ADS-Based Arrays for Radioastronomy Applications

G. Oliveri, F. Caramanica, A. Massa

Abstract

The exploitation of low correlation sequences called Almost Difference Sets (ADSs) is considered for the design of correlator arrays for radio astronomy applications. More specifically, an hybrid ADS-GA design method is presented and applied to the synthesis of open-ended “Y ” and “Cross” array configurations.

MATHEMATICAL FORMULATION

Quantities related to the radioastronomy array

- Number of total array elements: N
- Array element location: (x_i, y_i), $i = 0, ..., N-1$
- Baselines location: $\mathbf{b}_k = (x_i, y_i) - (x_j, y_j)$, $i \neq j$
- Number of baselines: B
- Number of gridded baselines: B^G
- Earth rotation duration: H
- Discretization of earth rotation: Δh
- Number of baselines after earth rotation: B_R
- Number of gridded baselines after earth rotation: B_R^G
- Gaussian tapering: T [dB]

Quantities related to the GA

- Population size: P
- Iteration number: I
- Crossover probability: p_ξ
- Mutation probability: p_μ
- Fitness definition: $F = \alpha \times \frac{1}{PSL} + \beta \times \frac{1}{N} + \gamma \times \frac{1}{B} + \delta \times \frac{1}{B_R^G}$

TEST CASE

Goal: minimize the PSL of a triangular shaped array by means of ADSs chosen by means of a GA. The **same** ADS is employed in the three arms, with different shifts.

- Number of array arms: A
- Arm length: L_i, $i = 0, .., A-1$
- Number of array elements for each arm: N_i, $i = 0, .., A-1$ ($N = \sum_{i=0}^{A-1} N_i$)
- Array rotation with respect to north-south: ρ [deg]

Test Case Description

Geometry:

- Triangular array: $A = 3$
- $L_i = 21$ [Km] $\forall i \in 0, .., A-1$
- Element number: $N_i = 9$ $\forall i \in 0, .., A-1$ (the **same** ADS is employed in the three arms)
- Unconstrained last elements (lattice spacing: $d_i = \frac{L_i}{N_i - 1}$)
- $\rho = 0$ [deg]
- $T = -15$ [dB]

Geographical information:

- Array rotation duration: $H = 8$ [h]
- Sampling step: $\Delta h = 5$ [min]
- Latitude: 34 [deg]
- Elevation: 0 [deg]
- Declination: 34 [deg]

Numerical simulation parameters:

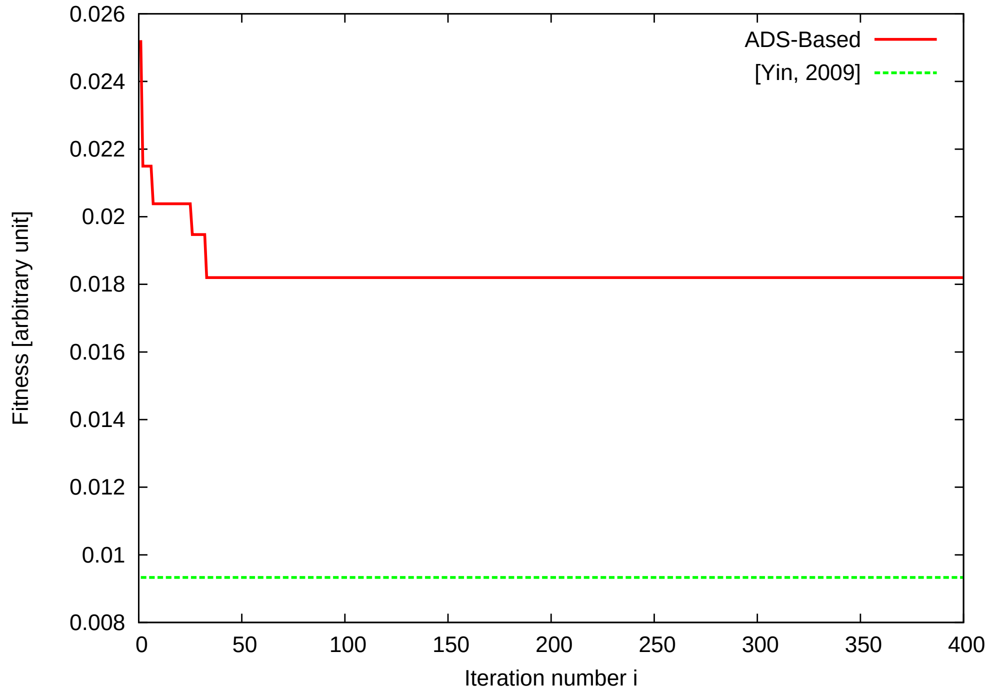
- Grid discretization: $G_X \times G_Y = 128 \times 128$
- Grid dimension: $D_X \times D_Y = 50000 \times 50000$ [λ^2]
- FFT dimension: $F_L \times F_M = 512 \times 512$

GA parameters:

- $P = 20$
- $I = 400$
- $p_\xi = 0.9$
- $p_\mu = 0.01$
- $\alpha = 1$, $\beta = \gamma = \delta = 0$

RESULTS

Fitness and PSL behaviour



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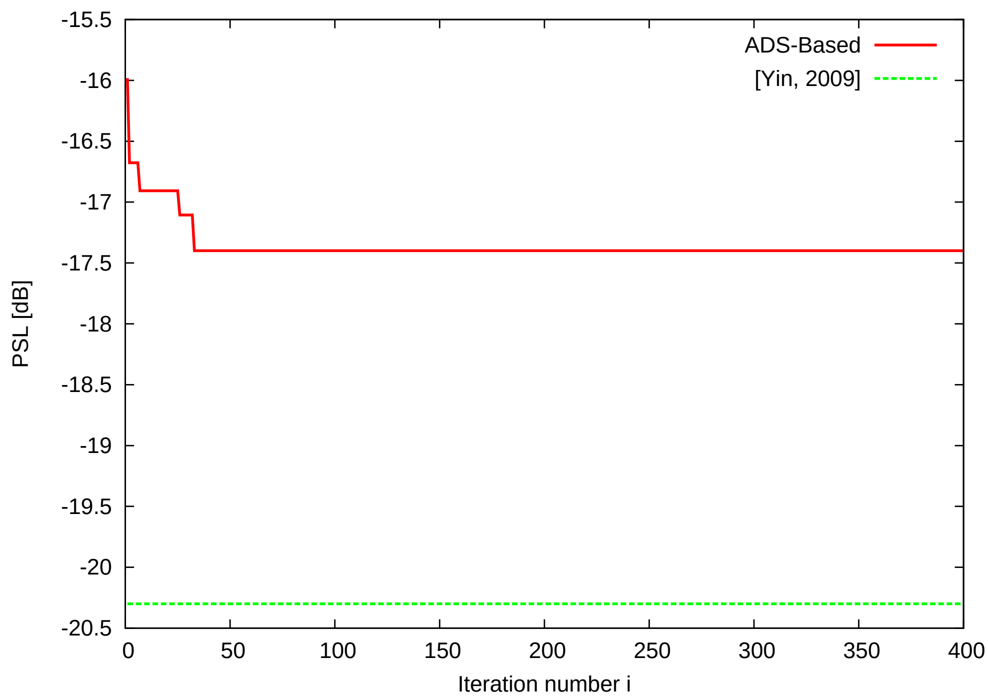

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Figure 1.

