# ADS-Guided Design of Planar Thinned Phased Arrays Through Genetic Optimization

M. Salucci, G. Gottardi, N. Anselmi, and G. Oliveri

## Abstract

This work presents an innovative hybrid approach for synthesizing thinned planar phased arrays. The *a-priori* information provided by analytical almost difference sets (*ADS*s) is profitably exploited by a customized stochastic optimization approach based on genetic algorithms (*GA*s). Such an *ADSGA* approach is able to overcome the current limitations of state-of-the-art techniques based on *ADS*s. Some numerical results are shown in order to assess the potentialities, as well as the limitations, of the proposed design methodology.

# 1 Problem III - Definition of a General Purpose ADS Construction technique for Array Synthesis

With reference to the potential limitation outlined in the Introduction, the aim is now to and the explicit forms of ADS s sequences (i.e., binary sequences with a three-level auto-correlation function) for arbitrary values of N . Towards this end, let us denote with $L\{\rho\}$ and $R\{\rho\}$ the number of levels of the auto-correlation function $\xi(\tau)$ of a trial solution $\rho$ and the number of $\tau$ values for which $\xi(\tau)$ differ from . Then, the search for admissible (but not available in ADS repositories) ADS sequences is recast as the solution of the following problem

$$Min\left(F\{\rho\}\right) = \alpha\left[L\{\rho\} - 3\right] + \beta R\{\rho\}$$

subject to $N_x \neq N_{x-ADS}$ and $N_y \neq N_{y-ADS}$ The ADSGA within the *auto-correlation space* instead of in the *pattern space*, while the constraints are still on the set of parameters defining the ADS as well as the corresponding array arrangement.

- Initialization: Random

# RESULTS: $P = 6$ , $Q = 6$, $K = 32$

## Setting Parameters of Algorithms

### GA Parameters

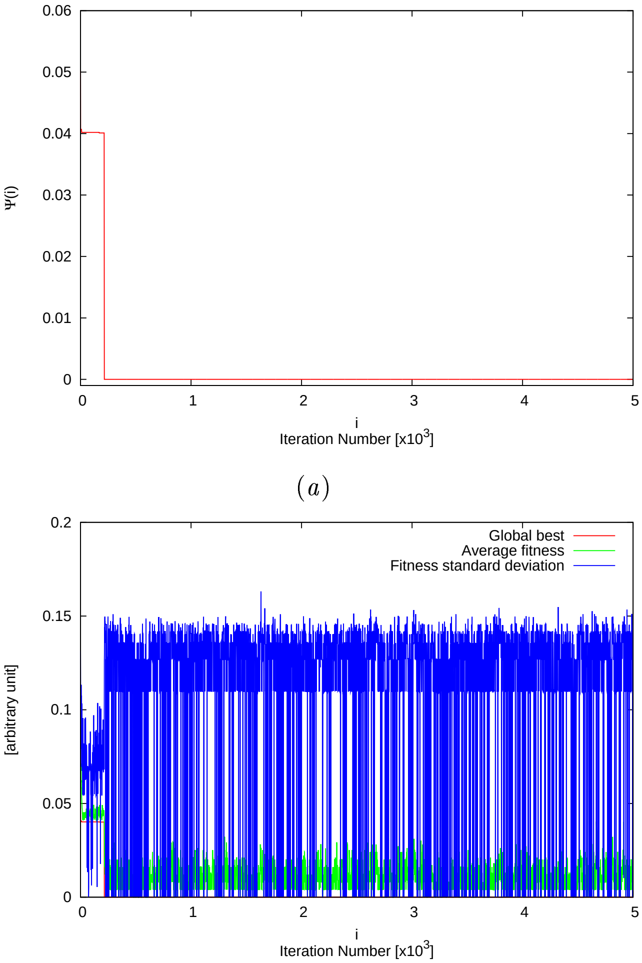
- Chromosome Dimension $C = 36\, bits$
- Population Dimension $S = 10$
- Max Iteration number $K_{max} = 5000$

