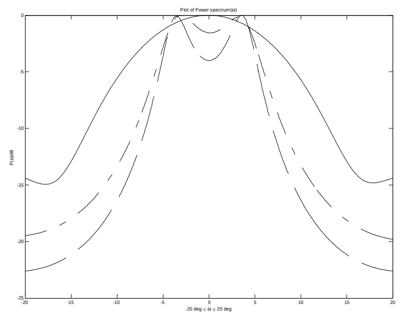

Fig. 6. Spatial DOA spectra, mutual coupling ULA , *N* = 8 , *S/N*=14 dB, *d* = 0.5
Solid - BF, dash dot - CAP, dashed line - MUSIC
Termination impedance 50 ohm

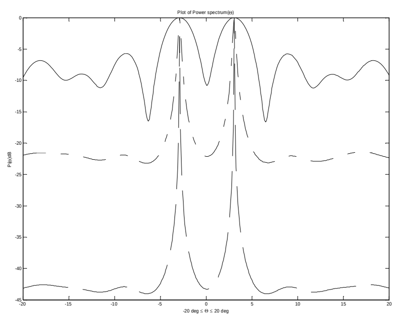

Fig. 7. Spatial DOA spectra, no mutual coupling MRA , *N* = 8 , *S/N*=14 dB, *d* = 0.5
Solid - BF, dash dot - CAP, dashed line - MUSIC

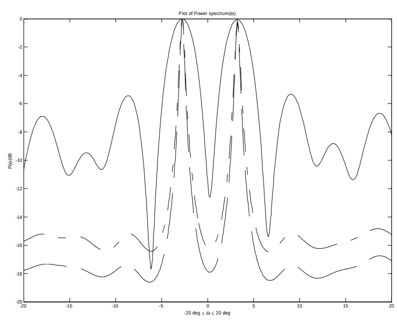

Fig. 8. Spatial DOA spectra, mutual coupling MRA , *N* = 8 , *S/N*=14 dB, *d* = 0.5
Solid - BF, dash dot - CAP, dashed line - MUSIC
Termination impedance 50 ohm

For **Fig**. **9**, and **10** the two incident waves have identical amplitude and the incidence angles are +57 and +63 degrees.

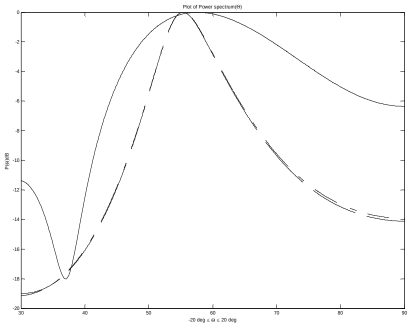

Fig. 9. Spatial DOA spectra, mutual coupling
ULA , N = 8 , S/N=30 dB, d = 0.5
Solid - BF, dash dot - CAP, dashed line - MUSIC
Termination impedance 50 ohm

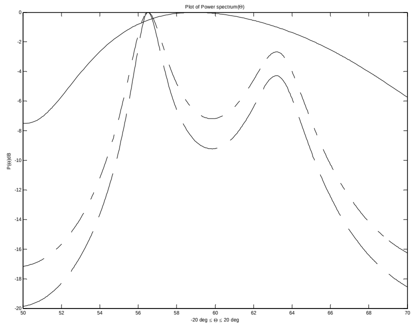

Fig. 10. Spatial DOA spectra, mutual coupling
MRA , N = 8 , S/N=14 dB, d = 0.5
Solid - BF, dash dot - CAP, dashed line - MUSIC
Termination impedance 50 ohm

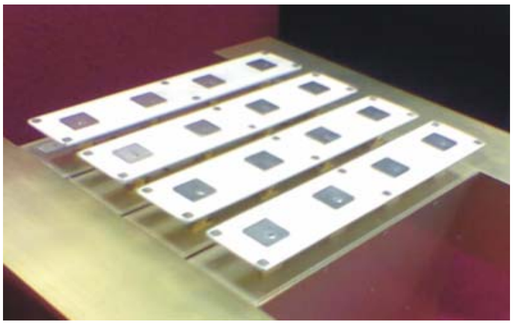

Fig. 11. Digital beamformer 4x4 element array

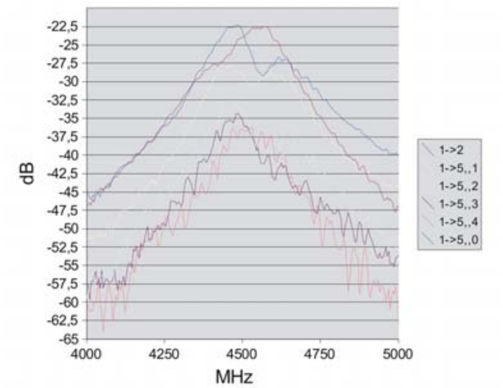

Fig. 12. Mutual coupling between elements of array in **Fig. 11**

The Fig. 12. ilustrates the effect of antenna geometry on mutual coupling between array elements. The effect measured will basically determine the resolution of beamformers as was showed in Fig. 5-10.

CONCLUSION

The comparison shows the different behavior of ULA and MRA in presence of mutual coupling. Based on this simulation the mutual coupling compensation have increased importance in MRA antenna arrays for simple beamforming but the direction estimation results show much better performance for MRA also in presence of mutual coupling.

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