Optimal geometry, autocorrelation, rotated autocorrelation and pattern

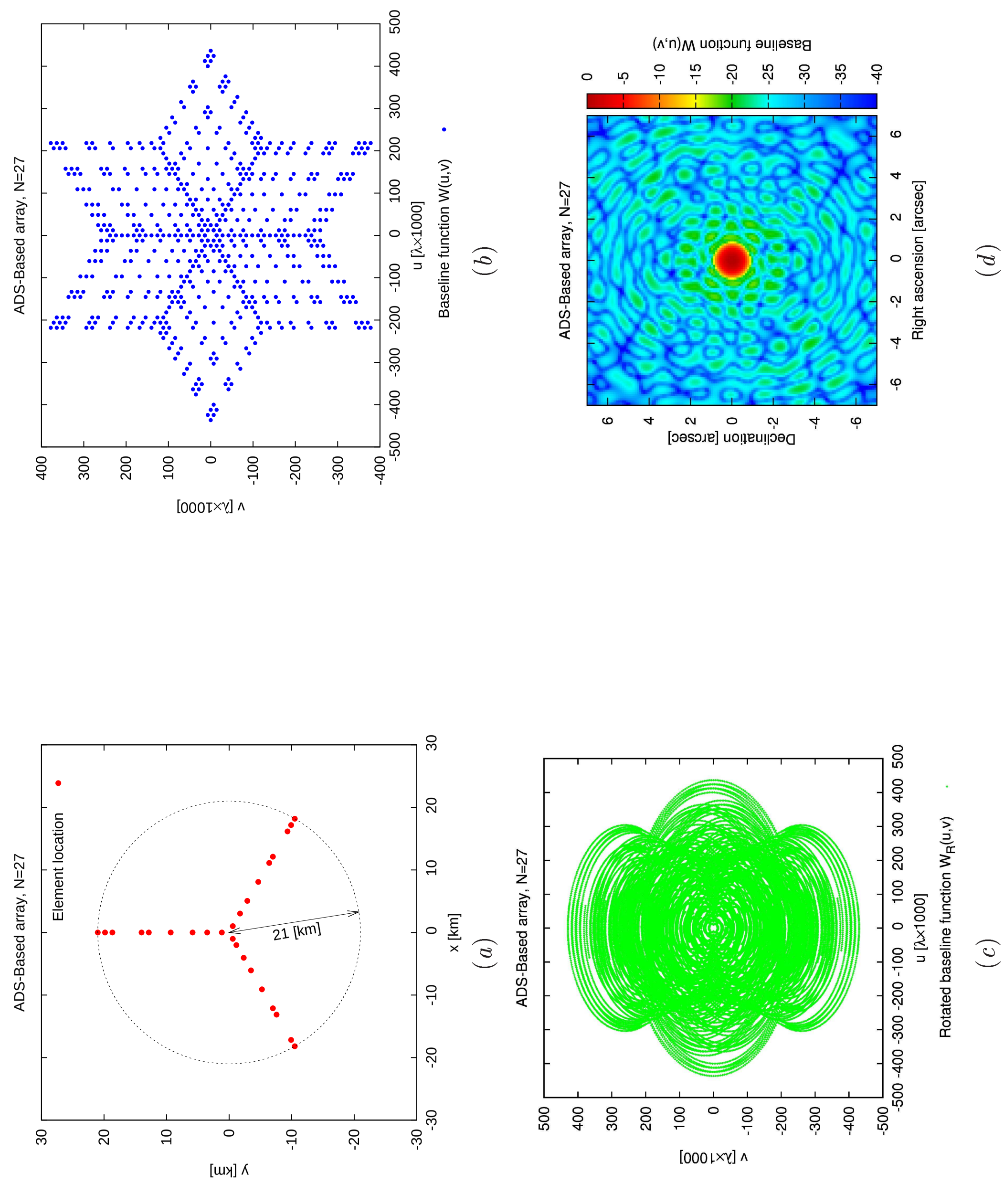

Figure 2.

Observations:

- The PSL behaviour is far from that of [2] (around than 3 dB worse)

TEST CASE

Goal: minimize the PSL of a triangular shaped array by means of ADSs chosen by means of a GA. The **same** ADS is employed in the three arms, with different shifts.

- Number of array arms: A
- Arm length: L_i, $i = 0, .., A-1$
- Number of array elements for each arm: N_i, $i = 0, .., A-1$ ($N = \sum_{i=0}^{A-1} N_i$)
- Array rotation with respect to north-south: ρ [deg]

Test Case Description

Geometry:

- Triangular array: $A = 3$
- $L_i = 21$ [Km] $\forall i \in 0, .., A-1$
- Element number: $N_i = 9$ $\forall i \in 0, .., A-1$ (the **same** ADS is employed in the three arms)
- Constrained last element of each arm (arm length is constant, spacing is not constant)
- $\rho = 0$ [deg]
- $T = -15$ [dB]

Geographical information:

- Array rotation duration: $H = 8$ [h]
- Sampling step: $\Delta h = 5$ [min]
- Latitude: 34 [deg]
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- Declination: 34 [deg]

Numerical simulation parameters:

- Grid discretization: $G_X \times G_Y = 128 \times 128$
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GA parameters:

- $P = 20$
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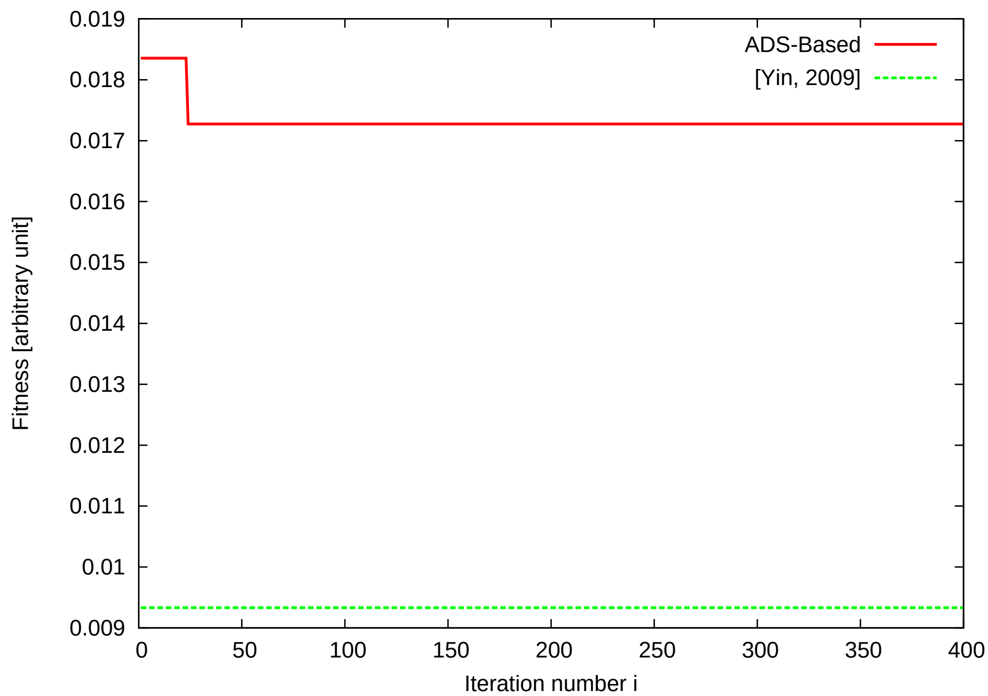
- $\alpha = 1$, $\beta = \gamma = \delta = 0$

RESULTS

Fitness and PSL behaviour



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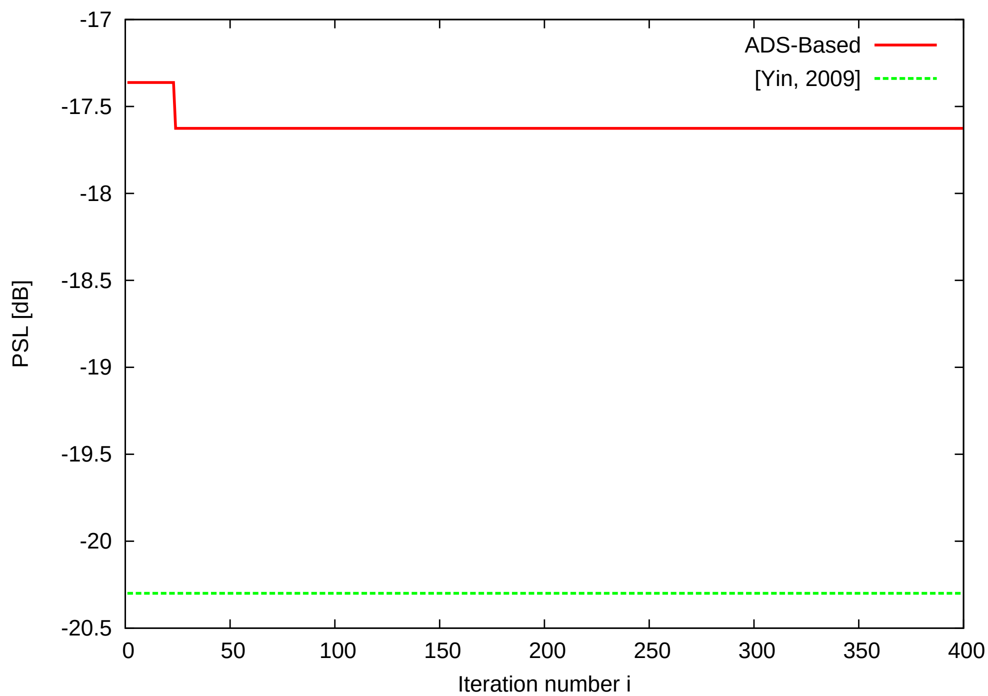

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Figure 3.