### Array Parameters

- Number of total cells $N = 32$
- Dimension X: 6
- Dimension Y: 6

### Thinning

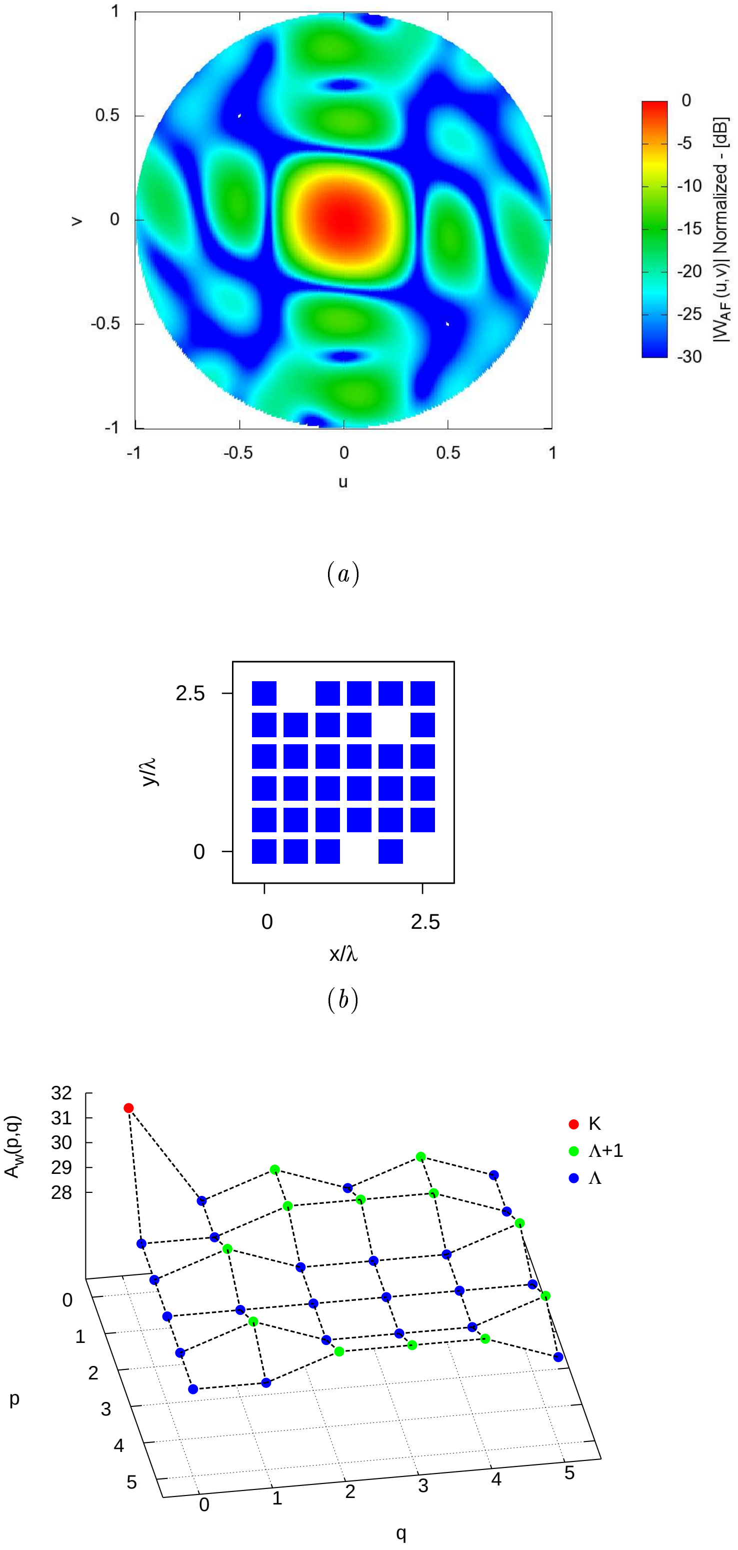
- $\nu = \frac{32}{36} = 88.9\%$



$(a)$

$(b)$

**Figure 1**.

1
0.5
0
-0.5
-1
v
-1
-0.5
0
0.5
1
u
0
-5
-10
-15
-20
-25
-30
$|W_{AF}(u,v)|$ Normalized - [dB]
2.5
0
y/λ
0
2.5
x/λ
32
31
30
29
28
$A_W(p,q)$
K
Λ+1
Λ
0
1
2
3
4
5
p
0
1
2
3
4
5
q

$(a)$

$(b)$

$(c)$

**Figure 2**.

# RESULTS: $P = 6$ , $Q = 10$, $K = 6$

## Setting Parameters of Algorithms

### GA Parameters

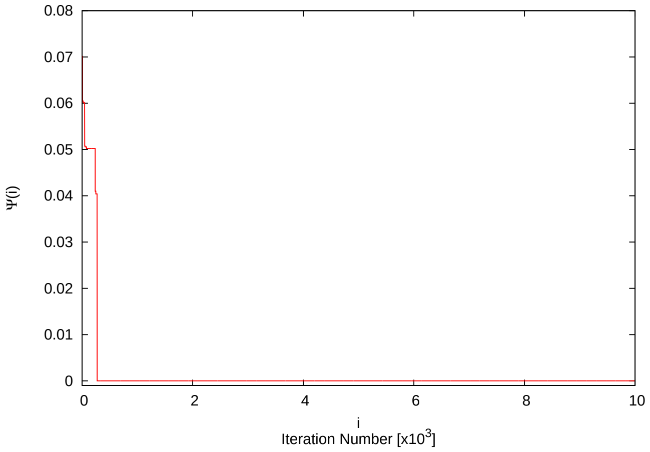
- Chromosome Dimension $C = 60\, bits$
- Population Dimension $S = 30$
- Max Iteration number $K_{max} = 10000$

### Array Parameters

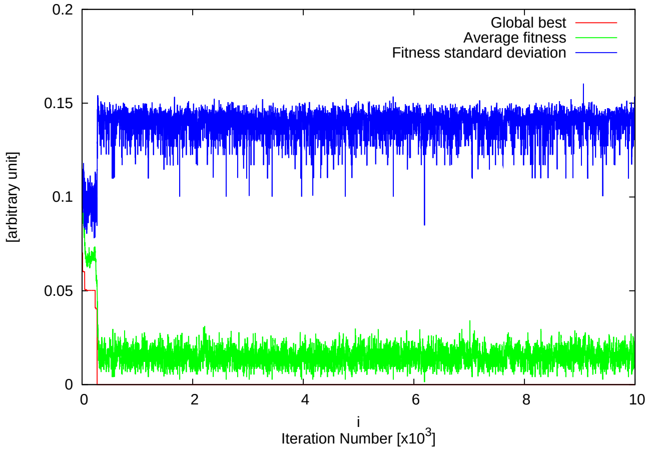
- Number of total cells $N = 60$
- Dimension X: 6
- Dimension Y: 10