Optimal geometry, autocorrelation, rotated autocorrelation and pattern

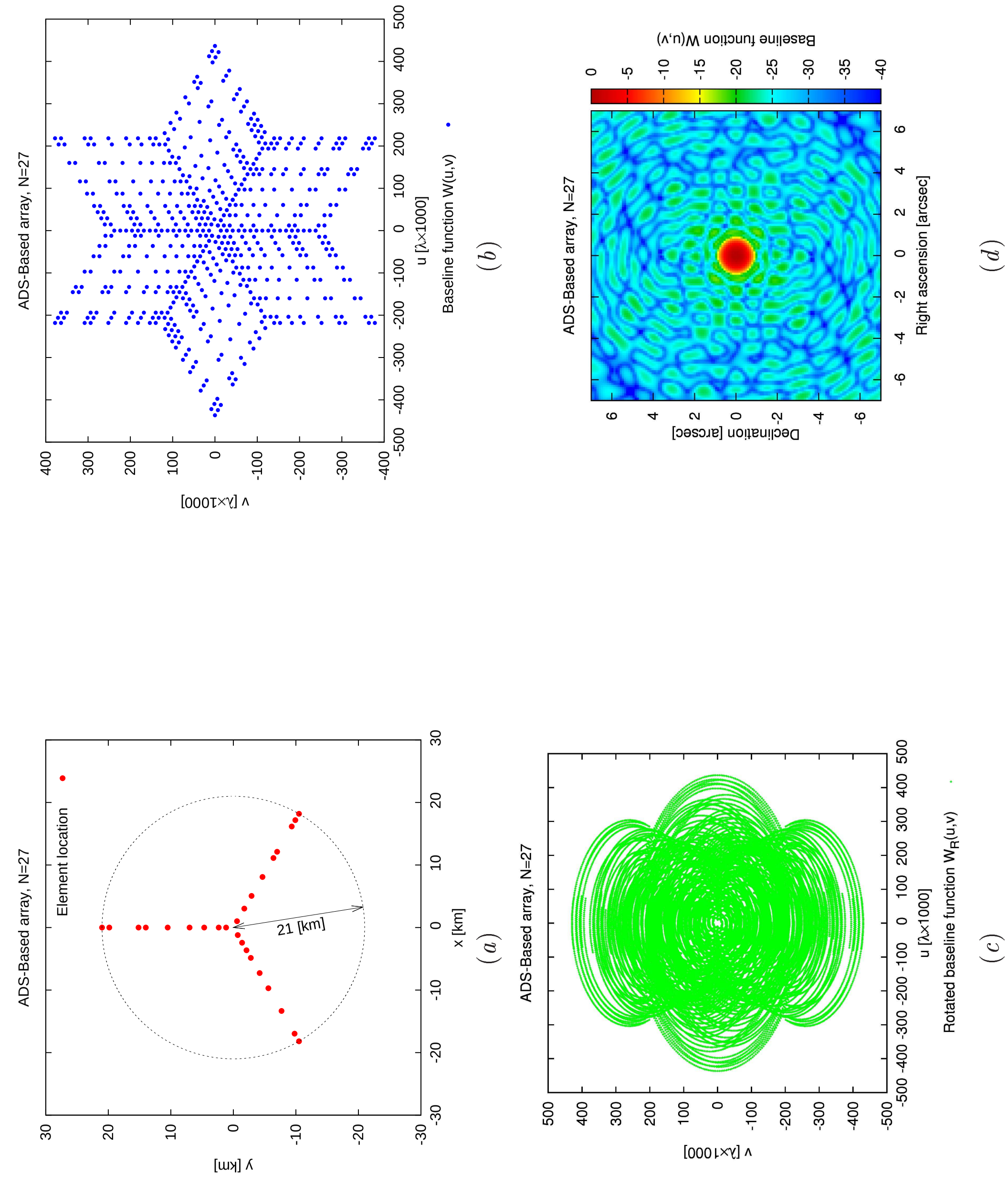


Figure 4.

Observations:

- The PSL behaviour is far from that of [2] (around than 2.5 dB worse)

TEST CASE

GOAL: minimize the PSL of a triangular shaped array by means of ADSs chosen by means of a GA. The **same** ADS is employed in the three arms, with different shifts.

- Number of array arms: A
- Arm length: L_i, $i = 0, .., A-1$
- Number of array elements for each arm: N_i, $i = 0, .., A-1$ ($N = \sum_{i=0}^{A-1} N_i$)
- Array rotation with respect to north-south: ρ [deg]

Test Case Description

Geometry:

- Triangular array: $A = 3$
- $L_i = 21$ [Km] $\forall i \in 0, .., A-1$
- Element number: $N_i = 9$ $\forall i \in 0, .., A-1$ (the **same** ADS is employed in the three arms)
- Unconstrained last elements (lattice spacing: $d_i = \frac{L_i}{N_i - 1}$)
- $\rho = 5$ [deg]
- $T = -15$ [dB]

Geographical information:

- Array rotation duration: $H = 8$ [h]
- Sampling step: $\Delta h = 5$ [min]
- Latitude: 34 [deg]
- Elevation: 0 [deg]
- Declination: 34 [deg]

Numerical simulation parameters:

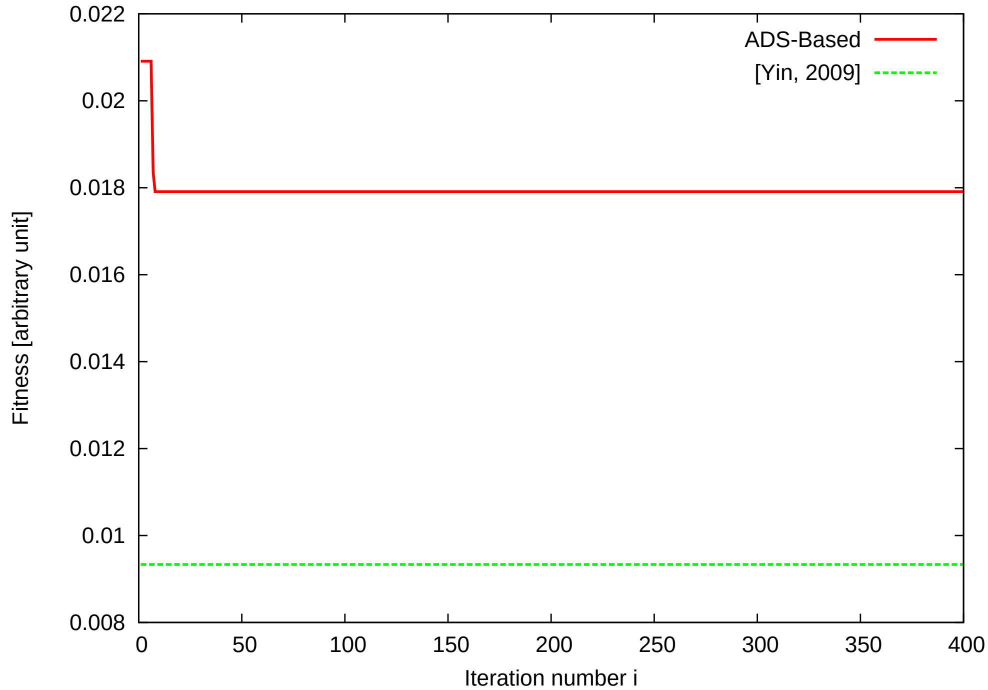
- Grid discretization: $G_X \times G_Y = 128 \times 128$
- Grid dimension: $D_X \times D_Y = 50000 \times 50000$ [λ^2]
- FFT dimension: $F_L \times F_M = 512 \times 512$

GA parameters:

- $P = 20$
- $I = 400$
- $p_\xi = 0.9$
- $p_\mu = 0.01$
- $\alpha = 1$, $\beta = \gamma = \delta = 0$

RESULTS

Fitness and PSL behaviour



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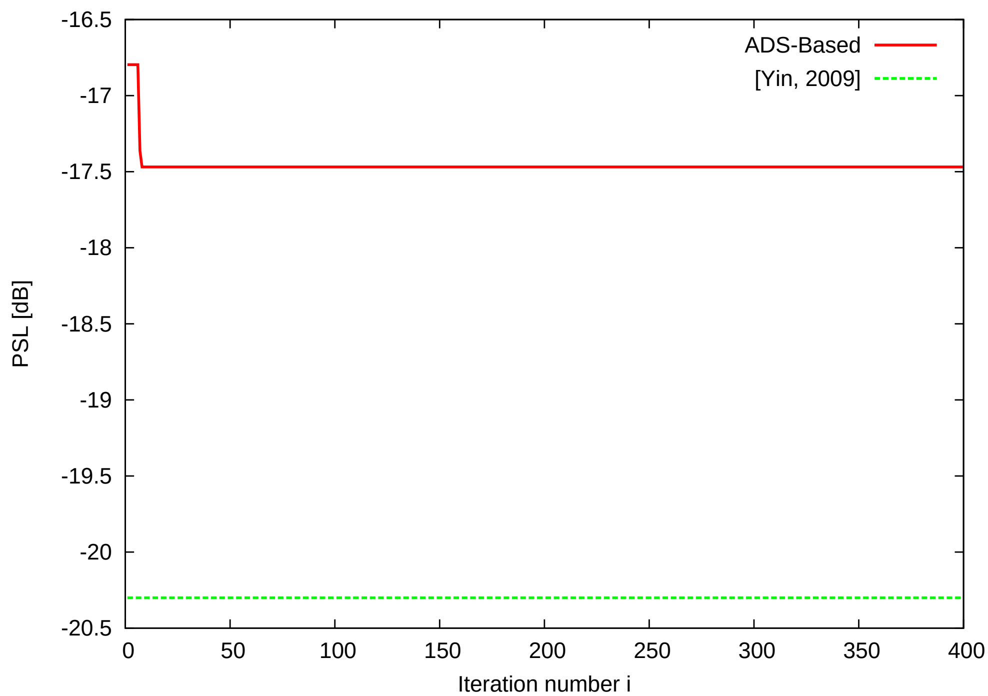

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Figure 5.

Optimal geometry, autocorrelation, rotated autocorrelation and pattern

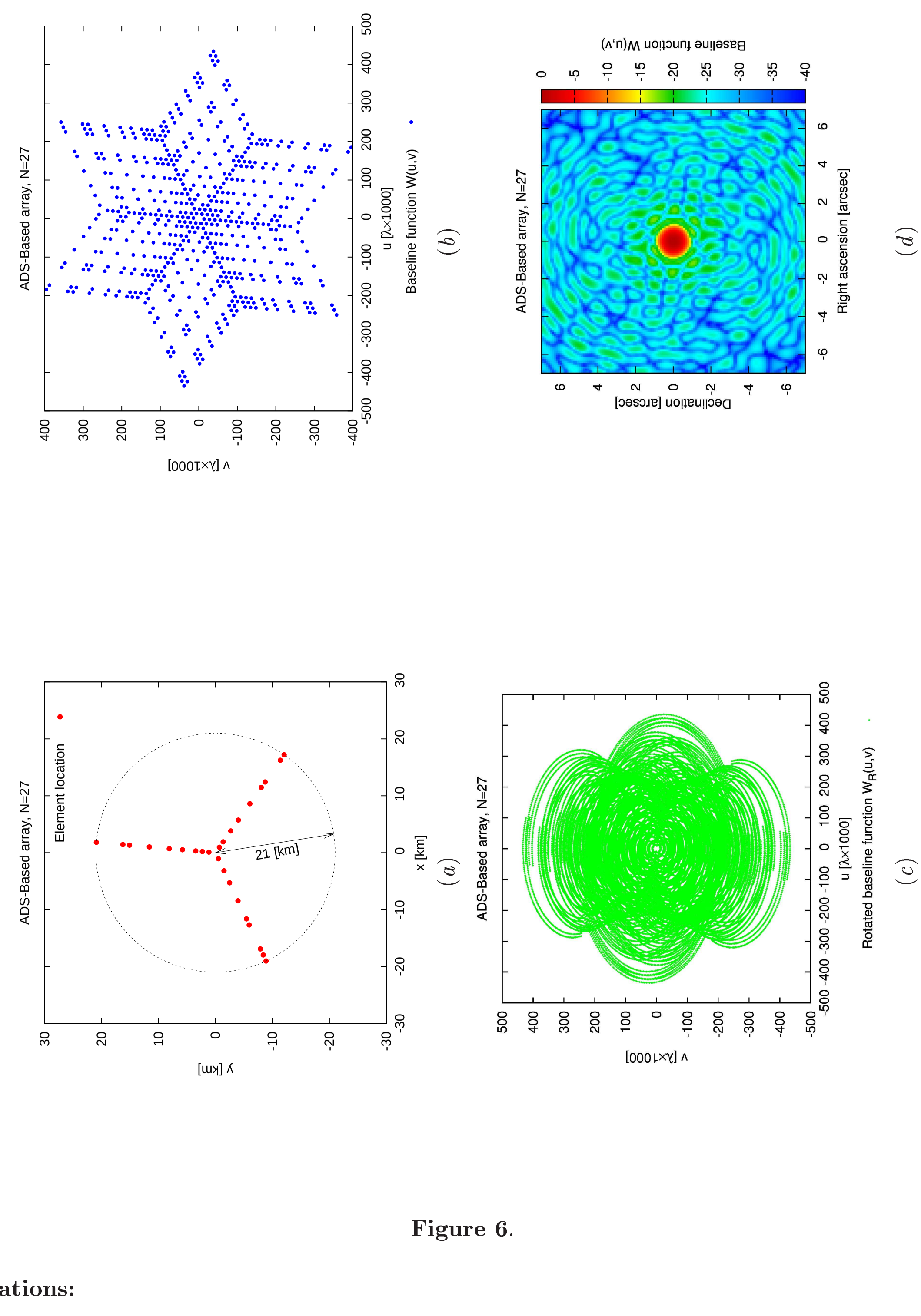

Figure 6.

Observations:

- The PSL behaviour is far from that of [2] (around than 3 dB worse)

TEST CASE

Goal: minimize the PSL of a triangular shaped array by means of ADSs chosen by means of a GA. The **same** ADS is employed in the three arms, with different shifts.

- Number of array arms: A
- Arm length: L_i, $i = 0, .., A-1$
- Number of array elements for each arm: N_i, $i = 0, .., A-1$ ($N = \sum_{i=0}^{A-1} N_i$)
- Array rotation with respect to north-south: ρ [deg]

Test Case Description

Geometry:

- Triangular array: $A = 3$
- $L_i = 21$ [Km] $\forall i \in 0, .., A-1$
- Element number: $N_i = 9$ $\forall i \in 0, .., A-1$ (the **same** ADS is employed in the three arms)
- Constrained last element of each arm (arm length is constant, spacing is not constant)
- $\rho = 5$ [deg]
- $T = -15$ [dB]

Geographical information:

- Array rotation duration: $H = 8$ [h]
- Sampling step: $\Delta h = 5$ [min]
- Latitude: 34 [deg]
- Elevation: 0 [deg]
- Declination: 34 [deg]

Numerical simulation parameters:

- Grid discretization: $G_X \times G_Y = 128 \times 128$
- Grid dimension: $D_X \times D_Y = 50000 \times 50000$ [λ^2]
- FFT dimension: $F_L \times F_M = 512 \times 512$

GA parameters:

- $P = 20$
- $I = 400$
- $p_\xi = 0.9$
- $p_\mu = 0.01$
- $\alpha = 1$, $\beta = \gamma = \delta = 0$