### Thinning

- $\nu = \frac{6}{60} = 0.10\%$

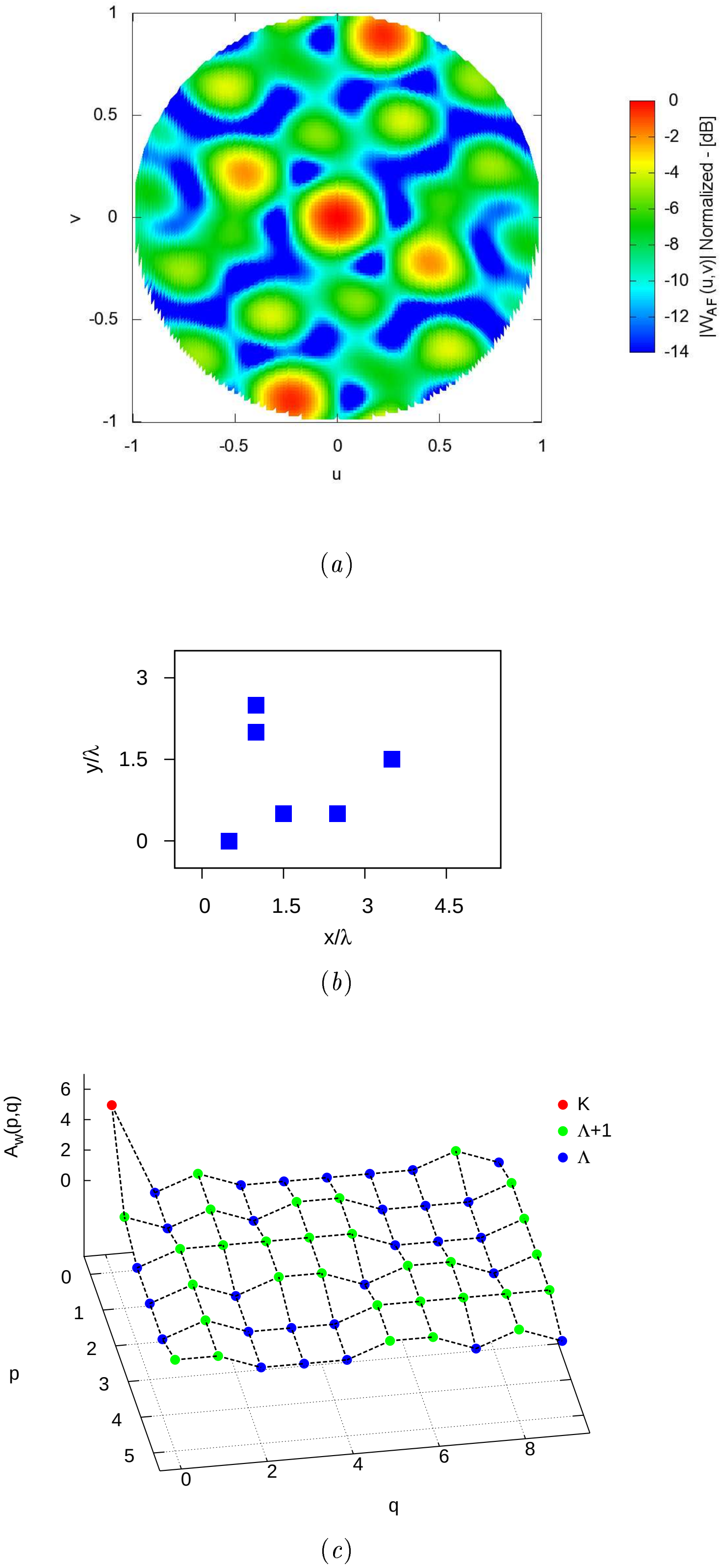


$(a)$



$(b)$

**Figure 3**.



v
u
$|W_{AF}(u,v)|$ Normalized - [dB]
0
-2
-4
-6
-8
-10
-12
-14
1
0.5
0
-0.5
-1
y/λ
x/λ
3
1.5
0
4.5
$A_W(p,q)$
6
4
2
0
p
q
1
2
3
4
5
6
8
K
Λ+1
Λ

$(a)$

$(b)$

$(c)$

**Figure 4**.

# RESULTS: $P = 10$ , $Q = 10$, $K = 5$

## Setting Parameters of Algorithms

### GA Parameters

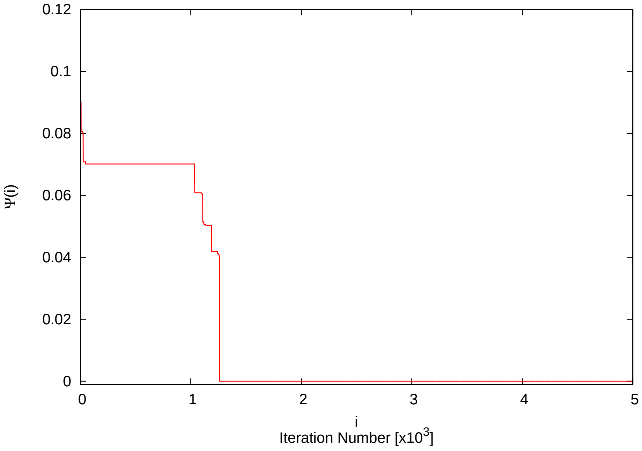
- Chromosome Dimension $C = 100\, bits$
- Population Dimension $S = 10$
- Max Iteration number $K_{max} = 5000$

### Array Parameters

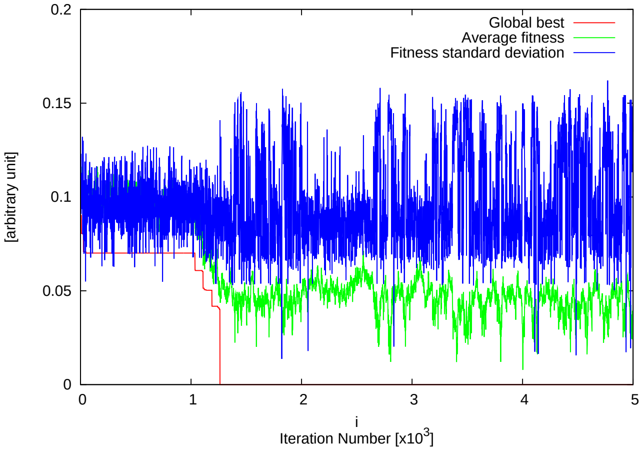
- Number of total cells $N = 100$
- Dimension X: 10
- Dimension Y: 10