RESULTS

Fitness and PSL behaviour

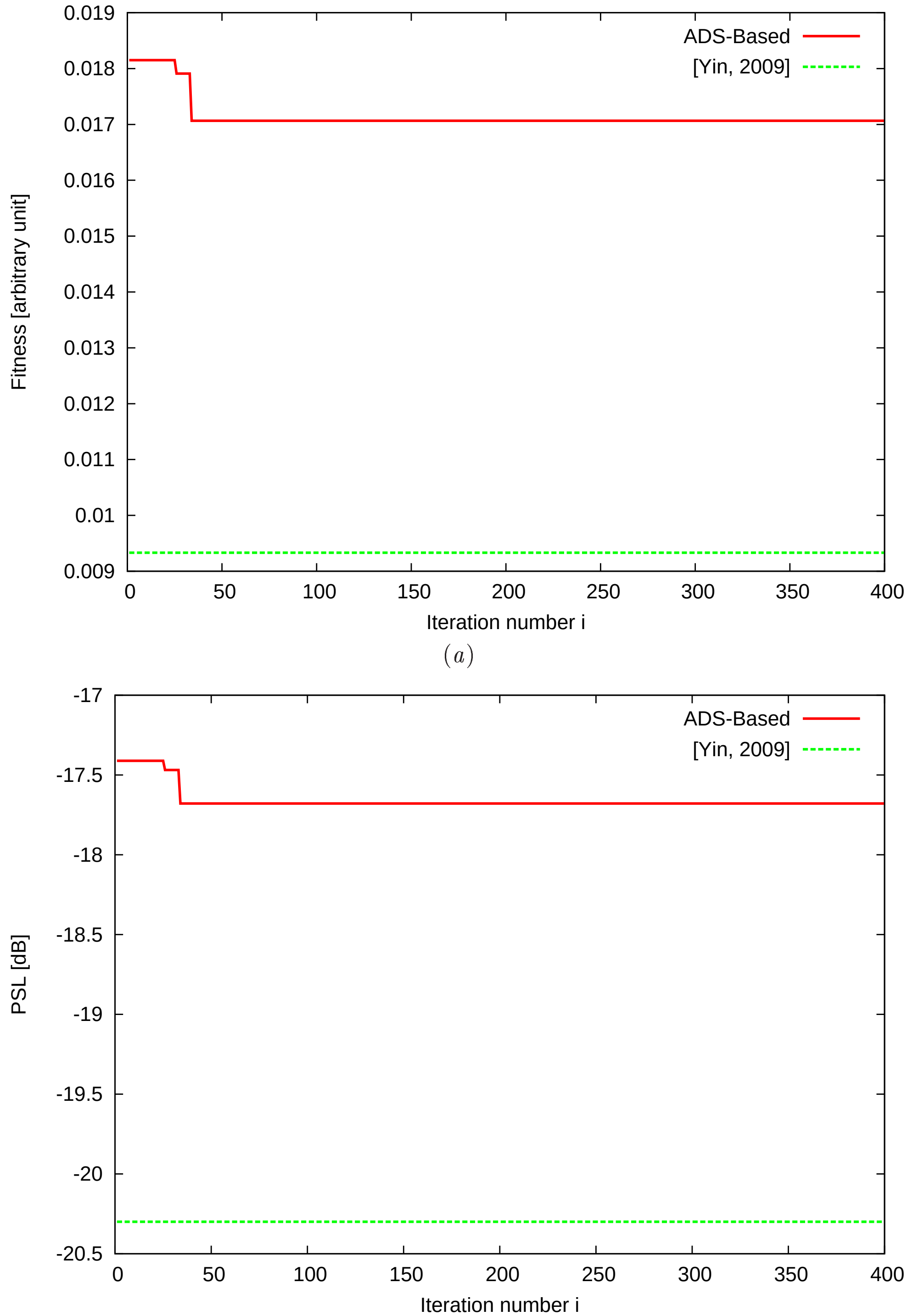

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Figure 7.

Optimal geometry, autocorrelation, rotated autocorrelation and pattern

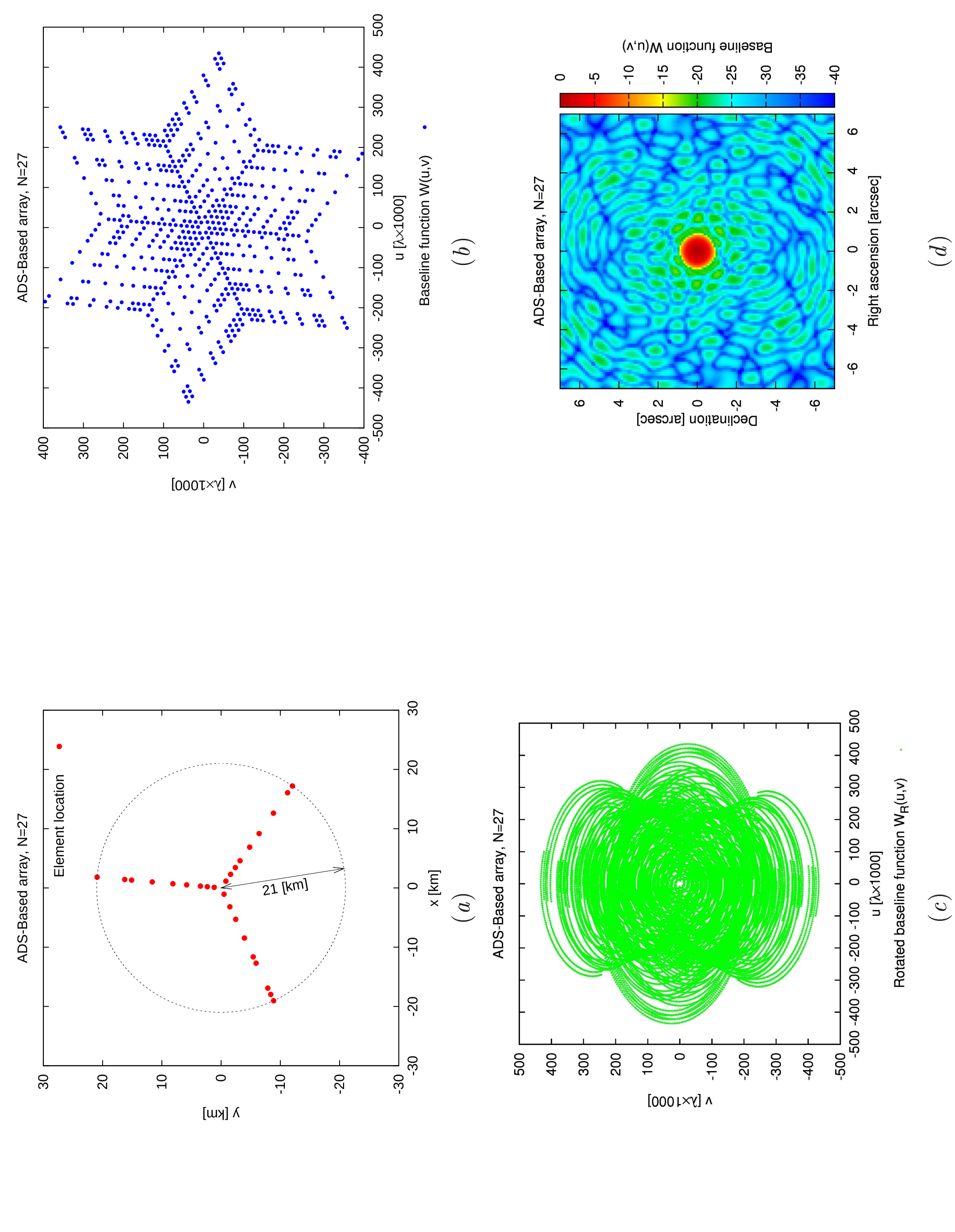


Figure 8.

Observations:

- The PSL behaviour is far from that of [2] (around than 2.5 dB worse)

RESUME: PSL MINIMIZATION, SAME ADS for all arms, DIFFERENT SHIFTS

PSL behaviour with respect to iteration number for optimal arrays

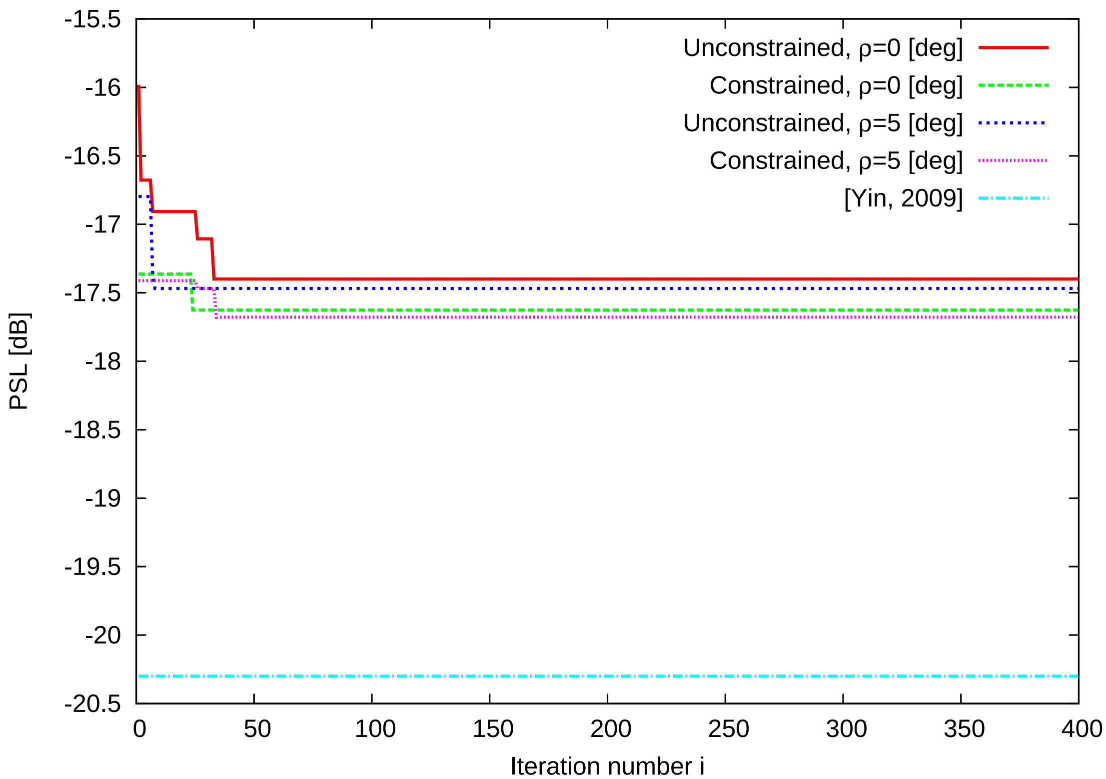


Figure 9.

Overall observations:

- The reported results show that there is not a significant dependency of the obtained PSL from the considered rotation angle (ρ) or the constrained/unconstrained geometry, since all the optimal solutions provide a PSL which is between -17.65 dB and -17.4 dB.
- However, it turns out that constrained and rotated geometries provide a slightly better PSL behaviour.
- It has to be remarked that, in all cases, the obtained PSL is far from that of [2]

TEST CASE

Goal: minimize the PSL of a triangular shaped array by means of ADSs chosen by means of a GA. **Different** ADS**s** are employed in the three arms, with different shifts.

- Number of array arms: A
- Arm length: L_i, $i = 0, .., A-1$
- Number of array elements for each arm: N_i, $i = 0, .., A-1$ ($N = \sum_{i=0}^{A-1} N_i$)
- Array rotation with respect to north-south: ρ [deg]

Test Case Description

Geometry:

- Triangular array: $A = 3$
- $L_i = 21$ [Km] $\forall i \in 0, .., A-1$
- Element number: $N_i \leq 9$ $\forall i \in 0, .., A-1$
- Unconstrained last elements on each arm (lattice spacing: $d_i = \frac{L_i}{N_i - 1}$, $i \in 0, .., A-1$)
- $\rho = 0$ [deg]
- $T = -15$ [dB]

Geographical information:

- Array rotation duration: $H = 8$ [h]
- Sampling step: $\Delta h = 5$ [min]
- Latitude: 34 [deg]
- Elevation: 0 [deg]
- Declination: 34 [deg]

Numerical simulation parameters:

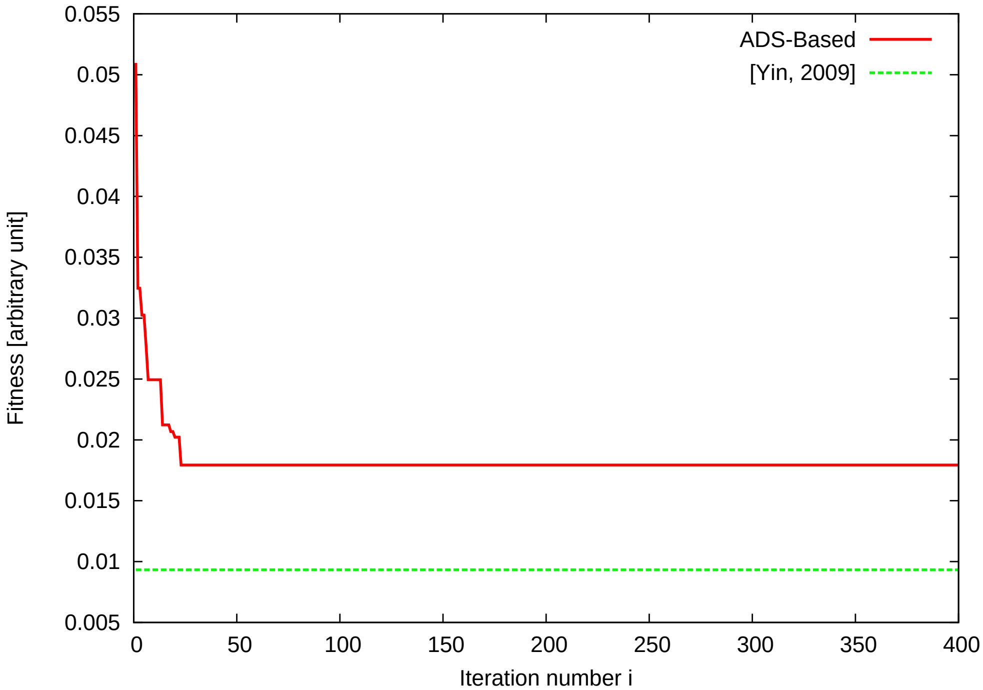
- Grid discretization: $G_X \times G_Y = 128 \times 128$
- Grid dimension: $D_X \times D_Y = 50000 \times 50000$ [λ^2]
- FFT dimension: $F_L \times F_M = 512 \times 512$

GA parameters:

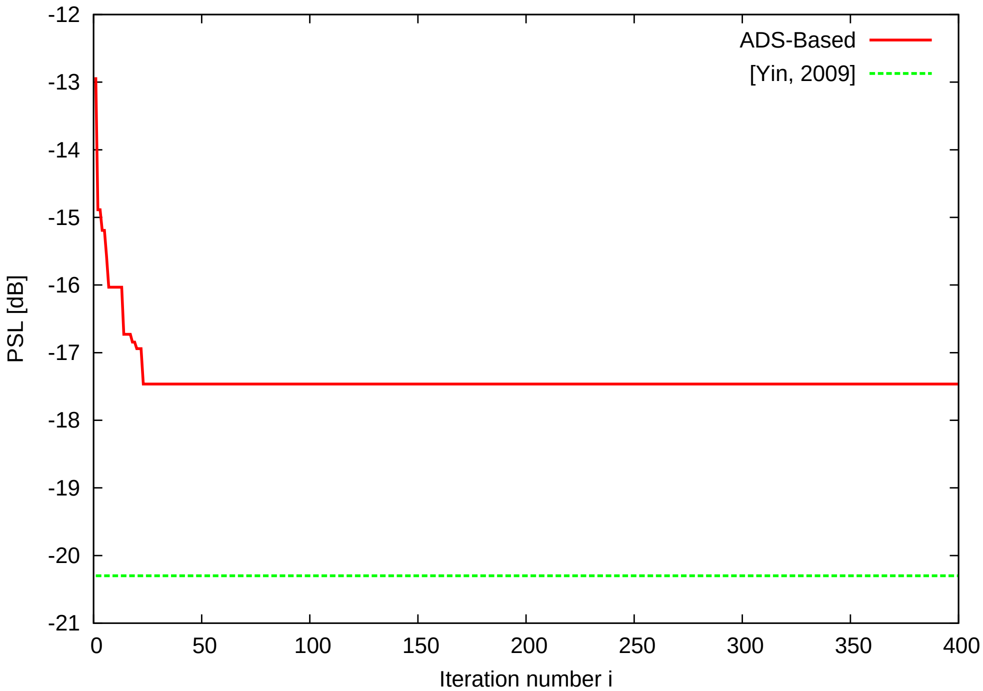
- $P = 20$
- $I = 400$
- $p_\xi = 0.9$
- $p_\mu = 0.01$
- $\alpha = 1$, $\beta = \gamma = \delta = 0$

RESULTS

Fitness and PSL behaviour



(a)



(b)

Figure 10.