### Thinning

- $\nu = \frac{5}{100} = 5\%$

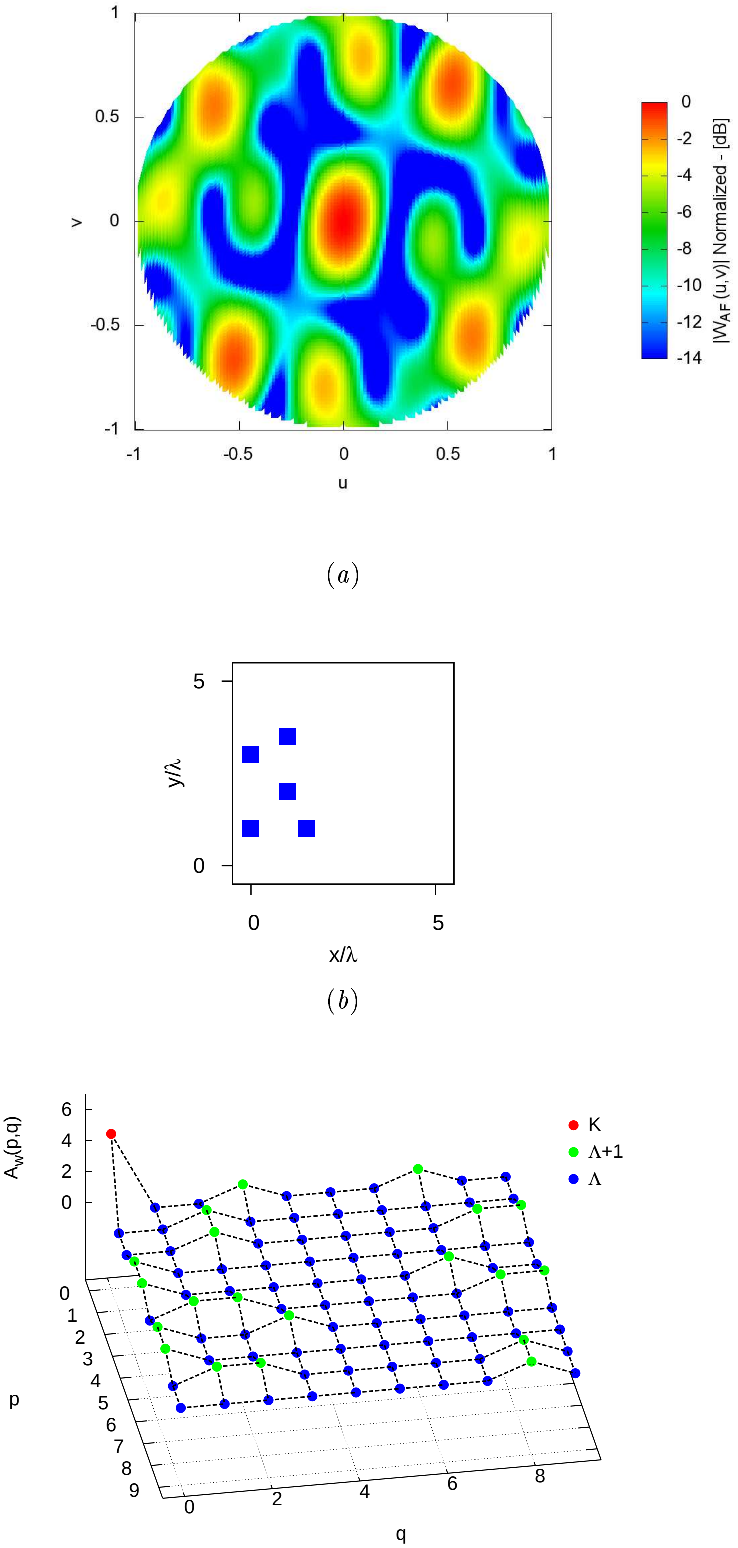


$(a)$



$(b)$

**Figure** 5.


1
0.5
0
-0.5
-1
v
-1
-0.5
0
0.5
1
u
0
-2
-4
-6
-8
-10
-12
-14
$|W_{AF}(u,v)|$ Normalized - [dB]
5
0
y/λ
0
5
x/λ
6
4
2
0
$A_W(p,q)$
K
Λ+1
Λ
0
1
2
3
4
5
6
7
8
9
p
0
2
4
6
8
q

$(a)$

$(b)$

$(c)$

**Figure** 6.

# RESULTS: $P = 12$ , $Q = 16$, $K = 184$

## Setting Parameters of Algorithms

### GA Parameters

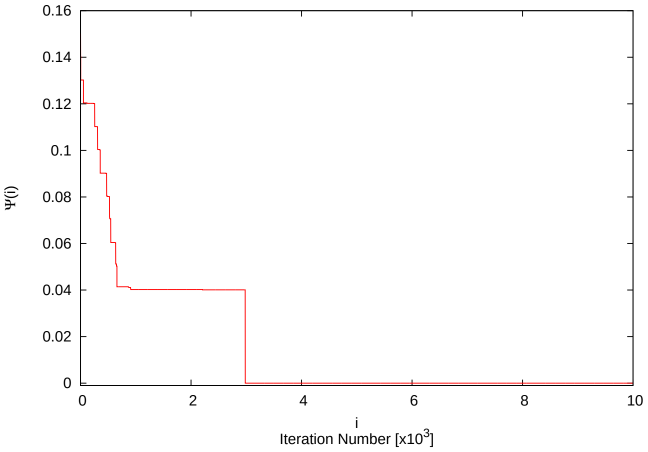
- Chromosome Dimension $C = 192\,bits$
- Population Dimension $S = 50$
- Max Iteration number $K_{max} = 10000$

### Array Parameters

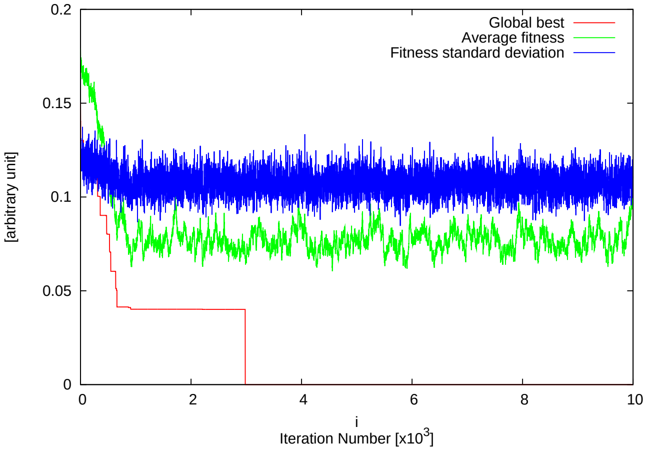
- Number of total cells $N = 192$
- Dimension X: 12
- Dimension Y: 16

### Thinning

- $\nu = \frac{184}{192} = 95.83\%$

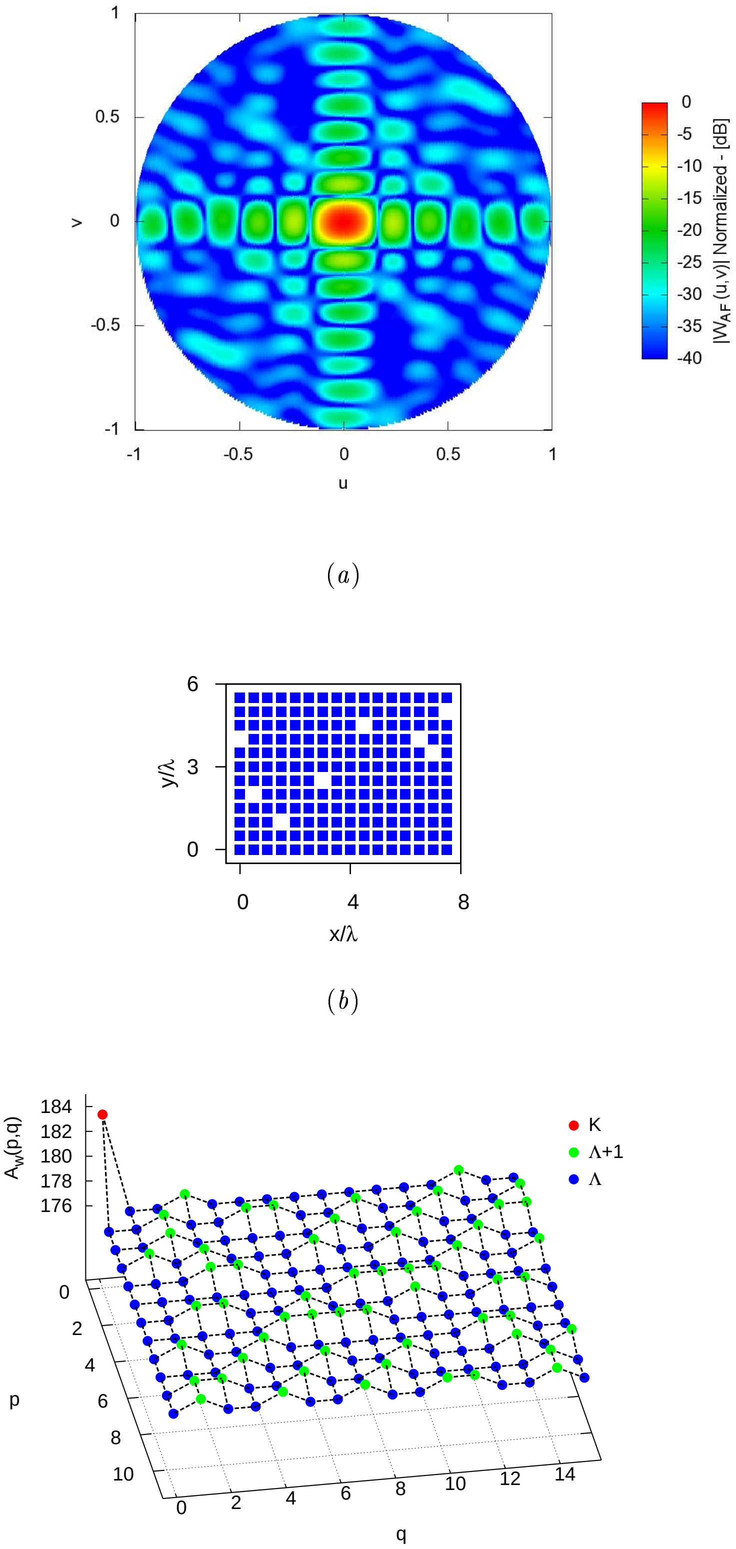


$(a)$



$(b)$

**Figure** 7.


v
u
|W_AF (u,v)| Normalized - [dB]
0
-5
-10
-15
-20
-25
-30
-35
-40
-1
-0.5
0
0.5
1
y/λ
x/λ
6
3
0
4
8
A_W(p,q)
184
182
180
178
176
p
q
2
6
10
12
14
K
Λ+1
Λ