Optimal geometry, autocorrelation, rotated autocorrelation and pattern

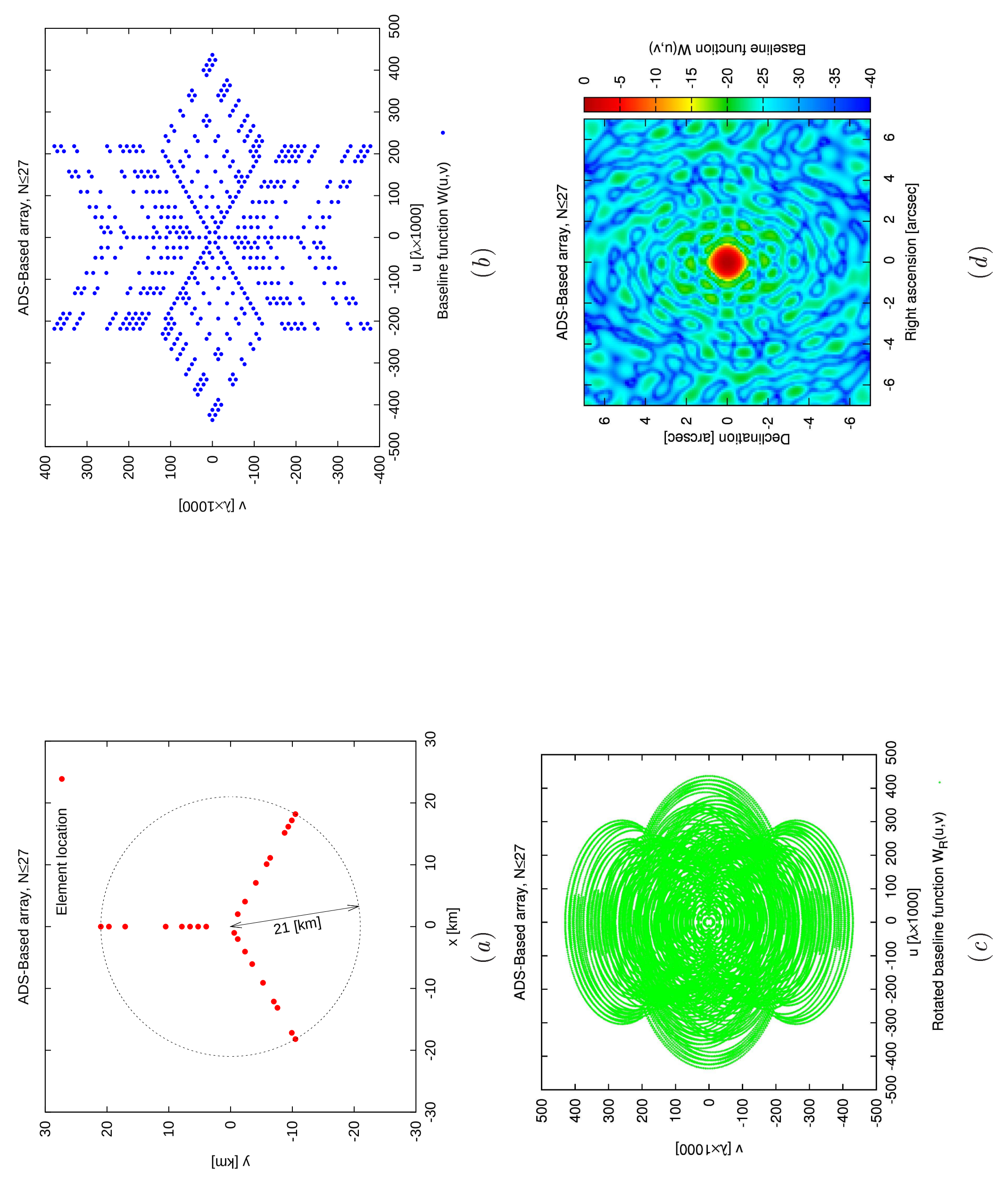


Figure 11.

Observations:

- The PSL behaviour is far from that of [2]

TEST CASE

Goal: minimize the PSL of a triangular shaped array by means of ADSs chosen by means of a GA. **Different ADSs** are employed in the three arms, with different shifts.

- Number of array arms: A
- Arm length: L_i, $i = 0, .., A-1$
- Number of array elements for each arm: N_i, $i = 0, .., A-1$ ($N = \sum_{i=0}^{A-1} N_i$)
- Array rotation with respect to north-south: ρ [deg]

Test Case Description

Geometry:

- Triangular array: $A = 3$
- $L_i = 21$ [Km] $\forall i \in 0, .., A-1$
- Element number: $N_i \leq 9$ $\forall i \in 0, .., A-1$
- Constrained last elements on each arm (arm length is constant, spacing is not constant)
- $\rho = 0$ [deg]
- $T = -15$ [dB]

Geographical information:

- Array rotation duration: $H = 8$ [h]
- Sampling step: $\Delta h = 5$ [min]
- Latitude: 34 [deg]
- Elevation: 0 [deg]
- Declination: 34 [deg]

Numerical simulation parameters:

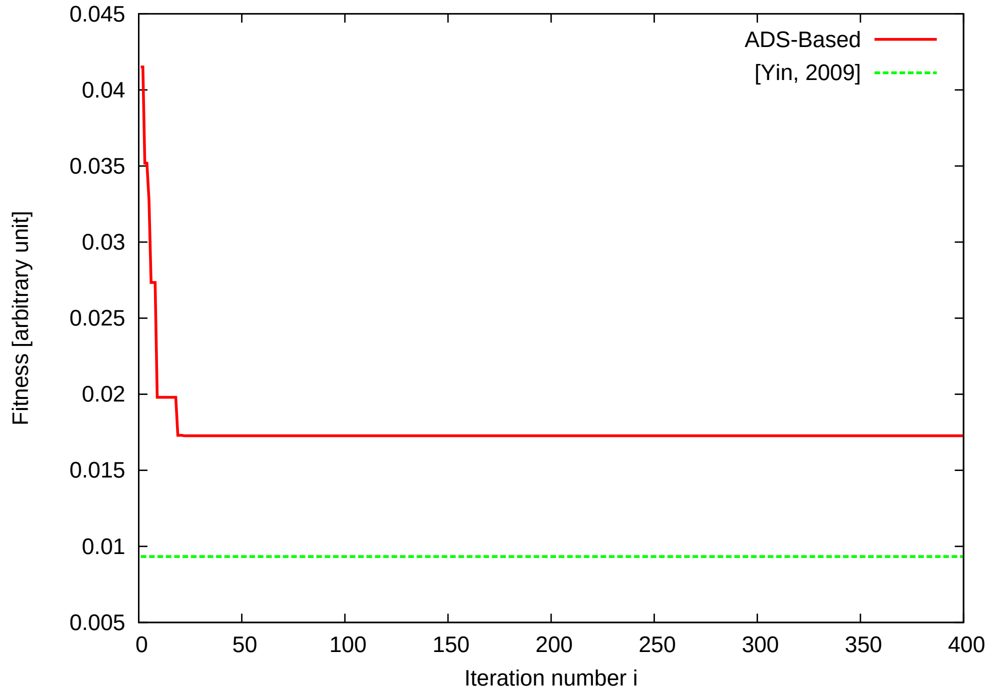
- Grid discretization: $G_X \times G_Y = 128 \times 128$
- Grid dimension: $D_X \times D_Y = 50000 \times 50000$ [λ^2]
- FFT dimension: $F_L \times F_M = 512 \times 512$

GA parameters:

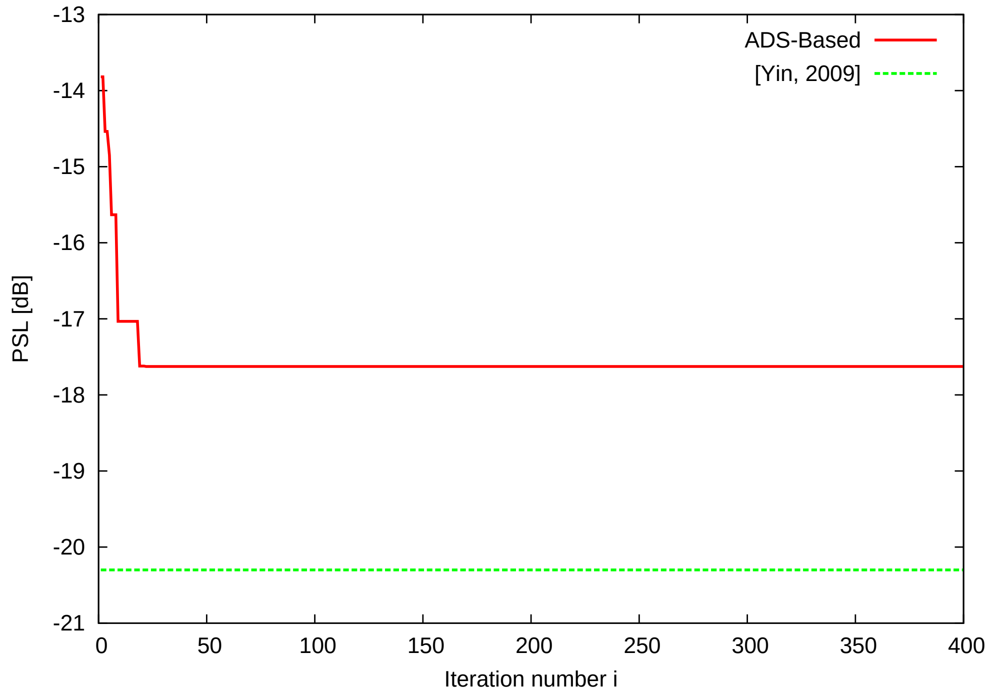
- $P = 20$
- $I = 400$
- $p_\xi = 0.9$
- $p_\mu = 0.01$
- $\alpha = 1$, $\beta = \gamma = \delta = 0$

RESULTS

Fitness and PSL behaviour



(a)



(b)

Figure 12.