$(a)$

$(b)$

$(c)$

**Figure** 8.

# RESULTS: $P = 14$ , $Q = 14$, $K = 7$

## Setting Parameters of Algorithms

### GA Parameters

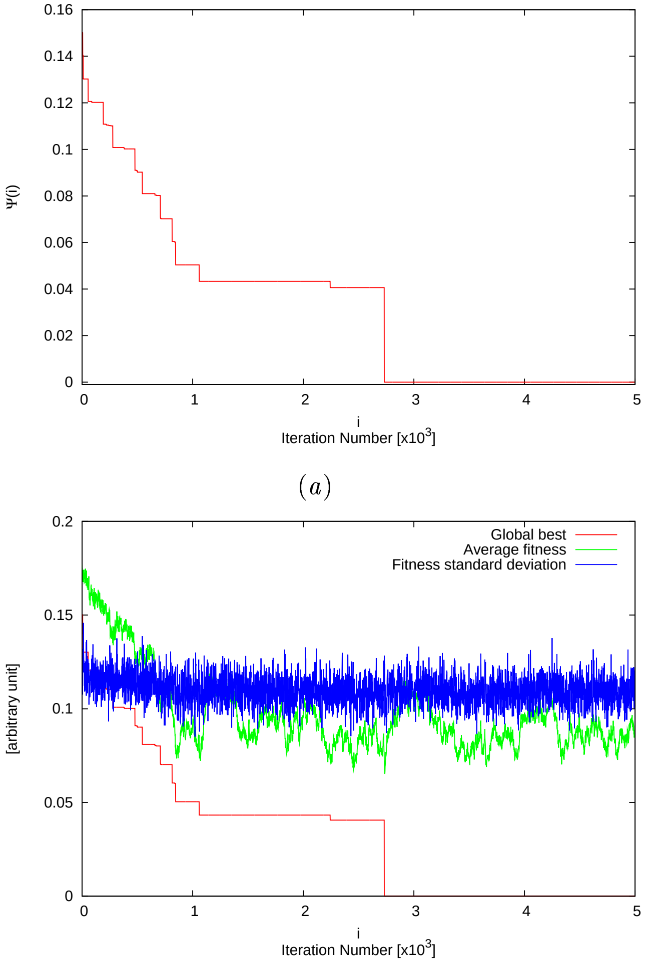
- Chromosome Dimension $C = 196\,bits$
- Population Dimension $S = 40$
- Max Iteration number $K_{max} = 5000$

### Array Parameters

- Number of total cells $N = 196$
- Dimension X: 14
- Dimension Y: 14

### Thinning

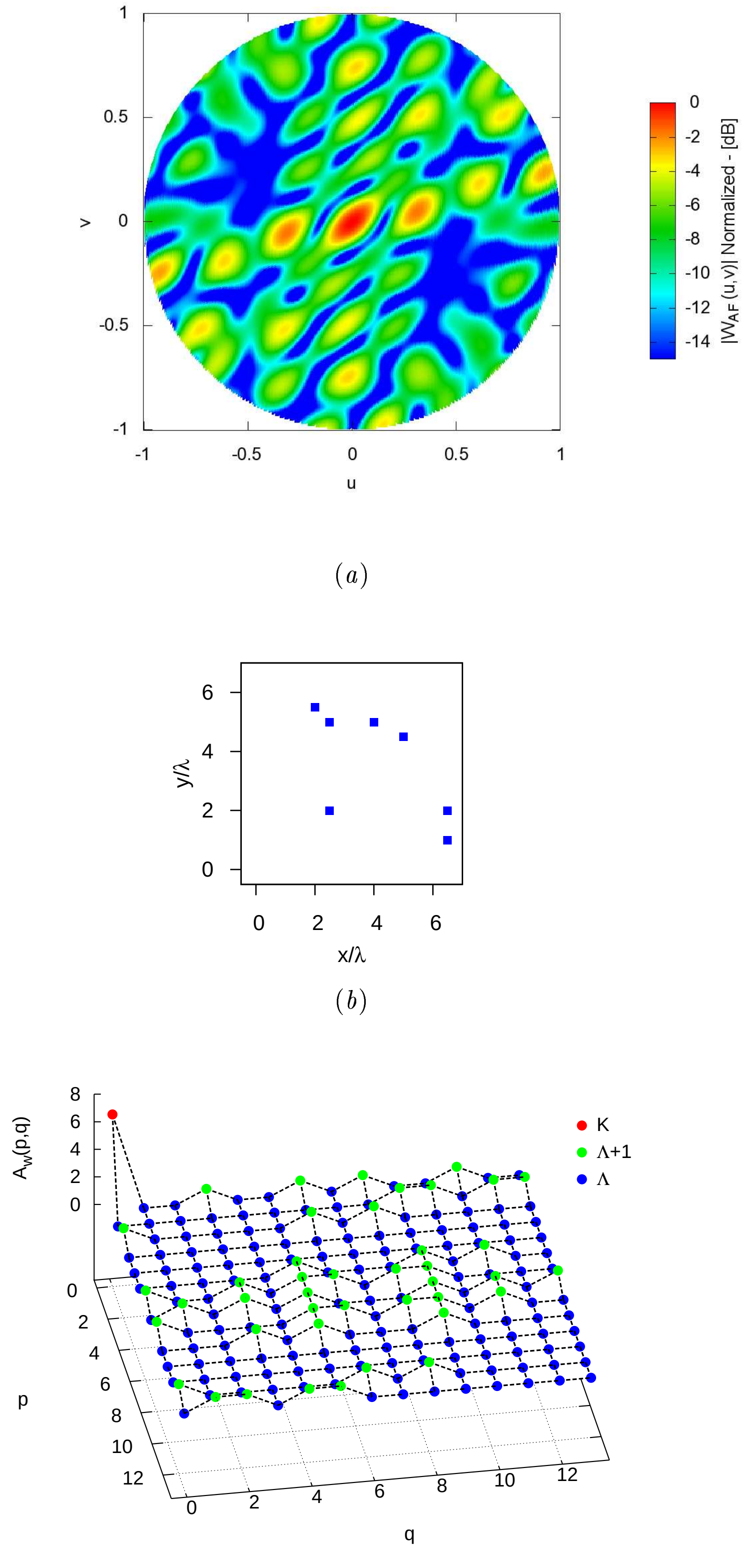
- $\nu = \frac{7}{196} = 3,57\%$



$(a)$

$(b)$

**Figure** 9.



$(a)$

$(b)$

$(c)$

**Figure** 10.

# RESULTS: $P = 15$ , $Q = 15$, $K = 8$

## Setting Parameters of Algorithms

### GA Parameters

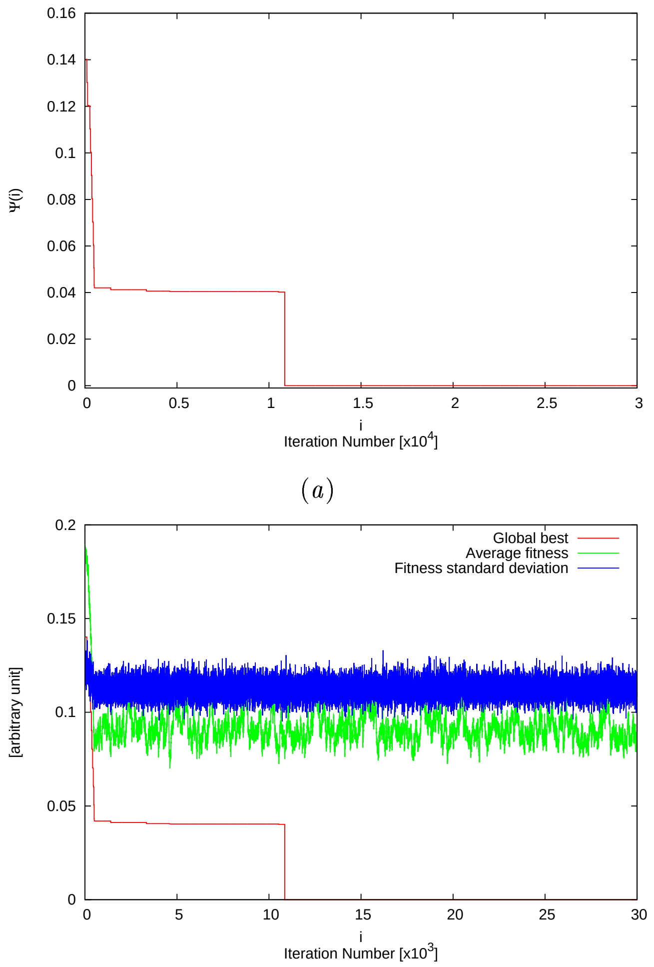
- Chromosome Dimension $C = 225\, bits$
- Population Dimension $S = 100$
- Max Iteration number $K_{max} = 30000$