Optimal geometry, autocorrelation, rotated autocorrelation and pattern

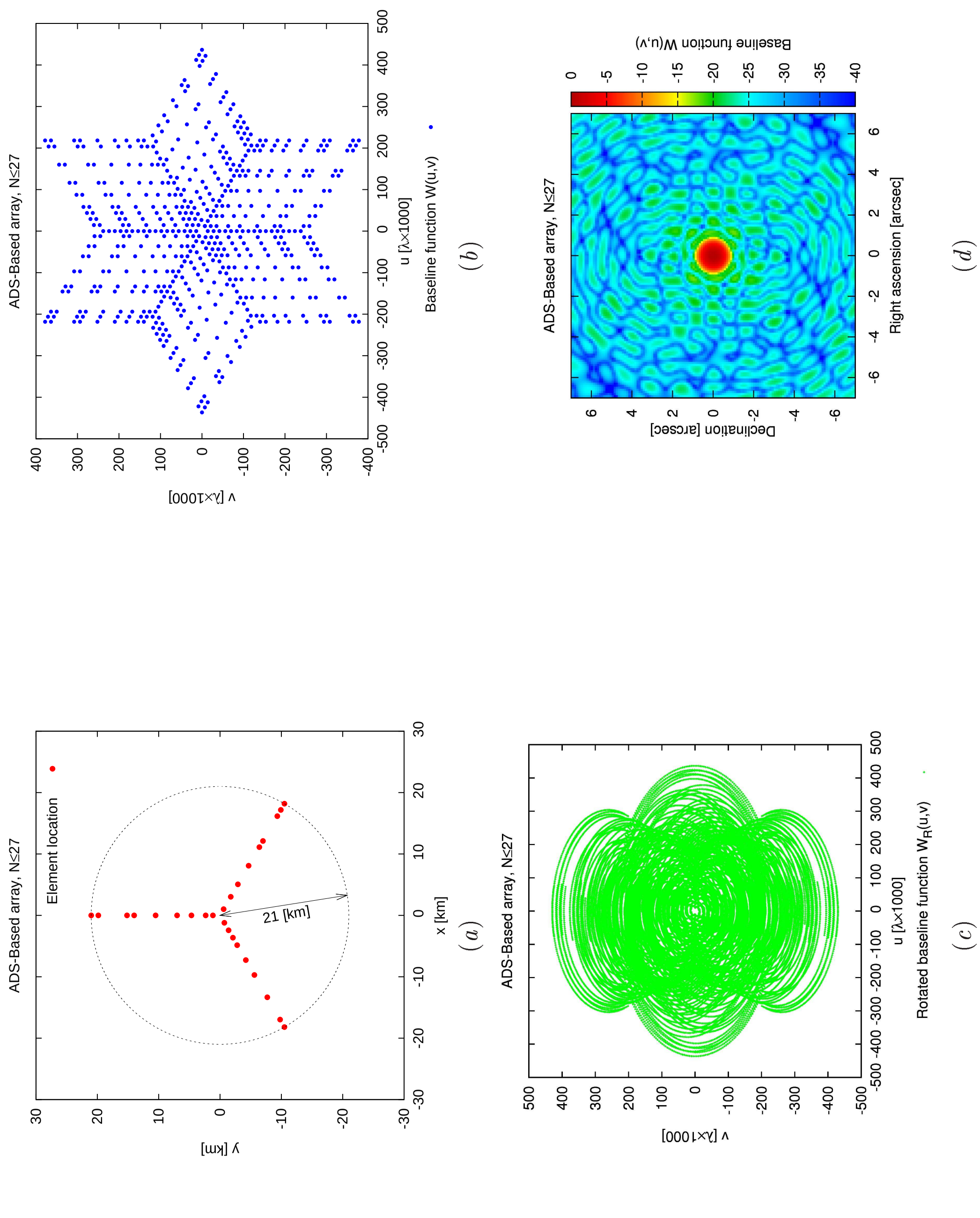


Figure 13.

Observations:

- The PSL behaviour is far from that of [2]

RESUME: PSL MINIMIZATION, DIFFERENT ADS for all arms, DIFFERENT SHIFTS

PSL behaviour with respect to iteration number for optimal arrays

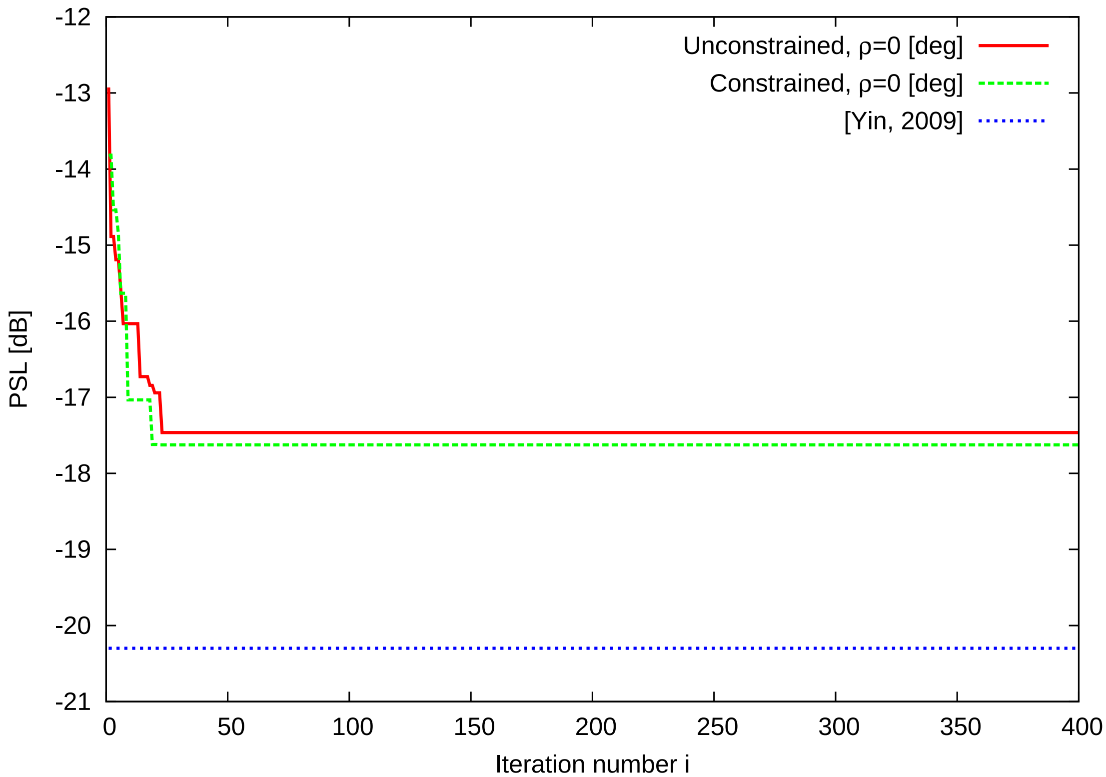


Figure 14.

Overall observations:

- The reported results show that there is not a significant dependency of the obtained PSL from the constrained/unconstrained geometry, since the optimal solutions provide a PSL which is very close.
- One can notice that allowing different ADS to be employed results in lower performances in the first steps of the optimization, while essentially the same performances resulting in the previous case (same ADS employed in all arms; the employed ADS correspond to the largest allowed in this case) are actually obtained. This is due to the fact that the PSL minimization selects those arrays with the maximum number of elements. As a consequence, in the last steps the two methods coincide (in both cases, all the arms employs the same ADS, i.e. the largest allowed).
- It has to be remarked that, in all cases, the obtained PSL is far from that of [2]

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