### Array Parameters

- Number of total cells $N = 225$
- Dimension X: 15
- Dimension Y: 15

### Thinning

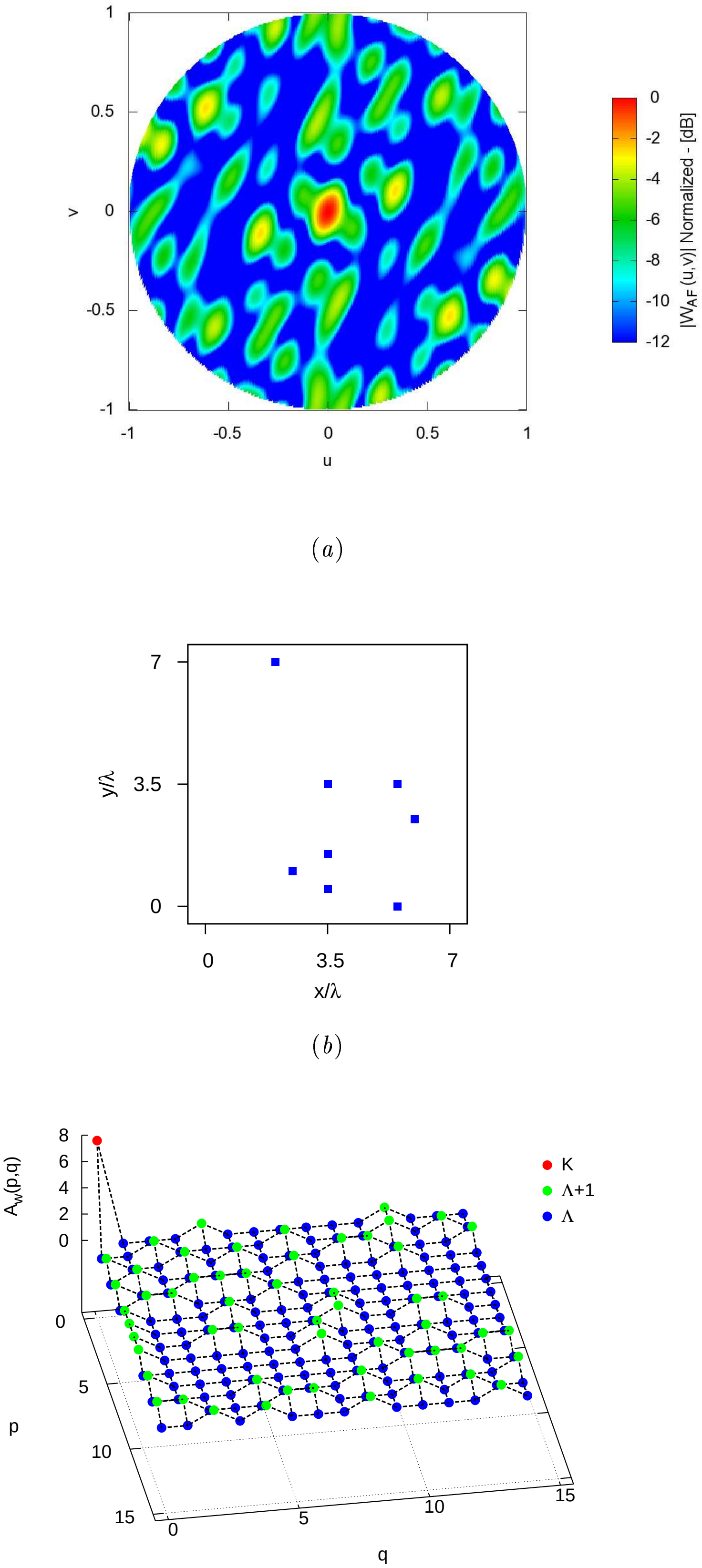
- $\nu = \frac{8}{225} = 3,55\%$



$(a)$

$(b)$

**Figure** 11.



$(a)$

$(b)$

$(c)$

**Figure** 12.

| $P$ | Q | $K$ | $\nu[\%]$ | $\Lambda$ | $\#(\Lambda)$ |
|---|---|---|---|---|---|
| 6 | 6 | 32 | 88.8 | 28 | 23 |
| 6 | 10 | 6 | 10.0 | 0 | 29 |
| 8 | 8 | 59 | 92.1 | 54 | 43 |
| 10 | 10 | 5 | 5.0 | 0 | 79 |
| 12 | 12 | 137 | 95.1 | 130 | 101 |
| 12 | 14 | 184 | 95.8 | 176 | 135 |
| 14 | 14 | 7 | 3.5 | 0 | 153 |
| 15 | 15 | 8 | 3.5 | 0 | 168 |

**Table I.**

- **Table I**: Properties of the new ADS sequences

# References

[1] P. Rocca, M. Benedetti, M. Donelli, D. Franceschini, and A. Massa, “Evolutionary optimization as applied to inverse problems,” Inverse Problems, vol. 25, pp. 1-41, Dec. 2009.

[2] P. Rocca, G. Oliveri, and A. Massa, “Differential Evolution as applied to electromagnetics,” *IEEE Antennas Propag. Mag.*, vol. 53, no. 1, pp. 38-49, Feb. 2011.

[3] M. Salucci, G. Gottardi, N. Anselmi, and G. Oliveri, “Planar thinned array design by hybrid analytical-stochastic optimization,” *IET Microwaves, Antennas & Propagation*, vol. 11, no. 13, pp. 1841-1845, Oct. 2017.

[4] G. Oliveri, M. Donelli, and A. Massa, “Genetically-designed arbitrary length almost difference sets,” *Electronics Letters*, vol. 5, no. 23, pp. 1182-1183, Nov. 2009.

[5] N. Anselmi, P. Rocca, M. Salucci, and A. Massa, “Irregular phased array tiling by means of analytic schemata-driven optimization,” *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 9, pp. 4495-4510, September 2017.

[6] N. Anselmi, P. Rocca, M. Salucci, and A. Massa, “Optimization of excitation tolerances for robust beamforming in linear arrays,” *IET Microwaves, Antennas & Propagation*, vol. 10, no. 2, pp. 208-214, 2016.

[7] P. Rocca, M. Donelli, G. Oliveri, F. Viani, and A. Massa, “Reconfigurable sum-difference pattern by means of parasitic elements for forward-looking monopulse radar,” *IET Radar, Sonar & Navigation*, vol 7, no. 7, pp. 747-754, 2013.

[8] T. Moriyama, L. Poli, and P. Rocca, "Adaptive nulling in thinned planar arrays through genetic algorithms," *IEICE Electronics Express*, vol. 11, no. 21, pp. 1-9, Sep. 2014.

[9] L. Poli, P. Rocca, M. Salucci, and A. Massa, “Reconfigurable thinning for the adaptive control of linear arrays,” *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 10, pp. 5068-5077, Oct. 2013.

[10] P. Rocca, L. Poli, G. Oliveri, and A. Massa, “Adaptive nulling in time-varying scenarios through time-modulated linear arrays,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 101-104, 2012.

[11] P. Rocca, G. Oliveri, R. J. Mailloux, and A. Massa, “Unconventional phased array architectures and design methodologies - A review,” *Proceedings of the IEEE*, vol. 104, no. 3, pp. 544-560, March 2016.

[12] L. Poli, P. Rocca, G. Oliveri, and A. Massa, “Failure correction in time-modulated linear arrays,” *IET Radar, Sonar & Navigation*, vol. 8, no. 3, pp. 195-201, 2014.

[13] G. Oliveri, M. Salucci, and A. Massa, “Synthesis of modular contiguously clustered linear arrays through a sparseness-regularized solver,” *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 10, pp. 4277-4287, Oct. 2016.

[14] P. Rocca, N. Anselmi, and A. Massa "Optimal synthesis of robust beamformer weights exploiting interval analysis and convex optimization," *IEEE Trans. Antennas Propag.*, vol. 62, no. 7, pp. 3603-3612, Jul. 2014.

[15] N. Anselmi, P. Rocca, M. Salucci, and A. Massa, "Optimization of excitation tolerances for robust beamforming in linear arrays," *IET Microwaves, Antennas & Propagation*, vol. 10, no. 2, pp. 208-214, 2016.

[16] T. Moriyama, E. Giarola, M. Salucci, and G. Oliveri, "On the radiation properties of ADS-thinned dipole arrays" *IEICE Electronics Express*, vol. 11, no. 16, pp. 1-10, Aug. 2014.

[17] G. Oliveri, F. Viani, and A. Massa, "Synthesis of linear multi-beam arrays through hierarchical ADS-based interleaving," *IET Microw. Antennas Propag.*, vol. 8, no. 10, pp. 794-808, Jul. 2014.